Springer Proceedings in Mathematics & Statistics

Antônio Márcio Tavares Thomé
Rafael Garcia Barbastefano
Luiz Felipe Scavarda
João Carlos Gonçalves dos Reis
Marlene Paula Castro Amorim *Editors*

Industrial Engineering and Operations Management

XXVI IJCIEOM, Rio de Janeiro, Brazil, July 8–11, 2020

Springer

Springer Proceedings in Mathematics & Statistics

Volume 337

Springer Proceedings in Mathematics & Statistics

This book series features volumes composed of selected contributions from workshops and conferences in all areas of current research in mathematics and statistics, including operation research and optimization. In addition to an overall evaluation of the interest, scientific quality, and timeliness of each proposal at the hands of the publisher, individual contributions are all refereed to the high quality standards of leading journals in the field. Thus, this series provides the research community with well-edited, authoritative reports on developments in the most exciting areas of mathematical and statistical research today.

More information about this series at http://www.springer.com/series/10533

Antônio Márcio Tavares Thomé ·
Rafael Garcia Barbastefano ·
Luiz Felipe Scavarda ·
João Carlos Gonçalves dos Reis ·
Marlene Paula Castro Amorim
Editors

Industrial Engineering and Operations Management

XXVI IJCIEOM, Rio de Janeiro, Brazil, July 8–11, 2020

Challenge and Trends for Sustainability in the 21st Century

Springer

Editors
Antônio Márcio Tavares Thomé
Industrial Engineering Department
Pontifical Catholic
University of Rio de Janeiro
Rio de Janeiro, Brazil

Luiz Felipe Scavarda
Departamento de Engenharia Industrial
Pontifical Catholic
University of Rio de Janeiro
Rio de Janeiro, Brazil

Marlene Paula Castro Amorim
DEGEIT and GOVCOPP
University of Aveiro
Aveiro, Portugal

Rafael Garcia Barbastefano
Engenharia de Produção
Federal Center for Technological Education
Rio de Janeiro, Brazil

João Carlos Gonçalves dos Reis
DEGEIT and GOVCOPP
University of Aveiro
Aveiro, Portugal

ISSN 2194-1009 ISSN 2194-1017 (electronic)
Springer Proceedings in Mathematics & Statistics
ISBN 978-3-030-56919-8 ISBN 978-3-030-56920-4 (eBook)
https://doi.org/10.1007/978-3-030-56920-4

Mathematics Subject Classification: 49-XX, 90-XX, 60-XX, 68Uxx, 90xx, 90-06, 91B

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

The XXVI International Conference on Industrial Engineering and Operations Management (IJCIEOM) occurs in turbulent and pandemic times. It will take place at the campus of the Pontifical Catholic University of Rio de Janeiro in the first semester of 2021. We joined IJCIEOM 2020–2021 in one Conference and decided to publish the Proceedings for 2020 well in advance. The presence and persistence of our peers, writing, and submitting first quality papers on the varied subjects covered by the Conference is a clear demonstration of the vigor and relevance of our field.

IJCIEOM 2020–2021 embraces the theme of "Challenge and Trends for Sustainability in the 21st Century", looking ahead to bridge theory and practice of economic, social, and environmental sustainability. This Conference aims to enhance the connection between academia and industry and to gather researchers and practitioners specializing in operation management, industrial engineering, engineering management, and other related disciplines from around the world.

All papers went through a double-blind review process from renowned academics of Industrial Engineering and Operations Management (IE&OM). This joint Conference is a result of combined efforts from ABEPRO (Associação Brasileira de Engenharia de Produção), ADINGOR (Asociación para el Desarrollo de la Ingeniería de Organización), IISE (Institute of Industrial and Systems Engineers), AIM (European Academy for Industrial Management), and ASEM (American Society for Engineering Management). The Conference honors the highest academic standards from our field of research and offers studies and results of relevance for management practice and future research.

The Proceeding assembles 52 papers from several tracks, including Operations and Process Management, Quality Management, Logistics and Supply Chain Management, Product Development, Knowledge and Information Management, Strategy and Organizational Engineering, Sustainability, Global Operations, Production Engineering Education, Healthcare Operations Management, and Disaster Management.

The topics included in the different tracks give an excellent overview of the actual contribution of our field to bridge theory and practice. Not only because of the varied scientific methods applied, ranging from optimization, markovian chains, inventory models, data envelopment analysis (DEA), multicriteria decision-making, structural equation modeling, neural networks, and bibliometric reviews to empirical research using survey and case study data, but also because of the rigor and relevance of the themes.

Operations and process management covers optimizing water use in university settings, inventory and shop floor management, military social protection systems, production planning and control in Industry 4.0, a study of times and movements in a shipyard, economics and cultural influence of manufacturing strategy, practices and performance, energy efficiency in smart manufacturing, and process mining using neural networks.

Logistics and supply chain management embraces a bibliometric analysis of suppliers, EPQ inventory models under advanced-cash-credit payment, implications of sustainability in logistics, small enterprises management roadmap, vehicle routing problem considering cargo theft probability, an application of the SCOR process to porcelain export, social and environmental risks in supply chains, risk management in wind power, and omnichannel retailing.

Quality management focuses on indicators for monitoring the regulatory compliance of equipment in industrial plants in the oil and gas sector, use of DMAIC and Lean Six Sigma in an automotive factory, statistical process control, service quality scales, the importance of measurement uncertainty analysis on statistical quality control charts, variance modified control carts, and Lean Office application to public buildings. Under the product development track, pricing scenarios of sustainable product-service systems discuss its application in the agricultural sector, from the farmers' viewpoint.

The production strategy area applies multicriteria analysis to Navy warship selection, offers an integrated model of organizational diagnostics, analyzes the competitive advantages arising from industrial clusters, uses logistic regression model for predicting cost performance in new product development, performance measurement systems, proposes a model for organizational performance assessments, and analyzes the success factors for civil construction projects management.

Knowledge and information management brings valuable discussions on scorecard applied to the organizational performance of distributed generation in electric utilities, on information and data quality states model in information systems, cost information systems applied to the public sector, data reconciliation and parameter estimation applied to a heat exchange process, and a data mining application in a higher education institution. The track on work and human factors shed light on occupational accidents among construction workers, purchase systems for people with reduced mobility, and competence management under Industry 4.0.

Sustainability, the central theme of the Conference, contributes papers in varied areas. Several articles cover environmental sustainability, as the psychological factors affecting the use of plastic cups, use of eggshell in circular economies, a data enveloping analysis (DEA) of the efficiency of environmental sanitation in Brazil, and an analysis of greenhouse gases and atmospheric pollutant emissions by helicopters in the oil and gas industry. The track also offers an inventory model with the inclusion of environmental parameter in stochastic EPQ with partial backorders. The sustainability track also included several papers on circular economy for lubricating oils in Brazil, and for devising strategies toward a transition to the circular economy. The sustainability track brought equally discussions on renewable energy, a historical review of the electricity sector in Brazil, cleaner services production, Sustainable Supply Chain Management in the food industry, extraction of oil of soursop (Annona muricata) and marolo (Annona crassiflora Mart) seeds, using different solvents and processes. It equally offers discussions on life cycle assessment (LCA) for photovoltaic solar energy, psychological aspects of buying green, energy management audit based on international standards, and introduced the discussion about local-level sustainability indicators, assessment of CO^2 emission in the soil-cement brick industry, and the circular economy for lubricating oils.

The track on production engineering education proposes measurement of the effectiveness of a Scrum Training Session. The healthcare track opens the discussion about the application of lean management and explores a multiple case study on patient demand forecast in emergency departments. The track of Global Operations offers a hybrid modeling for multicriteria evaluation of drones for use in naval warfare.

Finally and equally relevant was the track on disaster management, covering the selection of distribution centers, pedestrian evacuation plans for fire situations at a university, humanitarian relief for poverty zones, and a disaster response assessment applied to the case of the civil defence of the State of Rio de Janeiro, Brazil.

We hope the readers will enjoy the Proceedings organized within this book as much as we enjoyed preparing it for publication.

Rio de Janeiro, Brazil	Antônio Márcio Tavares Thomé
Rio de Janeiro, Brazil	Rafael Garcia Barbastefano
Rio de Janeiro, Brazil	Luiz Felipe Scavarda
Aveiro, Portugal	João Carlos Gonçalves dos Reis
Aveiro, Portugal	Marlene Paula Castro Amorim

Contents

Selecting Distribution Centers in Disaster Management by Network Analysis and Composition of Probabilistic Preferences

Luiz Octávio Gavião, Annibal Parracho Sant'Anna, Gilson Brito Alves Lima, Pauli Adriano de Almada Garcia, and Alessandro Mello de Sousa

Abstract Disaster management operations require adequate and rapid planning to efficiently serve the affected populations. In this context, an Area of Operations must be dimensioned with the main locations capable of receiving logistic facilities. These locations need to be connected by networks capable of ensuring the flow of critical supplies. The objective of this article is to identify the most influential nodes in a disaster management supply chain, by network analysis and a multicriteria decision aid method. Network analysis provides measures that indicate the most influential nodes in the network. These measures, called centralities, are selected through Principal Component Analysis (PCA). The nodes and their centrality evaluations configure a decision matrix to be modelled by the Composition of Probabilistic Preferences (CPP). CPP is an alternative to other MCDA methods used in this type of problem, such as TOPSIS, by exploring its non-linearity to highlight the best nodes in the network. The R software and specific packages were used to compute results. An undirected and weighted network of 12 nodes was used to test the model. Two nodes identified the best access to the affected area and suggested the best location to establish the distribution center or other logistics facilities.

L. O. Gavião (✉)
Brazilian War College, Rio de Janeiro, RJ 22291-090, Brazil
e-mail: luiz.gaviao67@gmail.com

A. P. Sant'Anna · G. B. A. Lima
Fluminense Federal University, Niterói, RJ 24220-240, Brazil
e-mail: annibal.parracho@gmail.com

G. B. A. Lima
e-mail: glima@id.uff.br

P. A. de Almada Garcia
Fluminense Federal University, Volta Redonda, RJ 27213-145, Brazil
e-mail: pauliadriano@id.uff.br

A. M. de Sousa
Pontifical Catholic University, Rio de Janeiro, RJ 22451-900, Brazil
e-mail: amsousa1972@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_1

Keywords Disaster management · Network analysis · Composition of probabilistic preferences

1 Introduction

The flow of critical supplies to populations affected by disasters is a key issue in humanitarian logistics [1–3]. Any delay in the arrival of medicines, blood plasma, water, food, personnel, among other emergency items impacts rescue. In this context, the road network that links possible points of the humanitarian supply chain is essential to guarantee the flow of personnel and material for assistance [4–7]. These points may receive command posts, logistical support areas, distribution centers or field hospitals to set up the disaster management support network [8, 9]. In this case, the identification of the most suitable points can assist in planning and, consequently, in the efficient execution of logistical support [10].

Network analysis provides a methodology and related metrics for mapping relationships between members of a group, characterizing the individual entities as nodes connected by ties to create networks [11]. The method is adaptable and highly useful in humanitarian research, quantifying patterns of community structure and collaboration among humanitarian organizations [12]. In this context, some early studies have associated network analysis with emergency response simulations [13, 14], with the Indonesian response after the Sumatran earthquake and tsunami [15], and with the 2015 Nepal/Gorkha earthquake [16].

Network analysis is especially useful to select nodes in a humanitarian supply chain. There are mathematical indicators that reflect the relative importance of each node. These measures are called centralities, which remain the most widely studied metrics in network analysis to date [11, 12]. However, the centrality results may not have the same importance for different nodes. Centrality measures are computed by different equations and represent different meanings in the network [11].

Several studies have used centrality measures with multicriteria methods to rank the most influential nodes [17–21]. The literature reveals that the Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) is one of the most used multicriteria decision aid method (MCDA) methods for this purpose. However, the Composition of Probabilistic Preferences (CPP) is an alternative to other methods used in this type of problem, by exploring its non-linearity to highlight the best nodes in the network.

In this context, as the first objective here is to identify the most influential nodes in disaster management supply chains, after choosing the set of centralities by Principal Component Analysis (PCA), the nodes are selected by CPP. The major insight extracted from the paper is the PCA-CPP association, which consists of a new methodological application to humanitarian supply chains.

The article consists of five sections. After the introduction, a brief review of CPP is presented in Sect. 2. Then, the steps of the proposed method are set out in Sect. 3. A numerical application illustrates the proposal in Sect. 4. Finally, a conclusion ends the research in Sect. 5.

2 The Composition of Probabilistic Preferences

CPP is a MCDA method, used in the most diverse areas of knowledge [22–25]. Among its various features, CPP can be applied to order alternatives evaluated under multiple criteria. Even though there are several other methods that would also be used to achieve the same objective, a special feature differentiates CPP from other multi-criteria methods; CPP normalizes evaluations by a non-linear algorithm, overvaluing the highest assessments and depreciating the lowest ones [22]. Figure 1 shows this characteristic, by comparing TOPSIS with CPP. For that, we explored a sample of data in arithmetic progression between 1 and 10, in the abscissa axis. The results are plotted on the ordinate axis. The slopes between the TOPSIS evaluations are uniform. On the other hand, CPP overvalues the best performances; the slope between 9 and 10 is higher and more inclined than the others.

CPP is computed in three steps. In the first one, the evaluations are randomized under a probability distribution. Then, Eqs. (1) and (2) are applied. The probabilities of the i-th alternative being higher (M_{ij}) and lower (m_{ij}) than the others are calculated for each criterion j. A random vector "X" symbolizes the alternatives of the problem. The functions related to the i-th alternative are indexed by "i" and the others by "$-i$". The F_X, f_X and D_{X_i} notations denote, respectively, the cumulative distribution function (cdf), the probability density function (pdf) and the domain of the random variable "X" [26].

$$M_{ij} = \int_{D_{X_i}} \left[\prod F_{X_{-i}}(x_{-i})\right] f_{X_i}(x_i)dx_i \tag{1}$$

$$m_{ij} = \int_{D_{X_i}} \left[\prod\left(1 - F_{X_{-i}}(x_{-i})\right)\right] f_{X_i}(x_i)dx_i \tag{2}$$

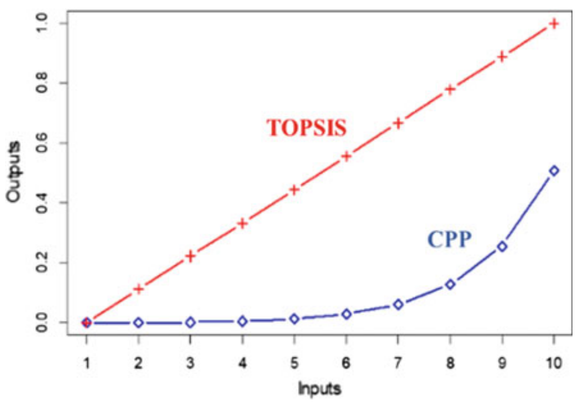


Fig. 1 Non linearity of CPP

Finally, the probabilities M_{ij} and m_{ij} are composed by four points of view for decision making: progressive, conservative, pessimistic and optimistic. The progressive point of view uses the probabilities M_{ij}, symbolizing the search for greater gains in the problem. The conservative point of view uses the probabilities m_{ij}, to avoid losses by increasing the distance to the worst results. The pessimistic point of view considers the progressive-conservative axis under all criteria, while the optimistic point of view is content to achieve results under at least one criterion. For the problem of choosing the best nodes in the network, the progressive-pessimistic (PP) and progressive-optimistic (PO) points of view are those that make sense for decision making in a disaster management context, due to the search for the best node centralities.

3 Method

The proposed model is developed in six steps, as shown in Fig. 2.

In Step 1, it is necessary to configure the Area of Operations (AO). This area should include, within its limits, the region affected by the disaster and the regions capable of receiving logistical facilities for the coordination of humanitarian assistance.

In Step 2, the main locations, large highways and paved or unpaved roads must also be raised. At the end of this stage, a undirected and weighted network of nodes (locations) and arcs (connections) must graphically translate the trafficability of the AO.

In Step 3, weights are established to qualify the connections between the locations of the AO. Among the criteria to be considered, it is suggested to evaluate the distances between the nodes, the quality of the road according to its characteristics and the degree of damage that the disaster caused to the conditions of use of the road. In this context, the best arc is the one that connects the shortest distances, with the best roads, with the least damage caused by the emergency.

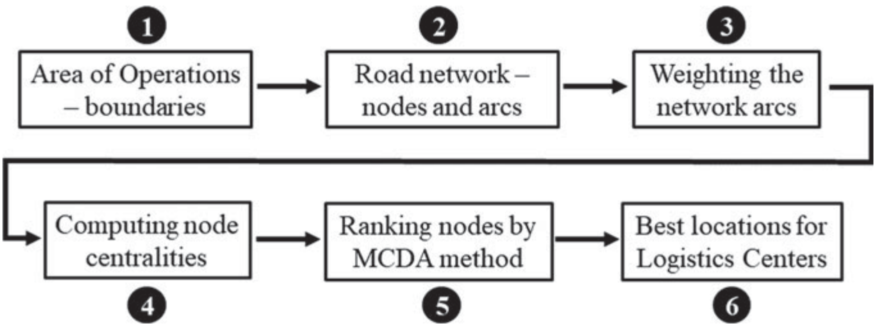


Fig. 2 Methodological steps

In Step 4, centrality measures of each node in the network are calculated. These measures identify the most important vertices within a network. The literature indicates that there are more than 50 types of centrality measures [27]. However, depending on the network features, some measures do not discriminate the nodes well. Thus, it is suggested to reduce the dimensionality of the problem by selecting the best results, with the use of PCA, for example.

In Step 5, after selecting the main centrality measures, a decision matrix is composed by the network nodes and their most relevant centrality measures. This matrix is the initial database for applying a MCDA to rank the nodes. If there is more than one rank for the same node, it is possible to merge the results using the Borda method [28].

In Step 6, results are analyzed to identify the best places to establish distribution centers and other logistical facilities that will support humanitarian assistance operations.

4 Application

4.1 Sample and Database

To illustrate the application of the proposed model, a network of localities and roads was created around a region affected by an environmental disaster, called “ground zero”. The network was configured by 12 locations, four of which show the last mile (I, J, K and L), providing direct support to the affected population, in addition to eight further locations, considered relevant by planning teams. Possible connections between locations are indicated by non-directional arcs in Fig. 3. Crash signs in red simulate problems in accessibility after disaster.

The arcs were weighted based on three assessments: road class, accessibility and distance between nodes. The road class was scored from 1 to 7, according to the table used in DNIT [29], which uses seven classifications for highways, which are adapted here to indicate the quality of the connection between the nodes. The accessibility of the road after disaster was scored from 0 to 1, varying from terrible to excellent conditions. The distance between the nodes was also evaluated between 0 and 1, which are equivalent to very long and very short distances, respectively. The products of these three variables provided the weights of the network’s adjacency matrix, as shown in Table 1. This matrix is the initial database for calculating the centralities of the network nodes. Null values indicate the absence of connection between the nodes.

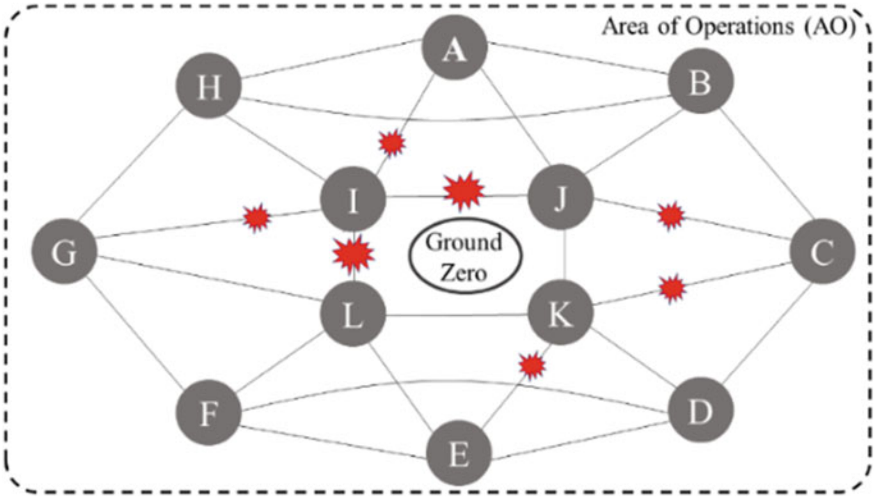


Fig. 3 Undirected and weighted network

Table 1 Adjacency matrix

Nodes	A	B	C	D	E	F	G	H	I	J	K	L
A	0	3.6	0	0	0	0	0	2.7	1.2	2	0	0
B	3.6	0	2.7	0	0	0	0	0	0	2	0	0
C	0	2.7	0	2.7	0	0	0	0	0	0.8	1.4	0
D	0	0	2.7	0	1.8	0	0	0	0	0	1	0
E	0	0	0	1.8	0	3.6	0	0	0	0	0.8	2
F	0	0	0	0	3.6	0	2.7	0	0	0	0	2
G	0	0	0	0	0	2.7	0	3.6	1	0	0	1
H	2.7	0	0	0	0	0	3.6	0	2	0	0	0
I	1.2	0	0	0	0	0	1	2	0	0.2	0	0.2
J	2	2	1.6	0	0	0	0	0	0.2	0	2	0
K	0	0	1.4	2	0.8	0	0	0	0	2	0	1
L	0	0	0	0	3	2	3	0	0.2	0	1	0

4.2 Results and Analysis

All calculations of the proposed model were performed using the R software. Centralities were computed by the R package CINNA. The functions '*calculate_centralities*' and '*pca_centralities*' returned 47 different measures of centrality of the nodes, according to Fig. 4 [27].

The best contributions to centrality measures are indicated by the red arrow in Fig. 4. The bars show that five measures differ significantly from the others. In

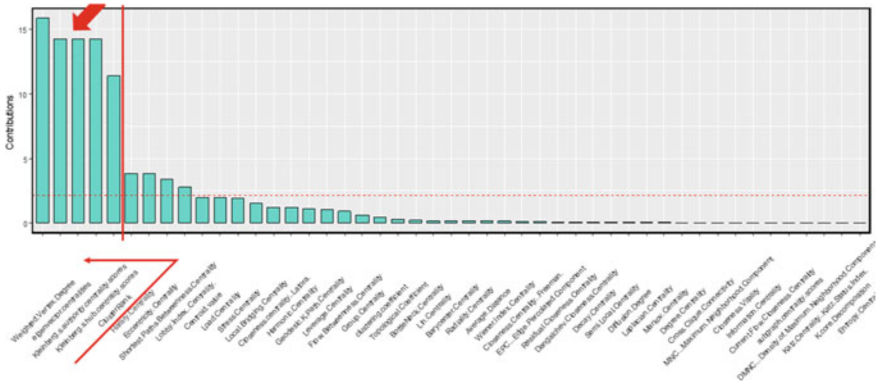


Fig. 4 PCA of centrality measures

practice, this indicates that their values are more discriminatory than the other indices. Thus, these best measures were exported to configure the decision matrix in Table 2.

Then, the CPP method was applied to the decision matrix, to select the most influential nodes in the network. The R package CPP was used to compute results [30]. After randomizing the variables with '*CPP.Axes.Beta*' function, the probabilities of each node centrality being higher than the others were calculated and shown in Table 3.

Table 4 shows the results of the compositions by PP and PO axes, with their respective rankings. The Borda ordinal MCDA method was also used to obtain the final ranking from the CPP progressive points of view [28]. Nodes F, G, H and L

Table 2 Centralities

	Weighted vertex degree	Eigenvector centralities	Kleinberg's authority centrality	Kleinberg's hub centrality	Cluster rank
A	9.5	0.6648324	0.6648324	0.6648324	10
B	8.3	0.5743593	0.5743593	0.5743593	10.666667
C	8.4	0.5222619	0.5222619	0.5222619	10
D	6.5	0.47874	0.47874	0.47874	10.666667
E	9.2	0.8851833	0.8851833	0.8851833	10
F	8.3	0.9234976	0.9234976	0.9234976	10.666667
G	10.3	1	1	1	10
H	8.3	0.7383063	0.7383063	0.7383063	10.666667
I	4.6	0.4225498	0.4225498	0.4225498	10.4
J	7.8	0.5254835	0.5254835	0.5254835	10.4
K	7.2	0.5214308	0.5214308	0.5214308	10.4
L	9.2	0.9593598	0.9593598	0.9593598	10.4

Table 3 Probabilities of maximizing the centralities

	Weighted vertex degree	Eigenvector centralities	Kleinberg's authority centrality	Kleinberg's hub centrality	Cluster rank
A	5.38E−02	7.47E−08	7.47E−08	7.47E−08	1.44E−22
B	3.99E−04	1.03E−10	1.03E−10	1.03E−10	2.50E−01
C	6.34E−04	1.10E−12	1.10E−12	1.10E−12	1.44E−22
D	1.06E−08	1.33E−14	1.33E−14	1.33E−14	2.50E−01
E	1.77E−02	8.65E−03	8.65E−03	8.65E−03	1.44E−22
F	3.99E−04	4.12E−02	4.12E−02	4.12E−02	2.50E−01
G	9.09E−01	7.86E−01	7.86E−01	7.86E−01	1.44E−22
H	3.99E−04	6.57E−06	6.57E−06	6.57E−06	2.50E−01
I	4.38E−17	8.93E−18	8.93E−18	8.93E−18	9.78E−08
J	3.33E−05	1.49E−12	1.49E−12	1.49E−12	9.78E−08
K	1.11E−06	1.02E−12	1.02E−12	1.02E−12	9.78E−08
L	1.77E−02	1.64E−01	1.64E−01	1.64E−01	9.78E−08

Table 4 CPP results and borda ranking

Vertices	CPP-PP	Rank	CPP-PO	Rank	Borda
A	3.217E−45	7	5.375E−02	7	14
B	1.086E−34	6	2.503E−01	5	11
C	1.221E−61	11	6.340E−04	9	20
D	6.239E−51	10	2.500E−01	6	16
E	1.650E−30	5	4.301E−02	8	13
F	6.962E−09	1	3.391E−01	3	4
G	6.348E−23	4	9.991E−01	1	5
H	2.825E−20	3	2.503E−01	4	7
I	3.046E−75	12	9.775E−08	12	24
J	1.077E−47	8	3.341E−05	10	18
K	1.151E−49	9	1.208E−06	11	20
L	7.631E−12	2	4.258E−01	2	4

received the lowest Borda sums. These nodes indicate the most favorable region for the establishment of distribution centers in the supply chain. They also show the best zone to access ground zero to provide the disaster relief.

The validity of the decision support models can be evaluated by calculating the degree of decision makers' satisfaction [31]. Other option to validate a MCDA model is to check its ability to mimic the real system, using statistical methods to compare model and real system outputs [32]. However, the application of the proposed model was not based on a real case. The nodes F, G, H and L form a coherent solution to the hypothetical problem, as it identifies a sector of approach to ground zero with lesser access limitations, which is visually evident in Fig. 3. Here it is assumed that the stakeholders involved in the disaster response would accept this result as the most favorable region to support the humanitarian supply chain.

5 Conclusion

Disaster management operations require adequate and rapid planning to efficiently serve the affected populations. In this context, an AO must be dimensioned with the main locations capable of receiving command and control, logistic facilities, distribution centers, storage facilities and others. These locations need to be connected by networks capable of ensuring the flow of critical supplies.

This article identified the most influential nodes in disaster management supply chains, using Network Analysis and CPP. The R software and specific packages were used to compute results. CPP is an alternative to other MCDA methods used in this type of problem, such as TOPSIS, by exploring its non-linearity to highlight the best nodes in the network.

Some options for further research are visualized. The establishment of the weights of the arches requires the subjectivity of specialists, being used here three variables considered most important in the analyzed literature. However, other variables can be considered, in order to improve the accuracy of these weights. We also see the possibility of applying the model to other types of networks in disaster management, such as airports and ports, or even interconnecting the different types of nodes.

References

1. Loree, N., Aros-Vera, F.: Points of distribution location and inventory management model for Post-Disaster Humanitarian Logistics. Transp. Res. Part E Logist. Transp. Rev. 116, 1–24 (2018)
2. Pérez-Rodríguez, N., Holguín-Veras, J.: Inventory-allocation distribution models for postdisaster humanitarian logistics with explicit consideration of deprivation costs. Transp. Sci. 50, 1261–1285 (2016)
3. Holguín-Veras, J., Taniguchi, E., Jaller, M., Aros-Vera, F., Ferreira, F., Thompson, R.G.: The Tohoku disasters: Chief lessons concerning the post disaster humanitarian logistics response and policy implications. Transp. Res. part A policy Pract. 69, 86–104 (2014)
4. Jha, A., Acharya, D., Tiwari, M.K.: Humanitarian relief supply chain: a multi-objective model and solution. Sādhanā. 42, 1167–1174 (2017)
5. Warnier, M., Alkema, V., Comes, T., Van de Walle, B.: Humanitarian access, interrupted: dynamic near real-time network analytics and mapping for reaching communities in disaster-affected countries. OR Spectr. 1–20 (2020)
6. Santos, A.C.: Advances in Network Accessibility and Reconstruction after Major Earthquakes. In: The Palgrave Handbook of Humanitarian Logistics and Supply Chain Management. pp. 547–565. Springer (2018)

7. Samed, M.M.A., Gonçalves, M.B.: Introdução à Logística Humanitária. In: Leiras, A., Yoshizaki, H.T.Y., Samed, M.M.A., and Gonçalves, M.B. (eds.) Logística Humanitária. pp. 27–37. Elsevier, Rio de Janeiro (2017)
8. Mwangi, P.M., Anaya, S.: Logistical factors influencing disaster responsiveness of humanitarian organizations in Kenya. Int. J. Supply Chain Manag. 5, 1–20 (2020)
9. Botchie, D., Damoah, I.S., Tingbani, I.: From preparedness to coordination: operational excellence in post-disaster supply chain management in Africa. Prod. Plan. Control. 1–18 (2019)
10. Varella, L., Gonçalves, M.B.: As Relações entre Logística Empresarial, Militar e Humanitária. In: Leiras, A., Yoshizaki, H.T.Y., Samed, M.M.A., and Gonçalves, M.B. (eds.) Logística Humanitária. pp. 39–56. Elsevier, Rio de Janeiro (2017)
11. Simpson, N., Tacheva, Z., Kao, T.-W.D.: Social Network Analysis in the Context of Humanitarian Logistics. In: The Palgrave Handbook of Humanitarian Logistics and Supply Chain Management. pp. 3–39. Springer (2018)
12. Tacheva, Z., Simpson, N.: Social network analysis in humanitarian logistics research. J. Humanit. Logist. Supply Chain Manag. (2019)
13. Houghton, R.J., Baber, C., McMaster, R., Stanton, N.A., Salmon, P., Stewart, R., Walker, G.: Command and control in emergency services operations: a social network analysis. Ergonomics. 49, 1204–1225 (2006)
14. Simpson, N.C., Hancock, P.G.: The incident commander's problem: Resource allocation in the context of emergency response. Int. J. Serv. Sci. 2, 102–124 (2009)
15. Haase, T.W.: International disaster resilience: preparing for transnational disaster. In: Comfort, L.K., Boin, A., and Demchak, C.C. (eds.) Designing Resilience: Preparing for Extreme Events. pp. 220–243. University of Pittsburgh Press, Pittsburgh (2010)
16. Bisri, M.B.F., Beniya, S.: Analyzing the national disaster response framework and interorganizational network of the 2015 Nepal/Gorkha earthquake. Procedia Eng. 159, 19–26 (2016)
17. Luo, L., Ren, H.: Node Importance Evaluation of Complex Network Based on M-TOPSIS Method. In: Journal of Physics: Conference Series. p. 12016. IOP Publishing (2019)
18. Yang, P., Liu, X., Xu, G.: A dynamic weighted TOPSIS method for identifying influential nodes in complex networks. Mod. Phys. Lett. B. 32, 1850216 (2018)
19. Hu, J., Du, Y., Mo, H., Wei, D., Deng, Y.: A modified weighted TOPSIS to identify influential nodes in complex networks. Phys. A Stat. Mech. its Appl. 444, 73–85 (2016)
20. Fox, W.P., Everton, S.F.: Mathematical modeling in social network analysis: using TOPSIS to find node influences in a social network. J. Math. Syst. Sci. 3, 531 (2013)
21. Zhang, W., Zhang, Q., Karimi, H.: Seeking the important nodes of complex networks in product R&D team based on fuzzy AHP and TOPSIS. Math. Probl. Eng. 2013, (2013)
22. Sant'Anna, A.P.: Probabilistic Composition of Preferences, Theory and Applications. Springer, New York (2015)
23. Gavião, L.O., Meza, L.A., Lima, G.B.A., Sant'Anna, A.P., Soares de Mello, J.C.C.B.: Improving discrimination in efficiency analysis of bioethanol processes. J. Clean. Prod. (2017). https://doi.org/10.1016/j.jclepro.2017.06.020
24. Gavião, L.O., Sant'Anna, A.P., Alves Lima, G.B., de Almada Garcia, P.A.: Evaluation of soccer players under the Moneyball concept. J. Sports Sci. (2019). https://doi.org/10.1080/02640414.2019.1702280
25. Sant'Anna, A.P., Lima, G.B.A., Gavião, L.O.: A probabilistic approach to the inequality adjustment of the human development index. Pesqui. Operacional. 38, (2018). https://doi.org/10.1590/0101-7438.2018.038.01.0099
26. Sant'Anna, A.P., Gomes, L.F.A.M., Costa, F.F. da, Rangel, L.A.D., Faria, M.J. da S., Ferreira, R.G., Filho, R.M.M., Ribeiro, R.O.A., Senna, V. de: Análise multicritério baseada em probabilidades de preferência. In: Oliveira, V.F. de, Cavenaghi, V., and Másculo, F.S. (eds.) Tópicos emergentes e desafios metodológicos em Engenharia de Produção: casos, experiências e proposições - Volume V. p. 258. ABEPRO, Rio de Janeiro (2012)

27. Ashtiani, M.: CINNA: Deciphering Central Informative Nodes in Network Analysis. R package version 1.1.53, https://cran.r-project.org/package=CINNA, (2019)
28. Pomerol, J.-C., Barba-Romero, S.: Multicriterion decision in management: principles and practice. Springer, New York (2012)
29. DNIT: IPR 742 - Manual de Implantação Básica de Rodovia, (2010)
30. Gavião, L.O., Sant'Anna, A.P., Lima, G.B.A., Garcia, P.A. de A.: CPP: Composition of Probabilistic Preferences. R package version 0.1.0., https://cran.r-project.org/package=CPP, (2018)
31. Alrashoud, M., AlMeshary, M., Abhari, A.: Automatic validation for multi criteria decision making models in simulation environments. In: Proceedings of the 18th Symposium on Communications & Networking. pp. 44–47b (2015)
32. Qureshi, M.E., Harrison, S.R., Wegener, M.K.: Validation of multicriteria analysis models. Agric. Syst. 62, 105–116 (1999)

Development of Indicators for Monitoring the Regulatory Compliance of Static Equipment in Industrial Plants—an Empirical Study in the Oil and Gas Sector

Rodrigo Goyannes Gusmão Caiado, Hugo Fernandes Neves, Eduardo Thadeu Corseuil, Leticia Bacoccoli, and Alexandre Reis Pinto de Castro

Abstract Safety management depends on systematic anticipation, monitoring and development of organizational performance. In this sense, this article aims to develop a set of regulatory compliance indicators based on a Regulatory Standard 13 (NR-13) to propose a tool for monitoring the conformity of static equipment and thus improve the safety of industrial plants. To do this, a mixed-method approach using interviews, focus groups and Multi-criteria decision making (MCDM) model was applied. The results show seven Key performance indicators (KPIs) composed by 14 metrics permeating inspections related to: Coverage, Control Instruments and Devices, Documentary Requirements, Ergonomic Aspects, Operation Safety, Safety inspection and Pendencies. Thus, the proposition of a standardized procedural systematic based on a set of KPIs represents an important contribution towards the automation of legal compliance verification, making it possible to understand the criticality of the verification of certain equipment, reducing the time and cost of processes (efficiency) and increasing plant compliance and quality (effectiveness).

Keywords KPIs · Regulatory compliance · MCDM · NR-13 · Oil & gas

R. G. G. Caiado (✉) · H. F. Neves · E. T. Corseuil
Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Marquês de São Vicente Street, 225 - Gávea, Rio de Janeiro, RJ 22451-900, Brazil
e-mail: rodrigocaiado@tecgraf.puc-rio.br

R. G. G. Caiado
Federal Fluminense University (UFF), Passo Da Pátria Street, 156, Niterói 22451-900, Brazil

L. Bacoccoli · A. R. P. de Castro
Petrobras, Henrique Valadares Avenue, 28 - Centro, Rio de Janeiro, RJ 20231-030, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_2

1 Introduction

The Oil & Gas (O&G) industry contains a characteristic convergence of several dangerous elements that have the potential for both occupational accidents and major disasters. The great challenge of industrial safety is being able to anticipate vulnerabilities, rather than acting reactively [1]. Serious accidents in industrial activities can lead to catastrophic damage such as damage to the company's reputation and fatalities, which highlights the importance of prevention and control tools [2–4]. Therefore, organizations and safety-critical systems must be able to proactively assess and manage the safety of their activities [5]. Safety, however, is a difficult phenomenon to describe, measure, confirm and manage [6]. Safety management depends on systematic anticipation, monitoring and development of organizational performance. In this sense, performance measurement is important for continuous improvement and for identifying and resolving priorities. Performance indicators are a set of measures used to measure the impact on process performance [7].

Currently, several indicators play a key role in providing information about the current performance of the organizational process. An indicator can be considered any measure—quantitative or qualitative—that seeks to produce information on an issue of interest. Indicators can play a key role in providing information on organizational performance, motivating people to work with quality and increasing the organizational safety potential [8].

In addition, the industry is experiencing the fourth revolution (Industry 4.0) that acts as a driving force for improving productivity, the efficiency of socio-technical systems, and the adoption of information and communication technologies (ICT) in a dynamic environment [9–11] consisting of several alternatives and multiple conflicting goals. Considering the complex interactions with industrial systems [6], the need for practical mathematical models associated with technological and analytical solutions to assist managers and decision makers is urgent, and can be important tools for strategic and operational decision making in the real world [12–14]. There is an increasing need for adequate analytical tools and qualified professionals capable of making the right decisions in the presence of multiple criteria, incomplete data, multiple decision agents and even uncertainties [15]. To that end, Multi-criteria decision making (MCDM) has been used to support people and organizations to make more satisfactory decisions under the influence of a variety of criteria [16].

2 Objectives

This research aims to develop indicators for monitoring the regulatory compliance of static equipment in industrial plants. The development of indicators that can compose a system for measuring legal compliance in line with Regulatory Standard 13 (NR-13) and with the organization's safety objectives and documents (checklists for each type of equipment) seeks to obtain a reliable tool for equipment comparison, identification of critical points that may compromise the conformity of operations, as well as the quality performance of processes and the safety, risk and health of workers.

3 Methods

The development of legal conformity assessment indicators involved five steps (see Fig. 1):

In the first step, there was a systematic and structured analysis of the standard and checklists (LVs) for the creation of parameters that will compose a set of metrics. First, the standard was interpreted, through manual coding, an analytical process in which these qualitative data (standard premises) are categorized to facilitate the interpretative analysis of the content. Logically, NR-13 was divided into five categories: coverage, general provisions, pressure vessels, boilers and pipes. Within these categories there are subcategories and the aim is to synthesize the content of the standard in the form of parameters and variables, as well as to understand the dependency relationship between them. Then, the NR-13 checklists of a large company operating in the O & G sector (named in this work as company X) were analyzed. In this analysis, we sought to understand the verification procedures used in the field, to compare the items of the LVs with the interpretation of the NR-13, as well as to obtain the crossing of the information of the LVs and the preliminary list of parameters, in order to complement this list, adding other parameters, thus adjusting the relationships between variables. During the analysis of the LVs, there was also the verification of the automated items. For that, colors were used in Excel spreadsheet to demarcate the difficulty level of automating the items. After completing the survey of parameters, meetings took place in order to define criticality and verify which variables would be feasible to be obtained.

After the survey and adjustment of the automated and critical parameters and the verification of the origin and access of this information, the second step of creating metrics and indicators began. Metrics are the raw variables defined based on the parameters that are being synthesized, while the indicators represent the measures that can be calculated in order to evaluate performance (in percentage). Thus, the indicators are composed of metrics. The empirical knowledge of the consultants of the digital engineering area of a R&D group that is exploring the subject in the

Fig. 1 Research steps

Tecgraf Institute at PUC-Rio was used as a basis and the consensus obtained through internal meetings involving consultants and researchers.

Then, the third step (verification and grouping of metrics) counted on the participation of five professionals from the company X, specialists in inspection of static equipment (pressure vessels, boilers, pipes and tanks) according to NR-13, in which through an interview protocol it was possible to collect information and perform analyzes for the development of legal compliance indicators, in addition to validating the metrics created in internal meetings with Tecgraf consultants. The interviews had an average duration of eight hours and consisted of: description of the research objectives and presentation of the metrics and indicators tables.

The interview protocol consisted of: verifying the agreement or disagreement of specialists in relation to the concept and purpose (validation) of the metrics composed by non-conformity verification parameters; select nine main metrics for each type of equipment and order them in terms of priority, that is, from the most important (1) to the least important (9); and group the metrics according to their gravity (G), urgency (U) and tendency (T)—GUT (grouping by dimension) with a scale of increasing importance from 1 (minimum) to 10 (maximum) for each dimension [17]. The concepts of the GUT matrix were adapted for research, seeking to evaluate the relationship of the metrics with potential non-conformities to be verified/evaluated in the process of verifying the legal compliance of static equipment. In this sense, G indicated the severity effects/impacts that the metric can cause on the quality of the verification of the legal compliance of the projects, U indicated the need to implement the metric for the use of the project equipment; and T indicated the frequency of a recurring pending metric to happen.

Based on the results of the interviews, a multicriteria analysis was performed, considering the three criteria (dimensions G, U and T) and multidecisor, grouping the responses of the five experts interviewed. In addition to this, a multidecisor analysis was also performed for each criterion. To calculate the GUT and each dimension, the TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution) was used, which is commonly applied to ranking problems. As [18], the TOPSIS technique for ordering preference by similarity for the ideal solution was first developed by [19], in order to solve a decision-making problem with multiple attributes and this provided the principle of commitment in which the chosen alternative should be the one with the shortest distance from the Positive Ideal Solution (PIS) and the one with the greatest distance from the Negative Ideal Solution (NIS). Thus, the TOPSIS method was chosen, as according to [20], it is adequate to model precisely known quantitative criteria values, the data collection process is less complex and requires less judgments. According to [21], the idea of the TOPSIS method can be expressed in the following stages:

Stage 1: Determination of the objectives in order to develop the decision matrix (Performance Matrix—PM) with m alternatives and n criteria, whereas the intersection between each alternative and criterion is given by x_{ij}, thus obtaining the matrix $\left(X_{ij}\right)_{ij}$;

$$PM = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Stage 2: Normalize the performance matrix for $R^* = \left(r_{ij}\right)$. In this research we use the vectoral normalization method, according to $r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}$

Stage 3: Matrix weighting: it is required to develop a set of values regarding the relative importance of different alternatives. Hence, it is developed a set of values w_k to each criterion. This weighting factor may be ad hoc reflex from relative importance, according to the formulation below;

$$V_{ij} = \left(w_{ij}\right)_{m_x n} = \left(w_j r_{ij}\right)_{m_x n} \quad (2)$$

In which w_j is the scale value for the criterion j, and $\sum_{i=1}^{n} w_j = 1$.

Stage 4: Identify and compute the ideal alternative (PIS);

Stage 5: Identify and compute the anti-ideal alternative (NIS);

Stage 6: Obtain distance measures based on the Euclid distance, thus developing an ideal distance measure for the ideal point $\left(D_i^+\right)$ and for the anti-ideal point $\left(D_i^-\right)$, given as follows:

$$D_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - s_{ij}^+\right)^2}, for \ \ i = 1, 2, \ldots, m \quad (3)$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - s_{ij}^-\right)^2}, for \ \ i = 1, 2, \ldots, m \quad (4)$$

Stage 7: Determine the R index, defined below:

$$R_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (5)$$

Stage 8: Obtain the ranking order according to the maximization of the values calculated in the step 7.

Then, in the fourth step (prioritization of metrics), the following criteria were used: the order (ranking) generated from the GUT multicriteria and multidecisor analysis, the frequency of the selected metrics from the ranking of metrics considered most important in the interviews, and the emphasis given to the metrics for the discussion (consensus) of focus groups, involving consultants and researchers. Thus, to prioritize the metrics, we sought to offer a more comprehensive point of view [22] based on the use of a mixed methodology (qualitative and quantitative) [23] balanced by three criteria. The priority value was considered proportional to the number of criteria used, ranging from 1 to 3 (maximum priority).

Finally, in the fifth step there were the selection—choosing the most significant and representative metrics from a relatively large number of predefined metrics—and aggregation—integrating metrics to reflect the values of other underlying metrics in a synthetic and collective way. These procedures were used to narrow the list of priority metrics in the form of an initially small and representative set of key performance indicators (KPIs). Such steps involved the analysis of the results of the evaluated metrics, the face-to-face discussions during the interviews; the results of the GUT analysis; and the checklists' analysis (LVs) of each equipment. It should be noted that in the aggregation step, the selected metrics were grouped considering the engineering design phases (basic design, detailed design, construction and assembly, and operation) and the standard hierarchy, that is, the metrics were grouped in order to maintain the unit by subject. Based on the discussions, an initial list of KPIs was obtained for each equipment. Therefore, the results of the calculation of the metrics using a MCDM model were grouped in the form of indicators, composed of metrics, which make up the KPIs of each type of static equipment in a weighted way. Thus, this set of KPIs can represent a legal conformity assessment system based on NR-13.

4 Results

In order to exemplify the indicator development process, this section describes part of the results of the creation of pressure vessel indicators. Table 1 below presents part of the results of the verification and grouping of metrics (with some metrics evaluated). In summary, the table shows the validated metrics (after verification), highlighting in pink the first ten results (rankings) of the TOPSIS application and the priority metrics (with a selection frequency greater than 50% of the respondents, that is, greater or equal to 3; and the results of the focus group (called "highlight") in green, generated through consensus in relation to the main ordered metrics.

Table 1, which shows nine of the 54 pressure vessel metrics (MVP), pointed out that the seventh pressure vessel metric (MVP_7) was considered the most serious and urgent by the interviews and was critical by the analysis of the focus group, which highlights the importance of checking safety devices (DS) in the Construction and Assembly (C&M) phase. On the other hand, by GUT multicriteria analysis, the MVP_5 metric stands out, which seeks to measure the number of vessels without DS already in the basic design phase, which expresses the concern of verifying this issue since the beginning of the project.

Table 1 Validated vessel metrics

Item	Code	Metric	Ranking (Top10)				Selection	Focal group
			G	U	T	GUT	Frequency	Highlight
1	MVP_1	Number of pressure vessels not framed correctly in basic design phase/total pressure vessels	43	40	4	9	0	
2	MVP_2	Number of pressure vessels not framed correctly in detailed design phase/total pressure vessels	29	29	21	29	1	X
3	MVP_3	Number of pressure vessels not framed correctly in C&A phase/total pressure vessels	9	7	48	30	3	X
5	MVP_5	Number of pressure vessels without safety device provided in basic design phase/total pressure vessels	12	18	3	1	2	
6	MVP_6	Number of pressure vessels without safety device provided in detailed design phase/total pressure vessels	5	9	8	3	1	X
7	MVP_7	Number of pressure vessels without safety device provided in C & A phase/total pressure vessels	1	1	20	6	3	X
9	MVP_9	Number of locked pressure vessels without justification on expected safety devices in detailed design phase/total pressure vessels	21	36	24	31	0	

In a complementary way, the frequency analysis points out the problem of poor framing in the C&M phase. (MVP_3) also as something critical. In addition, some observations were considered relevant to complement the qualitative analysis of the metrics or reports of lessons learned that could be used for future improvements or research.

By analyzing Table 2, it is noticed that there are convergences in relation to the prioritized metrics. In addition, the prioritized metrics were grouped into KPIs according to Table 3

Therefore, seven pressure vessel KPIs formed by a set of weighted, selected and grouped metrics were formed. Such KPIs indicate the full legal compliance of static pressure vessel equipment in industrial plants, which is calculated through the vessel indicator percentage given as follows:

$$KPI_{VP}(\%) = \frac{\sum_{i=1}^{n}(I_n * W_{In})}{\sum_{i=1}^{n} W_{In}} * 100 = \frac{\sum_{i=1}^{n}\left(\frac{\sum_{j=1}^{k}(MVP_k * w_{MVPk})}{\sum_{j=1}^{k} w_{MVPk}} * W_{In}\right)}{\sum_{i=1}^{n} W_{In}} * 100 =$$

Table 2 Priority Metrics

Code	GUT	Frequency	Highlight	Priority
MVP_1	9	0		1
MVP_2	29	1	X	1
MVP_3	30	3	X	2
MVP_5	1	2		1
MVP_6	3	1	X	2
MVP_7	6	3	X	3
MVP_10	15	2	X	1
MVP_18	13	4	X	2
MVP_23	18	5	X	2
MVP_25	36	4		1
MVP_27	17	4	X	2
MVP_32	4	0		1
MVP_33	10	0		1
MVP_42	5	0		1
MVP_43	16	2	X	1
MVP_45	14	4		1
MVP_46	7	0		1
MVP_49	24	1	X	1
MVP_50	35	2	X	1
MVP_51	8	3	X	3
MVP_54	2	3	X	3

Table 3 Pressure vessels KPIs

Id	KPI	Metric	Metric weight (w_{MVPk})	Description	Project phases	KPI weight (W_{In})
I_1	Coverage	MVP_3	1.000	Number of pressure vessels not framed in NR-13 correctly/total pressure vessels	Construction & assembly (C & A) and operation	1/7
I_2	Control instruments and devices	MVP_7	0.667	Number of pressure vessels without expected safety device/total pressure vessels	Basic design, detailed design, C & A and operation	1/7
		MVP_10	0.111	Number of locked pressure vessels without justification on expected safety devices/total pressure vessels	Basic design, detailed design, C & A and operation	
		MVP_18	0.222	Number of pressure vessels without operating pressure gauge/total pressure vessels	Detailed design, C & A and operation	
I_3	Documentary requirements	MVP_23	0.400	Pressure vessels amount without records issued (enchiridion) and available/total pressure vessels	C & A and operation	1/7
		MVP_25	0.200	Number of pressure vessels without safety log book/total pressure vessels	C & A and operation	
		MVP_27	0.400	Pressure vessels of quantity with calibration certificate of safety devices not issued (or no report) or not updated or without signature of a qualified professional/total pressure vessels	C & A and operation	

(continued)

Table 3 (continued)

Id	KPI	Metric	Metric weight (w_{MVPk})	Description	Project phases	KPI weight (W_{In})
I_4	Ergonomic aspects	MVP_33	1.000	Number of pressure vessels that do not consider ergonomic aspects for maintenance, operation, inspection and safety/total pressure vessels	Detailed design and C & A	1/7
I_5	Operation safety	MVP_43	1.000	Number of pressure vessels with the inadequate calibration of control instruments in safety operating procedure system (SOP)/total pressure vessels	C & A and operation	1/7
I_6	Safety inspection	MVP_45	0.143	Number of pressure vessels (new or used) without safety inspection report issued/total pressure vessels	C & A and operation	1/7
		MVP_46	0.143	Number of pressure vessels without initial safety inspection/total pressure vessels	C &A and operation	
		MVP_49	0.286	Number of pressure vessels without evidence in the enchiridion that performed hydrostatic testing (HT) and signature of qualified professional/total pressure vessels	Detailed design, C & A and operation	

(continued)

Table 3 (continued)

Id	KPI	Metric	Metric weight (w_{MVPk})	Description	Project phases	KPI weight (W_{In})
		MVP_51	0.428	Number of pressure vessels with inconsistencies of their operating condition in safety record/total pressure vessels	C & A and operation	
I_7	Pendencies	MVP_54	1.000	Pressure vessels amount with pending/total pressure vessels	C & A and operation	1/7

$$= \left(\left(\begin{array}{r} (I_1 * 1/7) + (I_2 * 1/7) + (I_3 * 1/7) + (I_4 * 1/7) + (I_5 * 1/7)+ \\ (I_6 * 1/7) + (I_7 * 1/7) \end{array} \right) \right) * 100$$

$$= \left(\begin{array}{r} (MVP_3 * 1) + (MVP_7 * 0.667 + MVP_{10} * 0.111 + MVP_{18} * 0.222) \\ +(MVP_{23} * 0.4 + MVP_{25} * 0.2 + MVP_{27} * 0.4) + (MVP_{33} * 1) \\ +(MVP_{43} * 1) \\ + \left(\begin{array}{r} MVP_{45} * 0.143 + MVP_{46} * 0.143 + MVP_{49} * 0.286 + MVP_{51} \\ *0.428 + (MVP_{54} * 1) * 100 \end{array} \right) \end{array} \right) \tag{6}$$

By analyzing the results, it can be seen that in order to assess the conformity of static equipment such as pressure vessels, it is a priority to have non-conformity indicators related to the coverage metrics, which determine whether the equipment is being covered by NR-13, and in a certain way direct the level of care and attention with them; control devices, which directly impact serious and imminent risk; and safety inspections, which must take place according to a certain periodicity (correctly documented) and must take place at the right time. Therefore, it is expected that these indicators will serve as reference measures for the process of verifying the legal compliance of the equipment and can be continuously improved or adjusted according to future updates or needs.

5 Conclusion

From an academic point of view, the development of metrics based on the requirements of a standard, using concepts of performance measurement and MCDM models, is still a fertile area for research. The proposition of a systematic to verify the legal compliance of static equipment through indicators based on parameters can serve as a positive stimulus for future research. Finally, this research highlights the importance of integrating technologies, methods and knowledge for legal compliance, considering gains related to: quality, safety, technical efficiency, environmental risks and optimization of inspection processes.

From a practical point of view, for the O & G industry, this research has the following contributions: development and validation with the technical staff of the company X, of metrics and indicators to be applied in the inspection and monitoring of the condition of equipment, in relation to critical parameters of compliance with NR-13. From this, the proposition of a standardized procedural systematic represents an important contribution towards the automation of legal compliance verification. The proposal of a performance measurement system with indicators seeks to help O&G professionals to understand the performance of the compliance dimensions, making it possible to understand the criticality of the verification of certain equipment, reducing the time and cost of processes (efficiency) and increasing plant compliance (effectiveness).

Acknowledgements : The following research agencies supported this work: Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES) (Finance Code 001), Brazilian National Council for Scientific and Technological Development (CNPq) (Grant Number 300007/2019-1) and National Agency of Petroleum, Natural Gas and Biofuels (20288-7).

References

1. Hollnagel, E., Woods, D.D., Epilogue: Resilience engineering precepts. Resilience engineering: Concepts and precepts, 347–358 (2006).
2. Muniz, M.V.P., Lima, G.B.A., Caiado, R.G.G., Quelhas, O.L.G., Bow tie to improve risk management of natural gas pipelines. Process safety progress, 37(2), 169–175 (2018).
3. Ceryno, P.S., Scavarda, L.F., Klingebiel, K., Yüzgülec, G. Supply chain risk management: a content analysis approach. International Journal of Industrial Engineering and Management, 4(3), 141–150 (2013).
4. Ceryno, P., Scavarda, L.F., Klingebiel, K. Supply chain risk: empirical research in the automotive industry. Journal of Risk Research (Print) 18, 1145–1164 (2015).
5. Fontainha, T.C., Leiras, A., de Mello Bandeira, R.A., Scavarda, L.F. Public-private-people relationship stakeholder model for disaster and humanitarian operations. International journal of disaster risk reduction, 22, 371–386 (2017).
6. Pereira, J.C., Bordeaux, R., Zotes, L.P., Lima, G.B., Quelhas, O.L.G., Probabilistic risk analysis of safety management system failure and impact on economic performance: the case of jet engine manufacturing. International Journal of Management and Decision Making 14(4), 345–372, (2015).
7. Parida, A., Chattopadhyay, G. Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM). Journal of Quality in maintenance Engineering, 13(3), 241–258 (2007).
8. Reiman, T., Pietikäinen, E. Leading indicators of system safety–monitoring and driving the organizational safety potential. Safety science 50(10), 1993–2000 (2012).

9. Scavarda, A., Daú, G., Scavarda, L.F., Caiado, R.G.G. An Analysis of the Corporate Social Responsibility and the Industry 4.0 with Focus on the Youth Generation: A Sustainable Human Resource Management Framework. Sustainability 11, 5130 (2019).
10. Daú, G., Scavarda, A., Scavarda, L. F., & Portugal, V.J.T. The healthcare sustainable supply chain 4.0: The circular economy transition conceptual framework with the corporate social responsibility mirror. Sustainability 11(12), 3259 (2019).
11. Biaz, B.M., Ferreira, V.H., Fortes, M.Z., Lopes, T.T., Lima, G.B.A. Islanding detection in distributed generation using unsupervised learning techniques. IEEE Latin America Transactions 16(1), 118–125 (2018).
12. do Carmo Silva, M., Lima, G.B.A., Gomes, C.F.S., Rangel, L.A.D., Caiado, R.G.G. A SMARTS-Choquet's approach for multicriteria decision aid applied to the innovation indexes in sustainability dimensions. Soft Computing 23(16), 7117–7133 (2019).
13. Carvalho, A.N., Oliveira, F., Scavarda, L.F. Tactical capacity planning in a real-world ETO industry case: An action research. International Journal of Production Economics, 167, 187–203 (2015).
14. Carvalho, A.N., Oliveira, F., Scavarda, L.F. Tactical capacity planning in a real-world ETO industry case: A robust optimization approach. International Journal of Production Economics 180, 158–171 (2016).
15. Gomes, L.F.A.M., Araya, M.C.G., Carignano, C. Tomada de decisão em cenários complexos: introdução aos métodos discretos do apoio multicritério à decisão. São Paulo: Pioneira Thomson Learning 107 (2004).
16. Caiado, R.G.G., Lima, G.B.A., Gaviao, L.O., Quelhas, O.L.G., Paschoalino, F.F. Sustainability analysis in electrical energy companies by similarity technique to ideal solution. IEEE Latin America Transactions 15(4), 675–681 (2017).
17. Franzosi, F., Teresinha-Kist, L., Ribas-Moraes, J.A., Machado, Ê.L. Diagnosis of the health care waste management system of hospitals in the west of Santa Catarina State-Brazil. Producción + Limpia 13(1), 54–64 (2018).
18. Hwang, C.L., Lai, Y.J., Liu, T.Y. A new approach for multiple objective decision making. Computers & operations research 20(8), 889–899 (1993).
19. Hwang, C.L. Yoon, K. Methods for multiple attribute decision making. In Multiple attribute decision making (pp. 58–191). Springer, Berlin, Heidelberg (1981).
20. Lima Junior, F.R. and Carpinetti, L.C.R. A comparison between TOPSIS and Fuzzy-TOPSIS methods to support multicriteria decision making for supplier selection. Gestão & Produção 22(1), 17–34 (2015).
21. Olson, D.L. Comparison of weights in TOPSIS models. Mathematical and Computer Modelling 40(7–8), 721-727, (2004).
22. Haas, E.J., Yorio, P. Exploring the state of health and safety management system performance measurement in mining organizations. Safety science 83, 48–58 (2016).
23. Caiado, R.G.G., Quelhas, O.L.G., Nascimento, D.L.D.M., Anholon, R., Leal Filho, W. Towards sustainability by aligning operational programmes and sustainable performance measures. Production Planning & Control, 30(5–6), 413–425 (2019).

Navy Warship Selection and Multicriteria Analysis: The THOR Method Supporting Decision Making

Fabricio Maione Tenório, Marcos dos Santos, Carlos Francisco Simões Gomes, and Jean de Carvalho Araujo

Abstract Due to successive budget restrictions, Brazilian Navy currently has an undersized fleet of only eleven escort ships, many of which are nearing the end of their useful lives. It's estimated that in 2024, when the first Tamandaré class frigate is due to be delivered, the country will have only five escort ships in operation. Thus, it is expected that Brazilian Navy will make opportunity purchases, in order to maintain the readiness of the fleet. The article aims to select a ship for purchase, among eight ships used by navies around the world, through Multicriteria Decision Aiding Hybrid Algorithm (THOR), identifying the alternative that "best" satisfies the replenishment of escorts. The use of pertinence associated with the values of the alternatives made it possible to quantify and include uncertainty in the decision-making process. In the result generated by THOR, the LCF alternative obtained the highest score in the three ordering types (S1, S2 and S3).

Keywords THOR · Ships · Brazilian navy

F. M. Tenório (✉) · M. dos Santos
Military Engineering Institute, Rio de Janeiro 22290-270, Brazil
e-mail: fabricio.tenorio@cefet-rj.br

M. dos Santos
e-mail: marcosdossantos_doutorado_uff@yahoo.com.br

F. M. Tenório · J. de C. Araujo
Federal Center of Technological Education Celso Suckow da Fonseca, Itaguaí 23812-101, Brazil
e-mail: jean.carvalhorj@gmail.com

C. F. S. Gomes
Fluminense Federal University, Niterói 24210-240, Brazil
e-mail: cfsg1@bol.com.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_3

1 Introduction

According to the National Defense Strategy (END), Brazil is a peaceful country by tradition and conviction, with its international affairs are governed, among others, by the constitutional principles of non-intervention, defense of peace and peaceful resolution of conflicts. It is part of the Brazilian identity, rooted in its values, the vocation for harmonious coexistence. In this way, the Brazilian people are not willing to exert their power on other nations. They want Brazil to grow without reigning upon others [1].

The preparation of defense against threats and aggressions must accompany Brazil's growing development. Among the National Defense Objectives (OND), are the guarantee of sovereignty, national heritage and territorial integrity, structuring the Armed Forces (AF) with adequate organizational and operational capacities, creating social and economic conditions to support National Defense in the Brazil. It also includes the contribution to international peace and security and the protection of Brazilian interests at the different levels of the country's external projection [1].

Within this scope, the Brazilian Navy (BN) has the following mission: "develop and employ Naval Power in the defense of the homeland, in accordance with the Federal Constitution and other laws; to safeguard the branches of state; and, by initiative of any of these branches, to ensure law and order. The BN also acts under mandate of international organizations and in support of the country's foreign policy." [2].

In order to achieve the objectives, the BN must have the minimum necessary means to exercise its constitutional attributions, being correctly sized and technologically equipped. However, due to successive budget restrictions, BN currently has an undersized fleet of only 11 escort ships, many of which are nearing the end of their useful lives [3]. By 2024, when the first Tamandaré class frigate is due to be delivered, the country will have only five escort ships in operation. Thus, it is expected that BN will make "opportunity purchases", in order to maintain the readiness of the fleet, as well as the training of its entire operating structure, until the entry into service of the "Tamandaré" class frigates.

The article aims to select a ship for purchase through Multicriteria Decision Aiding Hybrid Algorithm (THOR), identifying the alternative that "best" satisfies the replenishment of escorts. The study considered ships used by various navies of the world.

2 Theorical Foundation

The Operations Research (OR) makes use of mathematical and/or logical models in order to solve real problems, presenting a highly multidisciplinary [4]. Santos et al. [5] affirm that OR operates in 5 large areas that are interrelated: Operational Evaluation of Systems, Support the Decision Making, Problems Structuring, Optimization of

Productive Processes and Simulation of Processes. THOR can be applied to support the decision-making process.

THOR is based on three axiomatic concepts/theories for simultaneous use: Preference Modeling (approximating it to the French School), Multi attribute Utility Theory (approximating it to the American School) and Theories dealing with inaccurate information. The joint use of these theories allows the attractiveness of an alternative to be quantified, by creating a non-transitive aggregation function [6]. The use of THOR allows "faster and more efficient analysis" of the alternatives, considering the non-determinism of the weight assignment process and quantifying the non-determinism by reapplying it in the ordering process of the alternatives [7].

The main contributions of the THOR method to multicriteria theory involve [8]:

- Aggregate multi attribute utility theory and preference modelling;
- Order discrete alternatives in transitive or non-transitive decision-making processes;
- Quantify uncertainties in the prioritization process, through the use of fuzzy set theory, and then use it in the multicriteria decision support process;
- Eliminate the criteria that do not impact the ranking process, through the use of rough set theory;
- Enable simultaneous data entries from different decision makers, allowing judgments to be expressed in ratios, intervals or ordinal scales;
- Enable decision makers to not need to attribute weights to each criterion, but may make use of a feature which attributes weights to the criteria in an ordinal scale;
- Intuitive computer program that allows the user to analyze the problem quickly and efficiently.

The Decision Maker (DM) should represents the relative importance to the criteria in the form of a weight, establishing a preference threshold (p_j) and indifference (q_j) for each criterion j, establishing discordance and pertinence of the weight values assigned to each criterion, as well as the pertinence of the classification of the alternative in the criterion [9].

Faced with the lack of security and uncertainty in the value judgment employed in multicriteria support methods, it is necessary to quantify the imprecision for each weight and for each classification of the alternatives. The DM must express the levels of certainty through the use of pertinence indexes, associating to an element of the universe to a real number of the interval [0, 1]. An index of relevance equal to 1 corresponds to absolute certainty, that is, the DM is fully sure of the weight given to the criterion, while an index of relevance equal to zero indicates absolute uncertainty. Two pertinence indexes are used to reflect the degree of uncertainty of the DM, one of them referring to the criteria weights and the other to the classification of the alternatives in each criterion [8].

Given two alternatives a and b, three situations should be considered when using THOR: S1, S2 and S3. In using the S1 context, the alternatives have their attractiveness punctuated in situations where aP_jb occurs. Thus, comparing alternative with the other alternatives, we can identify the criteria in which aP_jb, considering the preference threshold, indifference and discordance, checking whether the imposed condition is satisfied. If satisfied, we know that a dominates b [9]. The relations P (strict preference), I (indifference) and Q (weak preference) are expressed in Eqs. (1), (2) and (3) respectively.

$$aPb \leftrightarrow g(a) - g(b) > p \tag{1}$$

$$aIb \leftrightarrow -q \leq |g(a) - g(b)| \leq q \tag{2}$$

$$aQb \leftrightarrow q < |g(a) - g(b)| \leq p \tag{3}$$

The Eqs. (4), (5) and (6) reflect the three situations for an alternative to be ranked better than the other [10].

$$S1 : \sum\nolimits_{j=1}^{n} (w_j | aP_j b) > \sum\nolimits_{j=1}^{n} (w_j | aQ_j b + aI_j b + aR_j b + bQ_j a + bP_j a) \tag{4}$$

$$S2 : \sum\nolimits_{j=1}^{n} (w_j | aP_j b + aQ_j b) > \sum\nolimits_{j=1}^{n} (w_j | aI_j b + aR_j b + bQ_j a + bP_j a) \tag{5}$$

$$S3 : \sum\nolimits_{j=1}^{n} (w_j | aP_j b + aQ_j b + aI_j b) > \sum\nolimits_{j=1}^{n} (w_j | aR_j b + bQ_j a + bP_j a) \tag{6}$$

When using the S2 context, the alternatives have their attractiveness punctuated in situations where aP_jb and aQ_jb occurs. When using the S3 context, the alternatives have their attractiveness punctuated in situations where aP_jb, aQ_jb and aI_jb occurs. In the situations S2 and S3, there is a more flexible scenario, where a smaller difference between the alternatives allows classifying one alternative as better than another [11].

Depending on the model, the criterion can be classified as true criterion, quasi-criterion or pseudo-criterion. In the true criterion model, any difference between the values of the function (or criterion) g implies a situation of strict preference, with the situation of indifference occurring when $f(g)$ assumes the same value for both a and b. However, it is reasonable to admit that small differences $g(a) - g(b)$ also reflect an indifference between a and b. Thus, another criterion called the limit of indifference (q) can be inserted, representing the largest deviation compatible with a situation of indifference between a and b. In this model, called quasi-criterion, the existence of any deviation slightly above the limit of indifference, configures a situation of strict preference. In the pseudo-criteria model, limits of indifference (q) and limits of preference (p) are established. In this way, a sudden passage between indifference and strict preference is avoided, creating a weak preference region (Q), which lies between indifference (I) and strict preference (P) [12].

It is recommended that THOR be used preferably in situations of pseudo-criteria and quasi-criteria, since the method can be used to its full capacity. The use of THOR in the situation of the true criterion, when the values of p and q assume a value equal to zero, leads to the equality of the orders corresponding to S1 and S2 [8, 13].

3 Problem Description and Modelling

Escort ships are composed of frigates, corvettes and destroyers. These ships differ by their size, the amount of armament and the strength of the engine. An escort has the function of protecting a higher value unit (HVU), which may be an aerodrome ship, a troop carrier or a logistical support vessel. Thus, its primary function is to destroy or neutralize enemy aircraft and ships. To this end, BN frigates, for example, have anti-ship missiles, cannons and torpedo launchers.

Escort ships must have anti-submarine, anti-surface and anti-aircraft capabilities for point-defense (missile availability). They must be capable of transporting, supplying, operating and maintaining helicopters, capable of attacking surface targets and submarines, and carrying out clarification operations [14]. In 2019, BN has 11 escort ships, with an average of over 30 years, close to the end of its useful life [3]. Thus, there is a need to replace ships that are going out of service so that their minimum combat capacity is not further compromised.

Of the 11 escort ships left, six “Niterói” class frigates, two “Greenhalgh” (Type 22) class frigates, two “Inhaúma” class corvettes and one “Barroso” class corvette. By 2025, at least six ships will be decommissioned, as their useful life is coming to an end and only two ships are expected to last until 2028, except for “Barroso”, which was incorporated in 2008. Three “Niterói” class frigates, two frigates Type 22, and a corvette should be deactivated before 2025. The remaining three frigates that are due to be revitalized, should continue operating until 2028. The “Julio de Noronha” corvette, which underwent refurbishment, will be the last “Inhaúma” class corvette to be disabled. Until the entry into service of the first “Tamandaré” class corvette, which is scheduled to be incorporated in 2024, the Brazilian Squadron will only be able to count on five escort ships, a very low number for missions destined for BN. The possibility of delayed delivery of the “Tamandaré” frigates should not be disregarded [15].

The “Barroso” corvette, for example, took about 14 years to be ready, due to the lack of resources to finish it [16]. In the meantime, BN may seek opportunity purchases from ships abroad to fill the gap left between the deactivation of the current ships and the entry into service of the new ships.

The studies that follow are intended to assist BN in the decision-making process of a reference ship for purchase. For this, the THOR method will be used. Eight ship alternatives were selected to be used.

1. F-124 (D)—The F-124 Sachsen class is the latest class of frigates from the German Navy, equipped with cutting edge air defense technology. The design of

these frigates is based on the F123 Brandenburg class, but with improved stealth (defense for radar detection) features, and also incorporates the advanced multi-function APAR radar, as well as the allegedly capable SMART-L long-range radar to detect planes and stealth missiles. Although designated as frigates, their size and characteristics can be compared to destroyers.

2. LCF (NL)—The four "De Zeven Provincien" frigates are advanced air defense ships in service at Koninklijke Marine (Royal Netherlands Navy). This class, also known as LCF, (Luchtverdedigings-en commandofregat), air defense and command frigate were designed to protect against air threats, but they also have weapons on board to engage surface targets and submarines: Harpoon anti-ship missiles and torpedoes anti-submarine Mk 46. The main weapon of the "De Zeven Provincien" is the Mk 41 Vertical Launch System (VLS), each with 32 Evolved Sea Sparrow missiles and 32 SM-2 Standard IIIA missiles, capable of intercepting ballistic missiles. The frigates are equipped with the Thales Anti Air Warfare suite, which consists of the multifunction APAR radar, capable of guiding multiple ESSM and SM-2 missiles simultaneously against multiple targets and the SMART-L radar, with a range of more than 400 km, capable of detecting and track thousands of simultaneous targets, even stealth targets [17].
3. F-100 (E)—The "Álvaro de Bazán" class (also known as the F-100 class of frigates) is a new class of defense frigates of the Aegis combat system equipped with the Spanish Navy. The ships are equipped with American Aegis weapon technology that allows them to track hundreds of air targets simultaneously as part of their air defense network. The F-100 is one of the few non-American ships that use the SPY-1D system [18].
4. FREMM (F) + (I)—FREMM (Multipurpose Frigate—Fregate multi-mission or Fregata Europea Multi-Missione) is the result of the most ambitious European cooperative naval program for France and Italy. They are frigates capable of ASW, ASuW, AAW and ground attack. The essential missions of FREMM are the domain of the aeromaritime environment and active participation together, as well as support for the aircraft and amphibious group [19].
5. HORIZON (F) + (I)—The main mission of the Horizon class frigates is the anti-aircraft defense against saturation attacks with anti-ship missiles. Even though the project has this objective, the ship still has a powerful anti-submarine capability. Horizon class ships have modern and efficient defense systems against enemy radars and against weapons such as anti-ship missiles and torpedoes that are eventually launched against the ship [20].
6. T-45 DARING (UK)—The Type 45 destroyer, also known as the D or Daring class, is a class of six guided missile destroyers built for the United Kingdom's Royal Navy. The class is designed primarily for anti-aircraft and anti-missile warfare and is built around the PAAMS (Sea Viper) air defense system using the SAMPSON AESA and S1850M long-range radars. The first three destroyers were assembled by BAE Systems Surface Fleet Solutions using partially prefabricated "blocks" built in different shipyards, the remaining three were built by BAE Systems Maritime Naval Ships.

7. DDG-51 (USNavy)—The USS Arleigh Burke (DDG-51) is a destroyer of the Arleigh Burke class belonging to the United States Navy. The DDG-51 is a multi-mission destroyer with an emphasis on air defense (AAW) and blue water operations. Throughout his career, he participated in several humanitarian and military missions. Among them, Operation Enduring Freedom, the 2003 invasion of Iraq and Operation Inherent Determination.
8. F-125 (D)—The F125 class frigates Baden-Württemberg are a series of frigates from the German Navy, which were designed and built by ARGE F125, a joint venture of Thyssen-Krupp and Lürssen [21].

Based on the parameters presented in Vogt [22], the following criteria were listed, after consultation with Brazilian Navy officers with more than 20 years of experience in the area:

- Maximum Speed (max speed): Speed corresponding to the maximum power regime of the machines. The maximum speed of a warship is rarely used in peacetime, as it implies higher fuel consumption and unnecessary machine effort.
- Radius of action: Maximum distance, in nautical miles, that the ship can reach leaving its base, and returning to it, without the need for refueling.
- Crew: Set of people, hierarchically organized, that ensure the operation of a vessel. It includes personnel from several certified professional careers responsible for ensuring the functioning of each of the departments, sections or services. The number of crew members will depend on the ship's missions and on-board technology, that is, the level of automation adopted. At the other extreme, a larger crew decreases the ship's comfort and autonomy in terms of supplies [22]. In the study, it was considered that the bigger the crew, the worse.
- Main Artillery: Armament or a set of armaments that gives the ship the main defense.
- Secondary Artillery: They act in addition to the main battery.
- AsuW (Anti-surface warfare): Branch of the naval war that refers to the suppression of surface combatants. More generally, they are any weapons, sensors or operations designed to attack or limit the effectiveness of an opponent's surface ships.
- ASW (Anti-submarine warfare): Branch of submarine warfare that uses surface warships, aircraft or other submarines to locate, track and detain, damage or destroy enemy submarines.
- He (helicopter): Contributes to combat value, cargo and material transfer, aeromedical evacuation.
- Cost: Ship acquisition cost.

Table 1, from the reference approached in Vogt [22], summarizes the main technical-operational characteristics of the main ships available in the world for sale.

Table 2 presents the alternatives and criteria used in the study; each cell corresponds to an alternative ship classified in its respective criterion. The assignment of the classification of the alternatives of the Main Artillery, Secondary Artillery, AsuW,

Table 1 Comparative table of modern frigate and destroyer parameters adapted from Vogt [22]

Typical data	F-124	LCF	F-100	FREMM	HORIZON	T-45 DARING	DDG-51	F-125
L (m)	143.0	144.2	146.7	137.0	153.0	152.4	153.8	149.5
LWL (m)	132.2	–	133.2	–	141.7	143.5	142.0	–
T (m)	5.0	5.2	4.9	5.0	5.1	5.7	6.3	5.0
DISPL. FL. (tons)	5.600	6.050	5.800	5.500	6.700	7.350	8.300	7.200
Max speed (kts)	29	30	29	27	29	29	32	26
Radius of action	4.000/18	5.000/18	4.500/18	6.000/15	7.000/18	7.000/18	8.150/20	4.000/?
Crew	243	230	250	145	230	235	380	190
Main artillery (mm)	1 × 76 mm SupRapid	1 × 127 mm OTO54LW	1 × 127/54 Mk 45-2	1 × 76 mm SupRapid	1 × 76 mm SupRapid	1 × 114 mm Mk 8-1	1 × 127 mm Mk 45-1	1 × 127 mm OTO62LW
Secondary artillery (mm)	2 × 27 mm	2 × CIWS 30 mm	2 × CIWS 20 mm	2 × KBA 25 mm	2 × KBA 25 mm	2 × CIWS 20 mm	2 × CIWS 20 mm	2 × 27 mm 7 × 12,7 mm
AAeW	ESSM SM-2 MR	ESSM SM-2 MR	ESSM SM-2 MR	ASTER-15/30	ASTER-15/30	ASTER-15/30	ESSM SM-2 MR	2 × RAM
ASuW	EXOCET	HARPOON	HARPOON	MM-40	MM-40 III	HARPOON	HARPOON	HARPOON
ASW	MU-90	Mk-46	Mk-46	MU-90	MU-90	STGRAY	ASROC	SUB ROV
He	2 × LYNX	1 × LYNX	1 × SH60B	1 × NH-90	1 × NH-90	LYNX 300	1 × SH60B	2 × NH-90

Table 2 Comparative table of modern frigate and destroyer parameters

	Max speed	Radius of action	Crew	Main artillery	Secondary artillery	ASuW	ASW	He	Cost ($)
F-124	29	4000	243	1	1	1	1	4	800
LCF	30	5000	230	3	5	4	1	1	500
F-100	29	4500	250	3	4	4	1	3	600
FREMM	27	6000	145	1	3	2	1	3	745
HORIZON	29	7000	230	1	3	3	1	3	1030
T-45 DARING	29	7000	235	2	4	4	1	2	1500
DDG-51	32	8150	380	3	4	4	3	3	1650
F-125	26	4000	190	3	2	4	2	5	740
Weights	2	2	1	3	3	3	3	4	6
p	3	400	28	1	1	1	1	1	200
q	1	40	14	0.5	0.5	0.5	0.5	0.5	50
Discordance	6.32	4231.5	238.8	2.03	4.05	3.04	2.03	4.05	1166.5

ASW and He criteria was done through an interval scale, where the distance between the values of the alternatives was considered. The classification of the alternatives, weights, preference limits, indifference and discordance limits for each criterion were attributed through a joint analysis with experts in the field.

Table 3 shows the relevance attributed to each weight and classification of the alternative in each criterion. For the pertinence of the criteria Maximum Speed, Radius of Action (at cruising speed) and Crew, since these are real data extracted from the technical specifications of the ships, the value 1 was assigned, indicating that there is no doubt as to the attribution of the data. As for the Main Artillery, Secondary Artillery, ASuW and He criteria, 0.9 was assigned, since it is a qualitative analysis carried out by specialists with extensive experience in the area, however, even so, subject to some inaccuracy. About the cost criterion, the values were attributed due to the degree of reliability of the sources from which the costs of the ships were extracted.

The AAeW (Anti-Air Warfare) criterion, although important, was not considered because the ships under study have very similar operational characteristics. Regarding the cost criterion, the cost of acquiring ships in Brazil was not found, therefore the cost of building (in million dollars) the ship in the country of origin was considered. However, it can be inferred that the acquisition cost will be proportional.

4 Results

THOR was used to rank the alternatives. The calculations were performed using a multicriteria decision method system (software) called THOR1 [23] developed at the Brazilian Military Engineering Institute (IME) located in Rio de Janeiro, Brazil. In the result generated by THOR (Table 4), the LCF alternative obtained the highest score in the three ordering types (S1, S2 and S3). It is important to notice that the alternatives F-124 and FREMM always took the last positions. The results can be grouped into 3 sets:

- Ships with the best performance: LCF, F-100, DDG-51 and F-125
- Ships with average performance: HORIZON and T-45 DARING
- Ships with weak performance: FREMM and F-124.

5 Conclusion

The proposed model was useful to reflect the preferences of the DM. The use of pertinence associated with the values of the alternatives made it possible to quantify and include uncertainty in the decision-making process. This allowed the DM to identify the most attractive alternative, compensating for the data uncertainties.

Table 3 Pertinences

	Max speed	Radius of action	Crew	Main artillery	Secondary artillery	ASuW	ASW	He	Cost ($)
F-124	1	1	1	0.9	0.9	0.9	0.9	0.9	0.8
LCF	1	1	1	0.9	0.9	0.9	0.9	0.9	0.8
F-100	1	1	1	0.9	0.9	0.9	0.9	0.9	0.7
FREMM	1	1	1	0.9	0.9	0,9	0.9	0.9	0.5
HORIZON	1	1	1	0.9	0.9	0.9	0,9	0.9	0.75
T-45 DARING	1	1	1	0.9	0.9	0.9	0.9	0.9	0.8
DDG-51	1	1	1	0.9	0.9	0.9	0.9	0.9	0.8
F-125	1	1	1	0.9	0.9	0.9	0.9	0.9	0.5

Table 4 Ordering of alternatives

S1		S2		S3	
LCF	3,849	LCF	4,106	LCF	5,058
DDG-51	3,551	DDG-51	3,962	F-100	4,746
F-100	3,500	F-100	3,699	DDG-51	4,543
T-45 DARING	3,500	F-125	3,350	F-125	3,717
F-125	3,034	T-45 DARING	1,506	HORIZON	1,842
HORIZON	2,500	HORIZON	1,500	T-45 DARING	1,705
FREMM	2,500	FREMM	1,116	FREMM	1,417
F-124	2,500	F-124	1,000	F-124	1,186

The study allowed learning and improving the understanding of the problem during modeling. The DM observed the transparency of the decision process. The model allows its application in other warship choices processes, as well as their adaptation to the choice of other military equipment.

References

1. Ministério da Defesa.: Estratégia Nacional de Defesa (END) (2012). https://www.defesa.gov.br/arquivos/2012/mes07/end.pdf. Accessed 06 jun 2019.
2. Marinha do Brasil.: Missão e Visão de Futuro da Marinha (2019). https://www.marinha.mil.br/content/missao-e-visao-de-futuro-da-marinha. Accessed 06 jun 2019.
3. Fuoco, T.: Marinha fará licitação de U$ 1,6 bi em navios de guerra no 1T19 (2018). https://economia.uol.com.br/noticias/bloomberg/2018/11/12/marinha-fara-licitacao-de-u-16-bi-em-navios-de-guerra-no-1t19.htm?cmpid=copiaecola. Accessed 06 jun 2019.
4. Santos, M., Quintal, R.S., Paixão, A.C., Gomes, C.F.S.: Simulation of Operation of an Integrated Information for Emergency Pre-Hospital Care in Rio de Janeiro Municipality. Procedia Computer Science, v. 55, pp. 931–938 (2015).
5. Santos, M., Silva, T.L.P.E., Gomes, C.F.S., Vieira, J.A.M., Walker, R.A.: Mapping the Perception of Users as the Usability of Smartphones: Benchmarking Features Through the Borda Count Method. New Global Perspectives on Industrial Engineering and Management. 1ªed.: Springer International Publishing, v., pp. 57–64 (2018).
6. Gomes, C.F.S., Costa, H.G.: Aplicação de métodos multicritério ao problema de escolha de modelos de pagamento eletrônico por cartão de crédito. Production, 25(1): 54–68 (2015).
7. Cardoso, R.S., Xavier, L.H., Gomes, C.F.S., Adissi, P.J.: Uso de SAD no apoio à decisão na destinação de resíduos plásticos e gestão de materiais. Pesquisa Operacional, 29(1): 67–95 (2008).
8. Gomes, C.F.S., Nunes, K.R., Xavier, L.H., Cardoso, R., Valle, R.: Multicriteria decision making applied to waste recycling in Brazil. Omega, 36(3):395–404 (2008).
9. Gomes, C.F.S., Gomes, L.F.A.M., Maranhão, F.J.C.: Decision analysis for the exploration of gas reserves: merging todim and thor. Pesquisa Operacional, 30(3):601–617 (2010).
10. Gomes, L.F.A.M., Gomes, C.F.S., Rangel, L.A.D.: A comparison of the applications of TODIM and THOR to an important environmental problem. In XLII Simpósio Brasileiro de Pesquisa Operacional, pp. 3177–3188, Ubatuba - SP. Sociedade Brasileira de Pesquisa Operacional (2011). https://www.researchgate.net/publication/264044569. Accessed 18 out. 2018.

11. Gomes, C.F.S.: THOR - Um Algoritmo Híbrido de Apoio Multicritério à Decisão para Processos Decisórios com Alternativas Discretas. Tese de doutorado, Universidade Federal do Rio de Janeiro, Rio de Janeiro (1999).
12. Gomes, L.F.A.M., Gomes, C.F.S.: Princípios e Métodos para Tomada de Decisão Enfoque Multicritério. 6rd ed. Atlas, Rio de Janeiro (2019).
13. Gomes, C.F.S.: Using MCDA methods THOR in an application for outranking the ballast water management options. Pesquisa Operacional, 25(1):11–28 (2005).
14. Santos, M., Gomes, C.F.S., Oliveira, A.S., Costa, H.G.: Uma abordagem multicritério para seleção de um navio de guerra de médio porte a ser construído no Brasil. In Anais do XLVIII Simpósio Brasileiro de Pesquisa Operacional, Vitoria (2016).
15. Galante, A.: Esquadra Brasileira deve perder mais seis navios de escolta até 2025 (2018). https://www.naval.com.br/blog/2018/09/27/esquadra-brasileira-deve-perder-mais-seis-navios-de-escolta-ate-2025/. Accessed 06 jun 2019.
16. Poder Naval.: Finalmente, a corveta Barroso (2008). https://www.naval.com.br/blog/2008/08/19/finalmente-a-barroso/. Accessed 04 jun 2019.
17. Poder Naval.: Candidata à nova escolta da MB: De Zeven Provincien (2008). https://www.naval.com.br/blog/2008/08/27/candidata-a-nova-fragata-da-mb-de-zeven-provincien/. Accessed 04 jun 2019.
18. Poder Naval.: Candidata à nova escolta da MB: fragata espanhola F-100 (2008). https://www.naval.com.br/blog/2008/08/29/candidata-a-nova-escolta-da-mbfragata-espanhola-f100//. Accessed 04 jun 2019.
19. Poder Naval.: Itália oferece fragatas FREMM ao Brasil (2019). https://www.naval.com.br/blog/2019/01/30/italia-oferece-fragatas-fremm-ao-brasil/. Accessed 04 jun 2019.
20. Warfare Blog. Fragata Classe Horizon Novos horizontes na cooperação naval europeia (2016). https://www.warfareblog.com.br/2016/01/fragata-classe-horizon-novos-horizontes.html/. Accessed 04 jun 2019.
21. Poder Naval.: Batizada a primeira fragata F125 alemã, a 'Baden-Württemberg' (2013). https://www.naval.com.br/blog/2013/12/22/batizada-a-primeira-fragata-f125-alema-a-baden-wurttemberg/. Accessed 04 jun 2019.
22. Vogt, R.: Novo estudo de um escolta para a Marinha do Brasil. Revista Marítima Brasileira, v. 138, n. 01/03, pp. 47–74 (2018).
23. Tenorio, F.M., Araujo, J.C., Santos, M., Gomes, C.F.S.: THOR1 [computer software]. Rio de Janeiro (2019).

Pricing Scenarios of Sustainable Product-Service System: A Post-Harvest by Brazilian Farmers View

Fernando Henrique Lermen, Carla Beatriz da Luz Peralta, Vera Lúcia Milani Martins, Marcia Elisa Echeveste, and José Luis Duarte Ribeiro

Abstract In the development of innovative offers, especially in startups, there is an uncertainty of market acceptance and understand how the target audience will absorb an innovation. In the agricultural sector, there is conservatism in the new products and services approval, in addition to a lack of confidence in the quality and future maintenance of unknown offers. In this context, traditional market research often provides inaccurate information, as the intention to acquire an offer may depend on current circumstances in addition to cultural and cognitive factors not directly captured by the research, preventing the identification of what is of value to the farmer. Without a structured method for understanding what value to the farmers is, in this case, the chance to understand how to make farmers aware of migrating from unsustainable solutions to new alternatives, such as product-service systems, is misplaced. This proposal is around an innovative grain drying that replaces firewood, a current process that causes damage to the environment and contaminates the grain. This study aims to present the development of the sustainable product-service system across innovative alternatives using the scenarios analysis to estimate the willingness-to-pay to anticipate value in terms of attribute importance of a for

F. H. Lermen (✉) · M. E. Echeveste · J. L. D. Ribeiro
Universidade Federal do Rio Grande do Sul, Porto Alegre, RS 90035190, Brazil
e-mail: fernando.lermen@ufrgs.br; fernando-lermen@hotmail.com; fernandohenriquelermen@gmail.com

M. E. Echeveste
e-mail: echeveste@producao.ufrgs.br; echeveste.mar@gmail.com

J. L. D. Ribeiro
e-mail: ribeiro@producao.ufrgs.br

C. B. da Luz Peralta
Universidade Federal do Pampa, Bagé, RS 96413170, Brazil
e-mail: carlaperalta@unipampa.edu.br; carlablp@gmail.com

V. L. M. Martins
Instituto Federal de Educação, Ciência e Tecnologia do Rio Grande do Sul, Porto Alegre, RS 90030041, Brazil
e-mail: vera.martins@poa.ifrs.edu.br; verinhammartins@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_4

Agricola drying process. Along with the scenarios, price estimates are associated as a trade-off, bringing a more realistic perspective than represents a balance of the value of attributes versus price for the acquisition. The method is easy to apply and represents an alternative for introducing more innovative and sustainable solutions in the agricultural environment.

Keywords Product-Service system · Sustainability · Willingness-to-pay · Agriculture · Post-harvest

1 Introduction

Solar energy is considered a cleaner and renewable energy source used in the past to the drying system for preserving grains. However, currently, for large-scale production, there are several known limitations of drying in the sun, such as damage to crops by pests and rodents, quality degradation due to direct exposure to solar radiation and weather [1]. The Brazilian agricultural sector was the only sector of the economy that, in 2016, grew 1.8% of the Gross Domestic Product [2]. This sector presents some problems, mainly in the consumption and post-harvest (drying, storage, and transport) of grains [3].

As for post-harvest grain wastes, 18.3% occur during the drying and storage process due to contamination, damage, and impurity of the grains [4]. The drying of the grains usually employed a method of moisture reduction, assigning particular importance to the storage, conservation, and physical-chemical stabilization of the grains [5, 6]. These activities can be conducted by traditional methods using a boiler for burning residues of these grains. Brazil can produce 237 million tons, and store 166 million tons, with a static storage capacity of only 71% of the production, generating many post-harvest wastes [2].

Among the problems of post-harvest grains, there is the drying operation, which is the process used to ensure quality and stability during grain storage. This process occurs by decreasing the amount of water in the grain (moisture), reducing the biological activity, and physical-chemical changes that occur during the post-harvest period [5]. The need for high yield and storage for long periods requires high control of the grain drying process, which reinforces the importance of studying these processes [7]. There are two drying methods: natural drying using room temperature and direct sunlight; and artificial drying using mechanical means, like firewood, Liquefied Petroleum Gas (LPG), and boiler to move the air through the crop [8].

For the execution of drying, the most used fuel is firewood, followed by LPG, being used in dryers with controlled burning conditions [9]. Both alternatives presented have problems in their drying processes. In essence, the firewood needs a high stock, has a risk of fire, has a high maintenance cost, generates residues due to smoke, and leaves a bad smell in the grain (carcinogenic effect), which results in loss of quality the final product. LPG, on the other hand, has high input costs, demand for dedicated labor needs fuel tanks, has supply restrictions, and requires minimum consumption contracts [10].

The farmers are complicated with the use of these drying methods, open space for the creation of alternative solutions to solve these problems. For this, the product and services development team must understand the user's real demand and the value perceived by the user when developing the product [11, 12] and focus on attributes that benefit him [13].

The idea, conceived by Startup, is to introduce a drying machine on the market that has the following competitive advantages concerning the available alternatives (firewood, LPG, natural air, and sunlight). These advantages consist in does not need a stock of inputs, like gas and water; a full-time operator is working with the system; it is sustainable in the face of current processes. Besides, as it performs clean-burning, without the spread of odors and Hydrocarbon Polycyclic Aromatic for grains; and, it does not need a minimum consumption contract.

There are problems in delivering this machine to the farmer without an integrated solution. The Product-Service System (PSS) approach allows us to purpose, perceive, capture, and provide value to the customer. PSS meet the customers' need and represent a viable strategy for the development of the offers [11, 14], promoting improvements and reducing waste over the traditional process. PSS postulates an integrated solution combining attributes of tangible products and intangible services [12].

The Sustainable PSS (S-PSS) improves this approach by emphasizing the assessment of the environmental, economic, and social impacts of a PSS offer, eliminating what not represent value for customers [15, 16]. This study aims to develop an S-PSS using the scenarios analysis to estimate the Willingness-To-Pay (WTP) to delivered farmers value of an S-PSS alternative for the drying process, considering the target audience WTP. This study assumes the hypothesis that farmers would be definitely acquired more than R$ 7,000.00 for purchase and R$ 1,500.00 for rental, the minimum acceptable amount to implement the increment.

2 Method

The motivation study appears of the need for a Startup incubated in a Public Higher Education Institution in the southern region of Brazil, aiming to improve technical and practical aspects of its offer. The company, as mentioned above, operates in the Brazilian grain drying market, and presents an alternative to the traditional grain drying process, using the burning of oxy-hydrogen extracted from water. The research is characterized as conclusive and involves a case study, in this example the development of a machine to perform the grain drying process by burning oxy-hydrogen extracted from the water, seeking to solve the problems caused by firewood drying (contamination and environmental impact) and LPG (logistics and raw material cost).

Fig. 1 Methodological procedure phases

However, to develop the sustainable PSS offer, an expanded vision is proposed, which transcends the product and offers a solution for process management considering the service that covers rental and consulting aspects. In addition to data analysis technologies that assist the farmer in carrying out the drying and storage process, offering a solution that improves the quality of the process and the product. To propose the solutions in sustainable PSS offers, part of the premise designed in the business model, which, the benefit is the quality of grains, process efficiency, less environmental impact and support, and rental service [15].

This study proposes to identify the value attributes and WTP analyzing scenarios with different offers, the observation of the initial stages of the process so that the understanding generating fosters complementary alternatives of the S-PSS offers (Phase 1—Defining the process and product). The definition of the attributes enables the survey organization and subsequent data collection (Phase 2—Survey development). The results indicate the tendency of acceptability witch offers, and the analyses instigate the learning about the value to the farmer; this phase uses the ruler proposal by Wang et al. [17] to mark out the selections and identify the WTP (Phase 3—Data Analysis). Figure 1 presents the study phases.

2.1 Phase 1—Defining the Process and Product

The drying and storage processes of grains in the Southern Region of Brazil have been mapped, illustrated in Fig. 2.

This study focuses on proposing an S-PSS solution for the stakeholders present in the stages of the square, being: Final weighing of the full truck; Grain Classification Laboratory; Grain drying; Grain Classification Laboratory (Collect the sample after drying and perform analysis of the mixture); and, Grain storage. Internally to this process, specifically in the grain drying process, there are currently three types of fuels that most used for drying grains, through the burning of firewood, through the use of LPG and natural air.

To deliver this process previously mentioned, directly to the farmer, for this purpose, we sought to identify different ways to assess the willingness-to-pay of services in the S-PSS solution. Initially, through unstructured interviews applied to five specialists in the field of agronomy, production engineering, and regulatory bodies, and its validation by others three specialists, two specialists in the grain drying process and one specialist in services. This interview aims to identify the combination of the attributes in different offers to solve the problems of the operation of the dry grain.

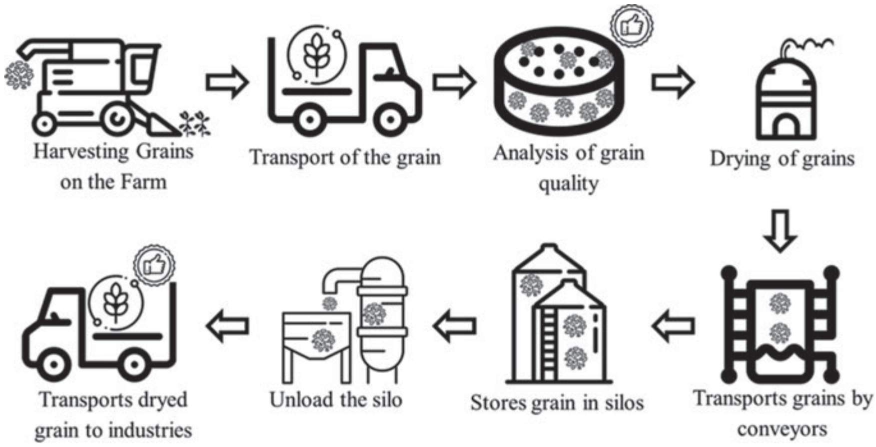


Fig. 2 Mapping of drying and grain storage processes in southern Brazil

2.2 *Phase 2—Survey Development*

The offers identified in Phase 1 make up the base of this survey. Each farmer answers about the preferred offer, indicating the modality (rental or purchase) and the amount that would be willing to pay. The willingness-to-pay method follows the ruler proposed by Wang et al. [17]. For this purpose, the WTP estimated prospect three hypothetical situations: (a) Definitely acquire until the price of X R$; (b) Definitely maybe acquire around a price of X R$; e, (c) Definitely NOT acquire from the price of X R$. The results of this analysis estimated the target audience's WTP for each alternative and also associated it with the type of culture and size of the farmer. Figure 3 shows a ruler based on the willingness to pay method for each chosen solution.

The WTP analysis showed the averages and confidence intervals (95%) to identify the willingness-to-pay of the farmer who selected the option to purchase or rent, and how much they are willing to pay for each alternative solution offered.

The population considered in this survey included farmers grain producers from the three states in the southern region of Brazil (Paraná, Santa Catarina, and the Rio

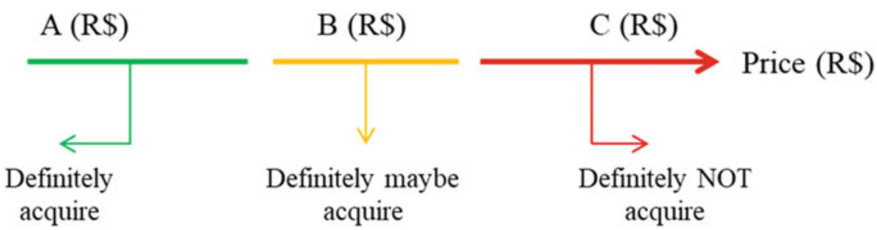


Fig. 3 Ruler to measure willingness-to-pay. *Source* Adapted from Wang et al. [17]

Grande do Sul). The minimum size of respondents required to obtain 95% confidence and 0.06% maximum error, for the worst possible variability, was estimated at 266 farmers. The 354 farmers answer the survey.

This study had access to interested farmers through social networks, offering a new drying and storage process for grains. As for farm size, in this research, 57.06% are Small size farm, 30.23% are Medium size farm, and 12.71% are Large size farm. According to the respondent's state of Brazil, 36.44% are from Paraná, 27.68% are from Santa Catarina, and 38.88% are from the Rio Grande do Sul.

This online survey occurred between November and December 2017 with a cover letter containing a description of the study, its objectives, and the research institutions involved. The data collect endly after twelve weeks.

2.3 Phase 3—Data Analysis

The results obtained in this study uses descriptive statistics. The mean calculation of the standard deviation was used to infer about the WTP. The frequency analysis was applied to define the preferred PSS type and modality. Thus, the higher frequency determines the majority chooses offers to each to modality.

The confidence intervals evidence of WTP amounts (significance level = 0.05) and the limits that the farmer is willing to pay for the offer. This analysis was carried out to, in addition to verifying the WTP, infer about the hypothesis that farmers would be definitely acquired for WTP more than R$ 7,000.00 for purchase and R$ 1,500.00 for rental, the minimum acceptable amount to implement the increment.

This study presents a box plot graph as complementary analyzes to WTP, indicating the interquartile distribution of WTP values for the most frequently chosen offers for rent and purchase. In this study, it is assumed that there is a difference between the WTP of the purchase and rent modalities [18]; for this reason, the box plot analyzes are separate. The data processing occurred in the PASW Statistics 18® software.

3 Results and Discussion

Based on the survey, 354 farmers answered the questionnaires to identify how much the farmers are willing to pay in different cases between purchase and rental, as well as the different alternative solutions of offers to be farmers delivered, being used below in the analysis (Table 1).

For this, an analysis was developed with the averages and confidence intervals (95%) to identify how much the farmer who selected the option to purchase or rent, is willing to pay for each alternative solution offered (Table 2).

As shown in Table 1, the option to purchase Alternative A3: drying machine + transportable storage silo + corrective maintenance during the warranty (2 years) +

Table 1 Alternative solutions of S-PSS offer

Alternative solutions
(A1) Drying machine + corrective maintenance during the warranty (2 years)
(A2) Drying machine + transportable storage silo + corrective maintenance during the warranty (2 years)
(A3) Drying machine + transportable storage silo + corrective maintenance during the warranty (2 years) + semiannual preventive maintenance
(A4) Drying machine + transportable storage silo + corrective maintenance during the warranty (2 years) + semiannual preventive maintenance + grain

semiannual preventive maintenance, selected by a sample of 87 respondents. For this alternative, the analysis of the behavior of the WTP of this offer, presented in Fig. 4.

Point A refers to the distribution of the maximum that the farmer is willing to pay. The center of the box shows the median, which in this case is R$ 120,000.00. In Fig. 4, around the median, the box represents the interquartile range (third quartile—first quartile), which founded 50% of the observations. The values away from the vertical rods represent possible outliers that are very different points from the data mass (Box).

At point B (Definitely maybe acquire), the median is R$ 115,000.00, and at point C (Definitely NOT acquire), the median is R$ 110,000.00. This distance between the rods' concerns the size of the box is higher at point A. This analysis was performed in general, considering all respondents. A more robust analysis could find respondents by size (small, medium, and large) to check the difference between them, concerning purchase and rent.

As for the hypothesis that farmers would definitely be acquired more than R$ 7,000.00 for purchase to implement each increment. This hypothesis can be confirmed only for option A3, in which 87 farmers are willing to pay more than R$ 7,000.00, making this option economically viable. According to Table 2, the rental modality in Alternative A2: drying machine + transportable storage silo + corrective maintenance during the warranty (2 years) was selected by 53 respondents, as shown in Fig. 5.

Point A refers to the maximum amount that the farmer is willing to pay. The center of the box shows the median, which in this case is R$ 8,500.00. The Boxplot showed more considerable variation in this point, concerning point B (Definitely maybe acquire) the median is R$ 8,000.00 and from point C (Definitely NOT acquire) the median is R$ 7,500.00.

This analysis, performed for each stratum and all alternatives, presents the options with a higher frequency. The main requirements and the value chain for the entire life cycle presents a product-service system with a sustainable bias.

As for the hypothesis that farmers would definitely be acquired more than R$ 1,500.00 for rental to implement each increment. This hypothesis can be confirmed only for option A2, in which 53 farmers are willing to pay more than R$ 1,500.00, making this option economically viable. Table 2 also shows that the option with the most choice of farmers who selected was the product-oriented PSS, which shows that

Table 2 Average and confidence interval (95%) of the solutions offered

Modality	Type of PSS	Option	Sample	A (R$)	B (R$)	C (R$)
Purchase 56.6% $n = 200$	Product-oriented	A1	7.5% $n = 15$	$\overline{X} = 106833.33$	$\overline{X} = 99000.00$	$\overline{X} = 89733.33$
				$[92975.66; 129556.63]_{95\%(1-\alpha)}$	$[88124.27; 115689.64]_{95\%(1-\alpha)}$	$[81083.33; 100818.18]_{95\%(1-\alpha)}$
		A2	18.5% $n = 37$	$\overline{X} = 112702.70$	$\overline{X} = 105000.00$	$\overline{X} = 93108.11$
				$[101206.90; 131434.49]_{95\%(1-\alpha)}$	$[93750.96; 122360.41]_{95\%(1-\alpha)}$	$[83491.49; 108368.30]_{95\%(1-\alpha)}$
		A3	43.5% $n = 87$	$\overline{X} = 142942.53$	$\overline{X} = 129655.17$	$\overline{X} = 115712.64$
				$[131067.33; 156804.23]_{95\%(1-\alpha)}$	$[120202.79; 140455.65]_{95\%(1-\alpha)}$	$[108662.89; 123687.86]_{95\%(1-\alpha)}$
		A4	30.5% $n = 61$	$\overline{X} = 127155.17$	$\overline{X} = 121137.93$	$\overline{X} = 112275.86$
				$[120755.47; 134166.27]_{95\%(1-\alpha)}$	$[115640.36; 127265.23]_{95\%(1-\alpha)}$	$[107188.82; 118172.70]_{95\%(1-\alpha)}$
Rental 43.5% $n = 154$	Use-oriented	A1	5.19% $n = 8$	$\overline{X} = 6775.00$	$\overline{X} = 6362.50$	$\overline{X} = 5387.50$
				[a]	[a]	[a]
		A2	34.41% $n = 53$	$\overline{X} = 8549.06$	$\overline{X} = 7904.91$	$\overline{X} = 7079.25$
				$[7643.83; 9372.88]_{95\%(1-\alpha)}$	$[7077.51; 8670.18]_{95\%(1-\alpha)}$	$[6300.00; 7819.40]_{95\%(1-\alpha)}$
		A3	33.76% $n = 52$	$\overline{X} = 8000.00$	$\overline{X} = 7292.31$	$\overline{X} = 6525.00$
				$[7000.00; 8963.63]_{95\%(1-\alpha)}$	$[6345.11; 8244.33]_{95\%(1-\alpha)}$	$[5620.41; 7426.40]_{95\%(1-\alpha)}$
	Result-oriented	A4	26.24% $n = 41$	$\overline{X} = 7195.12$	$\overline{X} = 6265.85$	$\overline{X} = 5280.49$
				$[5571.68; 9054.82]_{95\%(1-\alpha)}$	$[4860.07; 7824.79]_{95\%(1-\alpha)}$	$[4105.81; 6590.44]_{95\%(1-\alpha)}$

Note n is the sample size; $\overline{X}$ is the average of the sample; $95(1-\alpha)\%$ is the confidence interval (95%);[a] the A1 sample size for rent was not significant for calculating the confidence interval 95% by the method *Bootstrapping*. A (R$)—Definitely acquire X R$; B (R$) Definitely maybe acquire X R$; e, C (R$) Definitely NOT acquire X R$

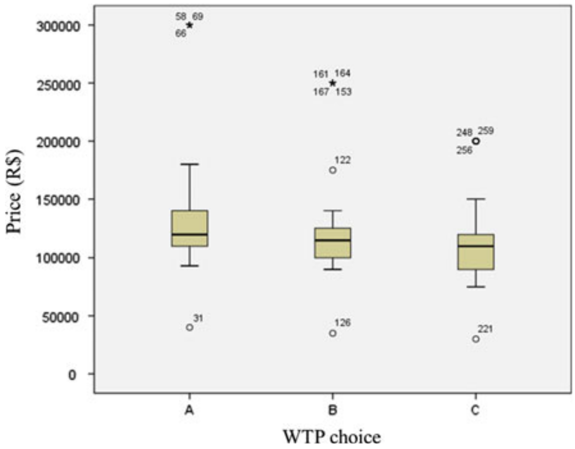


Fig. 4 Boxplot of the option to purchase the alternative A3 for the option to purchase

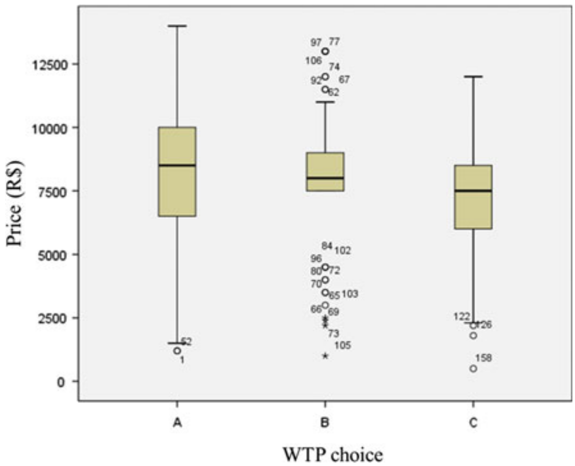


Fig. 5 Boxplot of the rent option of the A2 option for the rental option

farmers in the southern region of Brazil are not ready to receive a solution generated from a rental with consulting options and remote service as proposed in the PSS oriented to use and results.

In this case, the research suggests that the best initial option to improve the chances of being inserted in the market is to present the offer option A3 in the purchase modality. In contrast, the presentation of the rental modality cannot be ruled out since more than 43% of respondents opted for this alternative. The rental modality presentation to the market suggests the acceptance, to the A3 offer, of the A2 offer, selected by 68% of the farmers whom rental modality opted. To insert the rental modality in the agricultural equipment commercialization market, the development team can establish strategies of essential information to the farmer, aiming at the acceptance of the sustainable product-service presented.

4 Conclusions

This study presented an analysis of scenarios for understanding the value associated with the importance and willingness-to-pay for the agriculture PSS offer developed, initially tested in southern Brazil. The main practical benefit of the proposed innovation is the use of clean technology for drying grains, replacing traditional methods harmful to health and the environment.

This article aimed to demonstrate a structure of value identification that uses concepts of choice experiments in conjunction with WTP investigation. The applied approach contributes to a more realistic value search, as the scenarios represent a set of attributes simultaneously as possible offers associated with the price. In this study, the central learning was the discovery that the agriculture sector signaled a positive opening for the option of renting drying equipment instead of purchasing, although this is still the most widely accepted method for purchasing equipment, in the case of the proposed S-PSS solution.

It is important to highlight that the rental option would make the process an even more sustainable PSS. The next steps are the replication of broader scenarios in order to estimate the farmer's reaction to the acquisition possibilities and evaluate different applications of WTP in agriculture.

References

1. Tiwari, A.: A Review on Solar Drying of Agricultural Produce. Journal of Food Processing & Technology 7(9), 1–12 (2016).
2. CONAB—National Supply Company.: Follow-up of Brazilian Crop. 5(6):1–129 (2018).
3. Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R., Meybeck, A.: Global Food Losses and Food Waste: Extent Causes and Prevention. Rome, FAO of the United Nations (2011).
4. Reykdal, Ó.: Drying and storing of harvested grain A Review of Methods. Skýrsla Matís (2018).
5. Babalis, S.J., Belessiotis, V.G.: Influence of the drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. Journal of Food Engineering 65:449–458 (2004).
6. Diógenes, A.F., Basto, A., Estevão-Rodrigues, T.T., Moutinho, S., Aires, T., Oliva-teles, A., Peres, H.: Soybean meal replacement by corn distillers dried grains with solubles (DDGS) and exogenous non-starch polysaccharides supplementation in diets for gilthead seabream (Sparus aurata) juveniles. Aquaculture, 500:435–442 (2019).
7. Parry, M.E., Kawakami, T.: Virtual Word of Mouth and Willingness to Pay for Consumer Electronic Innovations. Journal of Product Innovation Management 32(2), pp. 192–200 (2015).
8. Mrema, G.C., Gumbe, L.O., Chepete, H.J., Agullo, J.O.: Rural structures in the tropics: Design and development. Food and Agriculture Organization of the United Nations, Rome (2011).
9. Franke, L.B., Torres, M.A.P., Lopes, R.R.: Performance of different drying methods and their effects on the physiological quality of grain sorghum seeds (S. bicolor (L.) Moench). Revista Brasileira de Sementes. 30(3):177–184 (2008).
10. Reed, D., Taylor, A., Knowles, C., Bergman, R., Harper, D., Puettmann, M.E.: Cradle-to-gate life-cycle inventory and impact assessment of wood fuel pellet manufacturing from hardwood flooring residues in the Southeastern United States. Forest Products Journal 62(4):280–288 (2012).

11. Baines, T.S., Lightfoot, H.W., Evans, S., Neely, A., Greenough, R., Peppard, J., Roy, R., Shehab, E., Braganza, A., Tiwari, A., Alcock, J.R., Angus, J.P., Bastl, M., Cousens, A., Irving, P., Johnson, M., Kingston, J., Lockett, H., Martinez, V., Michele, P., Tranfield, D., Walton, I.M., Wilson, H.: State-of-the-art in product-service systems. Journal of Engineering Manufacturing 221:1543–1552 (2007).
12. Zhu, H., Gao, J., Cai, Q.: A product-service system using requirement analysis and knowledge management technologies, Kybernetes 44(5):823–842 (2015).
13. Aurich, J.C., Fuchs, C., Wagenknecht, C.: Life cycle oriented design of technical Product-Service Systems. Journal of Cleaner Production 14:1480–1494 (2006).
14. Mont, O.K.: Clarifying the concept of product-service system. Journal of Cleaner Production 10(3):237–245 (2002).
15. Lermen, F.H., Echeveste, M.E., Peralta, C.B., Sonego, M., Marcon, A.: A framework for selecting lean practices in sustainable product development: The case study of Brazilian Agroindustry. Journal of Cleaner Production 191:261–272 (2018).
16. Tseng, M.L., Wu, K.J., Chiu, A.S.F., Tan, K., & Lim, K.: Service innovation in sustainable product-service systems: improving performance under linguistic preferences. International Journal of Production Economics 203:414–425 (2018).
17. Wang, T., Venkatesh, R., Chatterjee, R.: Reservation Price as a Range: An Incentive-Compatible Measurement Approach. Journal of Marketing Research 44:200–213 (2007).
18. Lermen, F.H., Ribeiro, J.L.D., Echeveste, M.E., Martins, V.L.M., Tinoco, M.A.C.: Sustainable offers for drying and storage of grains: Identifying perceived value for Brazilian farmers. Journal of Stored Products Research 87:1–12 (2020).

Supplier in the Supply Chain: A Bibliometric Analysis

Jefferson Augusto Krainer, Christiane Wagner Mainardes Krainer, Ana Celia Vidolin, and Cezar Augusto Romano

Abstract The literature highlights the importance of the supplier for a better performance of the supply chain. This article aims to identify the body of existing knowledge about suppliers in the supply chain, mapping the research areas and fields of study in clusters capable of guiding the researcher to the most influential works, results and questions. For this, we developed a bibliometric analysis with the help of the CiteSpace II software. We identified 11 fields of study and their corresponding areas of research. Highlight for the two areas of greatest interaction: "sustainable supply chain management" and "food supply chain" and the predilection on the part of researchers for the use of multivariate techniques of data analysis and the use of the case study method. This article serves, among others, as an exploratory study for future in-depth research work on a specific research area, or even on how research areas, fields of study and publications are linked and or related.

Keywords Supply chain · Supplier · Bibliometric analysis

J. A. Krainer (✉) · C. W. M. Krainer · A. C. Vidolin · C. A. Romano
Federal Technological University of Paraná, Curitiba 5000 Deputado Heitor de Alencar Furtado Avenue, 81280-340, Brazil
e-mail: profjeffersonkra@gmail.com; jeffkrainer@onda.com.br

C. W. M. Krainer
e-mail: chriswmk70@gmail.com; christianemainardes@hotmail.com

A. C. Vidolin
e-mail: anavidolin@gmail.com; anavidolin@alunos.utfpr.edu.br

C. A. Romano
e-mail: romano.utfpr@gmail.com; caromano@utfpr.edu.br; stricto-ecoville-ct@utfpr.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_5

1 Introduction

A supply chain, through structured processes, begins with the raw material that is transformed into a finished product and ends with the delivery of these products to end customers [1]. According to Chow and Heaver [2], the supply chain is the group of manufacturers, suppliers, distributors, retailers and transporters, information, and other logistics management services that are involved in supplying goods to consumers. It is a set of resources and integrated processes [3]. This integration corresponds to the degree to which a company strategically acts collaboratively with its partners to achieve effective and efficient flows of products and services, information, money, and decisions that provide maximum value to the customer [4]. Among these partners is the supplier who is responsible for supplying raw materials and or services, contributing to the establishment of an effective and sustainable chain.

Interest in the supplier has already resulted in a large number of additional contributions to the study of the supply chain. The literature highlights the importance of this agent for the efficiency and effectiveness of material and information flows. It shows exciting advances related to the internal and external performance of supply chains. According to Cao and Zhan [5], the collaboration of suppliers in the supply chain improves the organization's competitive advantage, allowing greater synergy and achieving superior performance. Suppliers have a fundamental role in the integration of processes in the supply chain [4, 6, 7]. Cooperation with suppliers has an impact on the performance of the chain, as it makes it possible to carry out joint actions, in addition to enabling the sustainable transaction of resources [8].

Indeed, a productive buyer-supplier relationship has become one of the primary sources for obtaining positive results, as a sustainable and long-term advantage [7, 9, 10], better operational and financial performance, less uncertainty and innovation in return [4, 11, 12]. However, it is not easy for researchers to identify which direction to take to make real contributions to the advancement of research on the subject. This article aims to identify the body of existing knowledge about suppliers in the supply chain, mapping the research areas and fields of study in clusters capable of guiding the researcher to the most influential works, results, and questions.

To this end, we developed a bibliometric analysis in this article. Among the different bibliometric methods, we adopted scientific mapping, which allows monitoring a research niche to determine its cognitive structure, its interactions, evolution, and the main internal actors [13]. We, therefore, seek to answer the following questions: What are the main areas of research? Where are the most active areas? What are the key articles? What are the origin and historical development of the research areas? What are the main fields of study?

2 Research Design

This section presents the research outline, outlining the characteristics of the bibliometric study undertaken and presenting the steps and parameters used in the organization of knowledge on the subject under investigation.

We opted for a bibliometric study because, unlike the usual qualitative approaches, it introduces a systematic, transparent and reproducible process of identifying relevant works through objective and quantitative indicators [14].

Bibliometrics is the study of the production, dissemination, and use of registered information that seeks to quantify written communication processes [15]. It is a series of statistical techniques that make it possible to measure the contribution and development of scientific knowledge, in addition to identifying patterns of authorship, publication, and use of research results [16]. In this bibliometric study, the analysis of citations and co-citations is used.

The analysis of citations consists of counting the frequency of quotations in articles, books, or other scientific works, being one of the most applied techniques in bibliometry [17, 18]. It is assumed that authors cite works that they consider most relevant [18]; therefore, the most cited publications have a more significant influence in the scientific world [17].

The study of cocitations considers the frequency of the pairs of documents that are simultaneously cited in a third later work [17, 19]. The more often two works are cited concurrently, the higher the likelihood of presenting associated content [17] and representing the knowledge structure of an area perceived by the researchers [20]. When two or more authors or publications are cited together in a third survey, there is a similarity of content among those cited. Higher is the frequency of cocitation, the closer the relationship between them, and the higher the recognition by the researchers.

The base used to survey the raw data was the Web of Science (WoS)—Main Collection (Clarivate Analytics). WoS was chosen as the primary source of data because it includes journals with a more significant impact factor when compared to those covered by Scopus (Elsevier) [21]. Also, the analysis of article references makes it possible to expand access to books, reports, and periodicals from other databases.

The treatment of the data was carried out with the aid of the bibliometric software CiteSpace II, which was designed to facilitate answers about the structure and dynamics of a domain of knowledge (set of bibliographic records of relevant publications). CiteSpace II develops the modeling network, thus allowing the visualization and tracking of the development of science, through the study of the paths revealed by scientific publications. The software points out and maps trends in the literature, identifying when knowledge demonstrates space for scientific news, that is, the intellectual tipping point [22].

3 Methodology

To achieve the objective of this study were selected references on supply chain with a focus on suppliers. We use the following search string: ["supply chain"] and ["supplier" or "provider"]. The search was carried out on January 22, 2020, selecting only articles and reviews published in the period from 2009 to 2020. Four thousand, five hundred seventy-six (4,576) publications returned from this search, whose citation report resulted in 24,494 items (without self-citations). Then, the metadata (title, abstract, authors, keywords, journal, references, and number of citations) of these articles from the WoS database were imported.

The data imported from WoS was standardized (elimination of duplicates) and processed in CiteSpace II. The software designed the networks that formed, showing the salient traces of the related research activities. Each point represents a node (quote), which is connected by quote links (lines that connect the nodes). The references that appeared with labels refer to prominent works, seminal articles in the field of study.

The questions of the present research to answer, several functions of CiteSpace II were used, especially those of clustering, labeling, and explosion.

4 Analysis of Citations and Co-citations

4.1 Main Research Areas and Respective Key Articles

CiteSpace II grouped 608,039 references from 24,494 articles (input data) into 11 main clusters, which represent the most prominent research areas. See in Fig. 1 that the substantial area (cluster #0, in red, with the significant works) is sustainable supply chain management, followed by food supply chain (cluster #1), supply chain integration (cluster #2), and so on until the efficient, robust global supply chain system design (cluster #14).

The labelled clusters point to the context in which they are most cited. The terms of the labels were extracted from the titles of the articles that cited the work. Table 1 shows the number of members (works) of each cluster, average year of publication, research area (label), most cited article and respective frequency of citation. The average year of publication indicates whether the cluster is made up of newer or older items. It can be seen that the oldest clusters (#8) date from 2004 and the most recent (#1, #6, and #9) correspond to 2014. The most cited works represent the critical articles for a given area. Thus, for example, the work entitled "The impact of supply chain integration on performance: a contingency and configuration approach" received 454 citations, so it is a key article for the area of supply integration (cluster #2).

Table 2 lists the 20 (twenty) most cited references, detailing the frequency of citation, the year of publication, and which cluster they belong to. Highlight to the

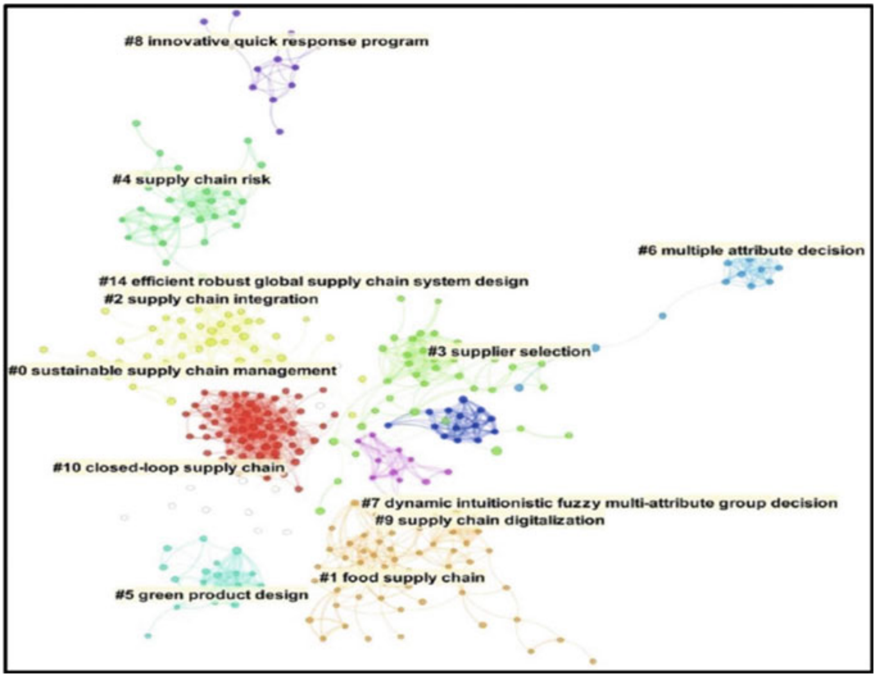


Fig. 1 Principais áreas de pesquisa

Table 1 Cluster, number of members, an average year, research area, most cited article, and respective citation frequency

C	M	Y	Area	Most Cited	Ct
0	65	2009	Sustainable supply chain management	Sarkis et al. [24]	377
1	52	2015	Food supply chain	Kannan et al. [26]	55
2	47	2007	Supply chain integration	Flynn et al. [4]	454
3	37	2009	Supplier selection	Behzadian et al. [23]	408
4	29	2006	Supply chain risk	Craighead et al. [27]	77
5	20	2014	Green product design	Benjaafar et al. [28]	167
6	14	2015	Multiple attribute decision	Torra [29]	116
7	14	2007	Dynamic intuitionistic fuzzy multi-attribute group decision	Boran et al. [30]	291
8	12	2004	Innovation quick response program	Cachon and Lariviere [31]	59
9	11	2015	Supply chain digitalization	Wang et al. [32]	82
10	9	2013	Closed-loop supply chain	Govindan et al. [33]	279
14	2	2009	Efficient robust global supply chain system design	Melo et al. [34]	120

C = Cluster M = Members Ct = Cited

Table 2 Cluster, number of members, an average year, research area, most cited article, and respective citation frequency

N	Ct	References	C	N	Ct	References	C
1	454	Flynn et al. [4]	2	11	235	Brandenburg et al. [37]	2
2	408	Behzadian et al. [23]	3	12	230	Büyüközkan and Çifçi [38]	3
3	377	Sarkis et al. [24]	0	13	228	Hair et al. [39]	2
4	346	Ho et al. [25]	3	14	217	Ahi and Searcy [40]	0
5	328	Hair et al. [35]	2	15	209	Prajogo and Olhager [7]	2
6	324	Seuring and Müller [8]	0	16	208	Carter and Rogers [41]	0
7	291	Boran et al. [30]	7	17	208	Hassini et al. [42]	0
8	284	Carter and Easton [36]	0	18	203	Diabat and Govindan [43]	0
9	279	Govindan et al. [33]	10	19	203	Seuring [44]	0
10	258	Cao and Zhang [5]	2	20	202	Yin [45]	2

Ct = Cited C = Cluster

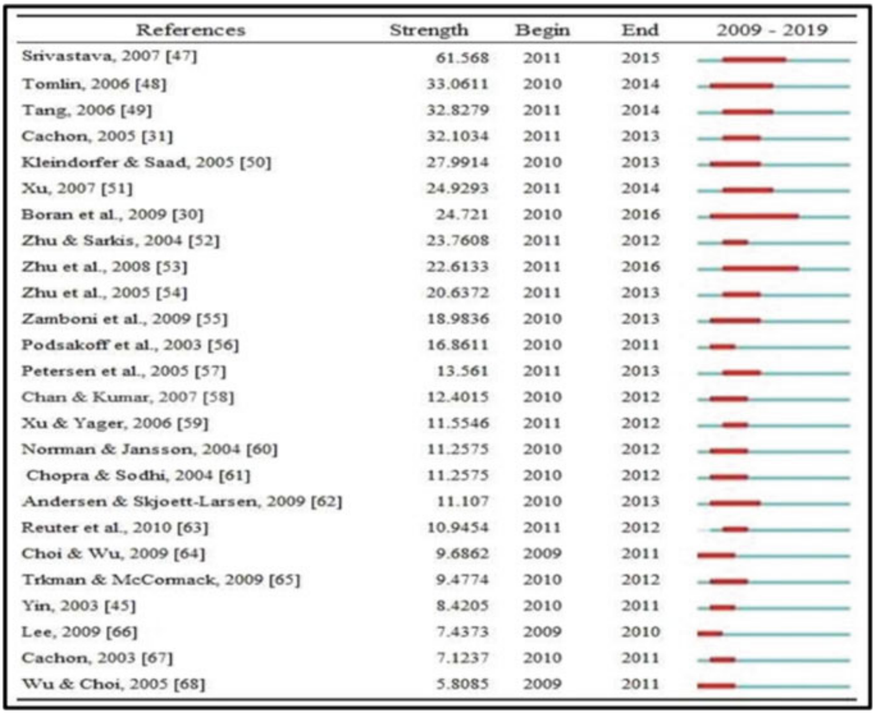
works of Flynn et al. [4], Behzadian et al. [23], Sarkis et al. [24], and Ho et al. [25], with, respectively, 454, 408, 377, and 346 citations.

4.2 Most Active Areas

To detect the most active research areas, we use the CiteSpace II quote explosion function, which is based on Kleinberg's algorithm [46]. A citation explosion links a specific publication to an increase in citations, capturing an active area of research, or an emerging trend [22]. Figure 2 shows the 25 references with the most substantial explosion of citations and their respective periods of occurrence.

4.3 Origin and Historical Development of the Research Areas

To understand the origin, the historical development, and the current state of the clusters (research areas), a visual analysis of the network's timeline was performed. In the view of the timetable generated in CiteSpace II each cluster is organized in a horizontal timeline growing from left to right. In Fig. 3 we observe that the research areas with the most recent studies (close to 2019) and promising ones (still under development) are: food supply chain (cluster #1) and green product design (cluster #5). Areas such as innovative quick response programs and efficient, robust global supply chain system design, for example, have not had a volume of publications since ≈2009 and ≈2010, respectively, which shows stagnation in the theme.



References	Strength	Begin	End	2009 - 2019
Srivastava, 2007 [47]	61.568	2011	2015	
Tomlin, 2006 [48]	33.0611	2010	2014	
Tang, 2006 [49]	32.8279	2011	2014	
Cachon, 2005 [31]	32.1034	2011	2013	
Kleindorfer & Saad, 2005 [50]	27.9914	2010	2013	
Xu, 2007 [51]	24.9293	2011	2014	
Boran et al., 2009 [30]	24.721	2010	2016	
Zhu & Sarkis, 2004 [52]	23.7608	2011	2012	
Zhu et al., 2008 [53]	22.6133	2011	2016	
Zhu et al., 2005 [54]	20.6372	2011	2013	
Zamboni et al., 2009 [55]	18.9836	2010	2013	
Podsakoff et al., 2003 [56]	16.8611	2010	2011	
Petersen et al., 2005 [57]	13.561	2011	2013	
Chan & Kumar, 2007 [58]	12.4015	2010	2012	
Xu & Yager, 2006 [59]	11.5546	2011	2012	
Norman & Jansson, 2004 [60]	11.2575	2010	2012	
Chopra & Sodhi, 2004 [61]	11.2575	2010	2012	
Andersen & Skjoett-Larsen, 2009 [62]	11.107	2010	2013	
Reuter et al., 2010 [63]	10.9454	2011	2012	
Choi & Wu, 2009 [64]	9.6862	2009	2011	
Trkman & McCormack, 2009 [65]	9.4774	2010	2012	
Yin, 2003 [45]	8.4205	2010	2011	
Lee, 2009 [66]	7.4373	2009	2010	
Cachon, 2003 [67]	7.1237	2010	2011	
Wu & Choi, 2005 [68]	5.8085	2009	2011	

Fig. 2 Twenty-five (25) references [30, 31, 45, 47–68] with the greatest explosion of citations between 2009 and 2020

4.4 Fields of Study

We visualize the fields of study according to the WoS subject categories with the help of the "Field of Study" function of CiteSpace II. The fields of study (11 in total—see Fig. 4) are related to the research areas (they are labeled in the same cluster). Thus, for example, within Environment Science (#4), research on supply chain risk (#4) stands out and so on in relation to the other clusters.

5 Conclusions

With the assistance of CiteSpace II software, we identified 11 fields of study and their corresponding research areas. Computer Science (clusters #0, #2; 6# and #9) is the field that has the most significant number of studies related to the supply chain (≈44%). "Food supply chain", "multiple attribute decision" and "supply chain digitalization" are the most recent research areas, with 2014 being the average year of publication of the several articles, which shows the absence (significant interactions)

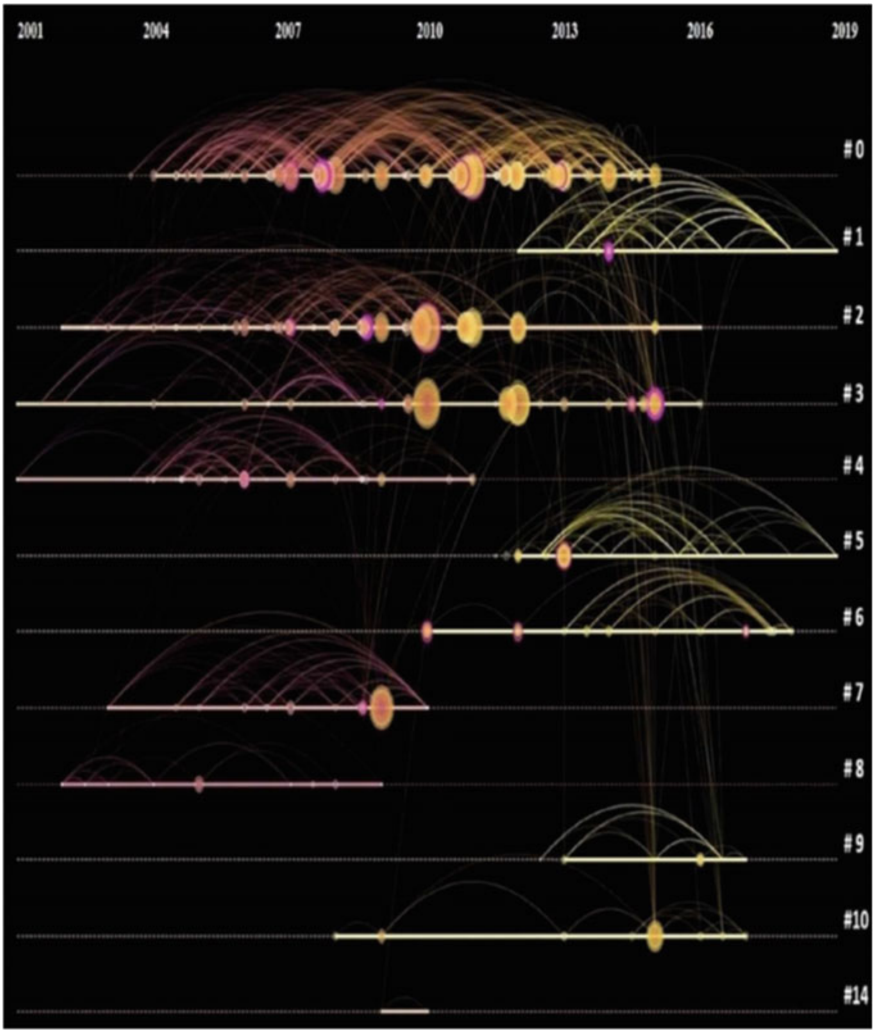


Fig. 3 Timeline view of the eleven (11) clusters

of new emerging sectors in the last six years. A highlight for the two areas of greatest interaction (greatest works related to each other): "sustainable supply chain management" and "food supply chain," totaling 65 and 52 works, and presenting as key articles, the publications of Sarkis [24] and Kannan et al. [26], respectively.

Despite the recognized importance attributed to the study of suppliers in the supply chain, we identified only one research area ("supplier selection"—cluster #3) directly related to the supplier, which denotes the scarcity of specific and focal works on the topic and the non-centrality of the term "supplier".

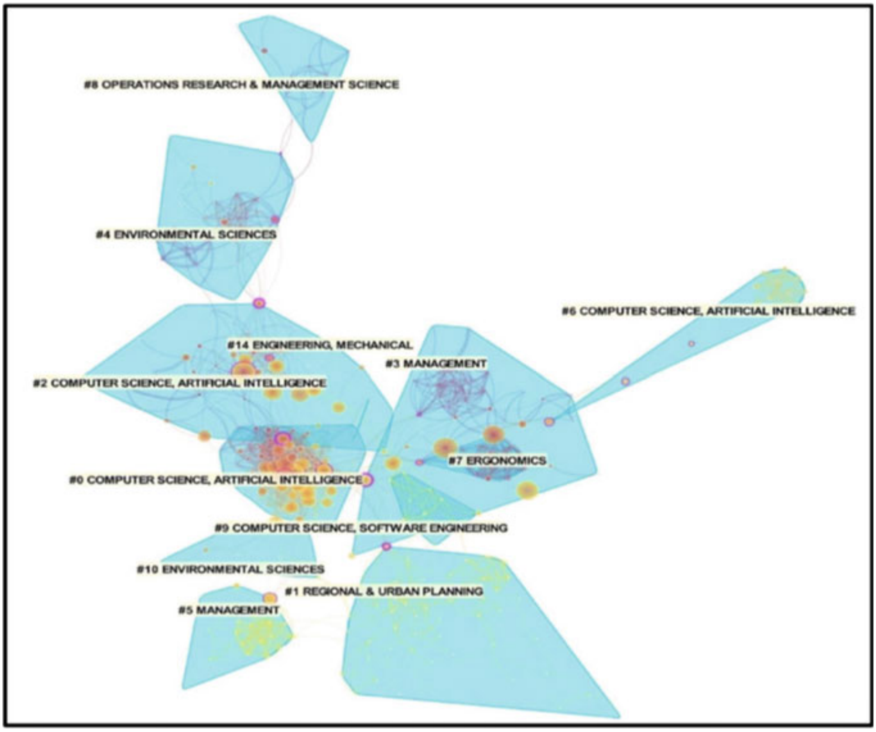


Fig. 4 Visualization of study fields

Among the 20 most cited references (Table 2), 9 (8 from cluster #0 and 1 from cluster #2) are associated with the theme of sustainability. Therefore, the current preference—and consequent volume of publications—for topics related to sustainability is noticeable. Analyzing the timeline, this preference is confirmed, as among the most recent and promising research areas, we have the "green product design" (cluster #5). Also, Srivastava's work [47], also related to the green supply chain, emerges as the one with the biggest explosion of quotes within the period from 2011 to 2015.

The frequency of citation (see Table 2) of the works by Hair Jr. et al. [35, 39] and Yin [45] also denounces, in the area of "supply chain integration" (cluster #2), the preference on the part of researchers for the use of multivariate techniques of data analysis and the use of the case study method. Literature review works (see Table 2, articles by Behzadian et al. [23], Sarkis et al. [24], Ho et al. [25], Seuring and Müller [8], Carter and Easton [36], Govindan et al. [33], Brandenburg [37], Ahi and Searcy [40], Carter and Rogers [41], Hassini et al. [42], Seuring [44]) are the most frequent among the most cited. Likewise, the use of the TOPSIS method (Technique for Order of Preference by Similarity to Ideal Solution) is repeated (see Table 1, most cited articles in clusters #1, #3; and #7) for solving the problem of providers.

In this way, a panoramic map was obtained of the leading publications on the analyzed topic and how they are distributed in fields of study and interconnected in networks, integrating and forming research areas. The present article, therefore, also serves as an exploratory study for future in-depth research work on a specific research area or even on how research areas, fields of education, and publications are linked and or related.

In future studies, we suggest the repetition of the research with raw input data extracted from another database, in addition to WoS, or, still, the standard treatment of input data from different databases.

References

1. Beamon, B. M.: Supply chain design and analysis: models and methods. International journal of production economics, 55(3), 281–294 (1998).
2. Chow, D., Heaver, T.: Logistics strategies for North America. 3rd edn. Global Logistics and Distribution Planning (1999).
3. Pienaar, W.: Introduction to Business Logistics. Oxford University, Southern Africa (2009).
4. Flynn, B. B., Huo, B., Zhao, X.: The impact of supply chain integration on performance: a contingency and configuration approach. Journal of Operations Management 28(1), 58–71 (2010).
5. Cao, M., Zhang, Q.: Supply chain collaboration: impact on collaborative advantage and firm performance. Journal of Operations Management 29(3), 163–180 (2011).
6. Krause, D. R., Handfield, R. B., Scannell, T. V.: An empirical investigation of supplier development: reactive and strategic processes. Journal of Operations Management 17 (1), 39–58 (1998).
7. Prajogo, D., Olhager, J.: Supply chain integration and performance: the effects of long-term relationships, information technology and sharing, and logistics integration. International Journal of Production Economics 135(1), 514–522 (2012).
8. Seuring, S., Müller, M.: From a literature review to a conceptual framework for sustainable supply chain management. Journal of Cleaner Production 16(15), 1699–1710 (2008).
9. Kalwani, M. U., Narayandas, N.: Long-term manufacturer-supplier relationships: do they pay off for supplier firms? Journal of Marketing 59(1), 1–16 (1995).
10. Golicic, S. L., Mentzer, J. T.: An empirical examination of relationship magnitude. Journal of Business Logistics 27(1), 81–108 (2006).
11. Gao, T., Sirgy, M. J., Bird, M. M.: Reducing buyer decision-making uncertainty in organizational purchasing: can supplier trust, commitment, and dependence help? Journal of Business Research 58(4), 397–405 (2005).
12. Krause, D. R., Handfield, R. B., Tyler, B. B.: The relationships between supplier development, commitment, social capital accumulation and performance improvement. Journal of Operations Management 25(2), 528–545 (2007).
13. Noyons, E., Moed, H., Van Raan, A.: Integrating research performance analysis and science mapping. Scientometrics 46, 591–604 (1999).
14. Tranfield, D., Denyer, D., Smart, P.: Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14, 207–22 (2003).
15. Tague-Sutckiffe, J.: An introduction to informetrics. Information Processing & Manage-ment 28 (1), 1–3 (1992).
16. Okubo, Y.: Bibliometric indicators and analysis of research systems: methods and examples. OECD Science, Technology and Industry Working Papers, No. 1997/01, OECD Publishing, Paris (1997), https://doi.org/10.1787/208277770603.

17. Spinak, E.: Dicionário Enciclopédico de Bibliometría, Cienciometría e Informetría. Unesco, Montevidéu (1996).
18. Rubin, R.: Foundations of library and information science. 3th edn. Neal-Schuman Publishers, New York (2012).
19. Miguel, S., Moya-Anegon, F., Herrero-Solana, V.: A new approach to institutional domain analysis: multilevel research fronts structure. Scientometrics 74(3), 331–344 (2008).
20. Gmür, M.: Co-citation analysis and the search for invisible colleges: a methodological evaluation. Scientometrics 57(1), 27–57 (2003).
21. Chadegani, A. C., Salehi, H., Yunus, M., Farhadi, H., Fooladi, M., Farhadi, M., Ebrahim, N. A.: A comparison between two main academic literature collections: Web of Science and Scopus databases. Asian Social Science 9(5), 18–26 (2013).
22. Chen, C.: CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. Journal of the American Society for Information Science and Technology 57(3), 359–377 (2006).
23. Behzadian, M., Otaghsara, S. K., Yazdani, M., Ignatius, J.: A state-of the-art survey of TOPSIS applications. Expert Systems with Applications 39(17), 13051–13069 (2012).
24. Sarkis, J., Zhu, Q., Lai, K.: An organizational theoretic review of green supply chain management literature. International Journal of Production Economics 130(1), 1–15 (2011).
25. Ho, W., Xu, X., Dey, P. K.: Multi-criteria decision making approaches for supplier evaluation and selection: a literature review. European Journal of Operational Research 202(1), 16–24 (2010).
26. Kannan, D., Jabbour, A. B. L. S, Jabbour, C. J. C.: Selecting green suppliers based on GSCM practices: Using fuzzy TOPSIS applied to a Brazilian electronics company.
27. Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J., Handfield, R. B.: The severity of supply chain disruptions: design characteristics and mitigation capabilities. Decision Sciences 38 (1), 131–156 (2007).
28. Benjaafar, S., Li, Y., Daskin, M.: Carbon footprint and the management of supply chains: Insights from simple models. IEEE Transactions on Automation Science and Engineering 10 (1), 99–116 (2012).
29. Torra, V.: Hesitant fuzzy sets. International Journal of Intelligent Systems 25(6), 529–539 (2010).
30. Boran, F. E., Genç, S., Kurt, M., Akay, D.: A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. Expert Systems with Applications 36(8), 11363–11368 (2009).
31. Cachon, G. P., Lariere, M. A.: Supply chain coordination with revenue-sharing contracts: strengths and limitations. Management science 51(1), 30–44 (2005).
32. Wang, G., Gunasekaran, A., Ngai, E. W. T., Papadopoulos, T.: Big data analytics in logistics and supply chain management: certain investigations for research and applications. International Journal of Production Economics 176, 98–110 (2016).
33. Govindan, K., Soleimani, H., Kannan, D.: Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. European Journal of Operational Research 240(3), 603–626 (2015).
34. Melo, M. T., Nickel, S., Saldanha-da-Gama, F.: Facility location and supply chain management–a review. European Journal of Operational Research 196(2), 401–412 (2009).
35. Hair Jr., J. F., Anderson, R. E., Babin, B. J., Black, W. C. Multivariate data analysis: a global perspective. 7th edn. Pearson Education, London (2010).
36. Carter, C. R., Easton, E. P.: Sustainable supply chain management: evolution and future directions. International Journal of Physical Distribution & Logistics Management 41(1), 46–62 (2011).
37. Brandenburg, M., Govindan, K., Sarkis, J., Seuring, S. Quantitative models for sustainable supply chain management: developments and directions. European Journal of Operational Research 233(2), 299–312 (2014).
38. Büyükȍozkan, G., Çifçi, G.: A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. Expert Systems with Applications 39(3), 3000–3011 (2012).

39. Hair Jr., J. F., Ringle, C. M., Sarstedt, M.: PLS-SEM: indeed a silver bullet. Journal of Marketing Theory and Practice 19(2), 139–152 (2011).
40. Ahi, P., Searcy, C.: A comparative literature analysis of definitions for green and sustainable supply chain management. Journal of Cleaner Production 52, 329–341 (2013).
41. Carter, C. R., Rogers, D. S.: A framework of sustainable supply chain management: moving toward new theory. International Journal of Physical Distribution & Logistics Management 38 (5), 360–387 (2008).
42. Hassini, E., Surti, C., Searcy, C.: A literature review and a case study of sustainable supply chains with a focus on metrics. International Journal of Production Economics 140(1), 69–82, (2012).
43. Diabat, A., Govindan, K.: An analysis of the drivers affecting the implementation of green supply chain management. Resources, Conservation and Recycling 55(6), 659–667 (2011).
44. Seuring, S.: A review of modeling approaches for sustainable supply chain management. Decision Support Systems 54(4), 1513–1520 (2013).
45. Yin, R. K. Case study research: design and methods. 4th edn. Thousand Oaks (2003).
46. Kleinberg, J.: Bursty and hierarchical structure in streams. Data Mining and Knowledge Discovery 7(4), 373–397 (2003).
47. Srivastava, S. K.: Green supply chain management: a state of the art literature review. International Journal of Management Reviews 9(1), 53-80 (2007).
48. Tomlin, B.: On the value of mitigation and contingency strategies for managing supply chain disruption risks. Management Science 52(5), 639-657 (2006).
49. Tang, C. S.: Perspectives in supply chain risk management. International Journal of Production Economics 103(2), 451–488 (2006).
50. Kleindorfer, P. R., Saad, G. H.: Managing disruption risks in supply chains. Production and operations management 14(1), 53–68 (2005).
51. Xu, Z.: Intuitionistic fuzzy aggregation operators. IEEE Transactions on Fuzzy Systems 15(6), 1179–1187 (2007).
52. Zhu, Q., Sarkis, J.: Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. Journal of Operations Management 22(3), 265–289 (2004).
53. Zhu, Q., Sarkis, J., Lai, K. H.: Confirmation of a measurement model for green supply chain management practices implementation. International Journal of Production Economics 111(2), 261–273 (2008).
54. Zhu, Q., Sarkis, J., Geng, Y.: Green supply chain management in China: pressures, practices and performance. International Journal of Operations & Production Management 25(5), 449–468 (2005).
55. Zamboni, A., Shah, N., Bezzo, F.: Spatially explicit static model for the strategic design of future bioethanol production systems. 1. Cost minimization. Energy & fuels 23(10), 5121–5133 (2009).
56. Podsakoff, P. M., MacKenzie, S. B., Lee, J. Y., Podsakoff, N. P.: Common method biases in behavioral research: a critical review of the literature and recommended remedies. Journal of Applied Psychology 88(5), 879 (2003).
57. Petersen, K. J., Handfield, R. B., Ragatz, G. L.: Supplier integration into new product development: coordinating product, process and supply chain design. Journal of Operations Management 23(3–4), 371–388 (2005).
58. Chan, F. T., & Kumar, N.: Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega 35(4), 417–431 (2007).
59. Xu, Z., Yager, R. R.: Some geometric aggregation operators based on intuitionistic fuzzy sets. International Journal of General Systems 35(4), 417–433 (2006).
60. Norrman, A., Jansson, U.: Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. International Journal of Physical Distribution & Logistics Management 34(5), 434–456 (2004).
61. Chopra, S., Sodhi, M. S.: Supply-chain breakdown. MIT Sloan Management Review 46(1), 53–61 (2004).

62. Andersen, M., Skjoett-Larsen, T.: Corporate social responsibility in global supply chains. Supply Chain Management 14(2), 75–86 (2009).
63. Reuter, C., Foerstl, K. A. I., Hartmann, E. V. I., Blome, C.: Sustainable global supplier management: the role of dynamic capabilities in achieving competitive advantage. Journal of Supply Chain Management 46(2), 45–63 (2010).
64. Choi, T. Y., Wu, Z.: Triads in supply networks: theorizing buyer–supplier–supplier relationships. Journal of Supply Chain Management 45(1), 8–25 (2009).
65. Trkman, P., McCormack, K.: Supply chain risk in turbulent environments – a conceptual model for managing supply chain network risk. International Journal of Production Economics 119(2), 247–258 (2009).
66. Lee, A. H.: A fuzzy supplier selection model with the consideration of benefits, opportunities, costs and risks. Expert Systems With Applications 36(2), 2879–2893 (2009).
67. Cachon, G. P. Supply chain coordination with contracts. Handbooks in Operations Research and Management Science 11, 227–339 (2003).
68. Wu, Z., Choi, T. Y. Supplier–supplier relationships in the buyer–supplier triad: Building theories from eight case studies. Journal of Operations management 24(1), 27–52 (2005).

Life Cycle Assessment (LCA) Photovoltaic Solar Energy: A Bibliometric Literature Review

Wilson de Paula Teixeira

Abstract With the increase in the world population, urbanization and industrialization, the demand for energy has continuously increased during the last decades. Fossil fuels (coal, oil, natural gas and their derivatives) are directly related to land and water degradation and global warming mainly as a consequence of greenhouse gases (GHG) emissions generated by anthropogenic activity. As an alternative to reduce GHG emissions, several countries are looking to use renewable energy. Among the various renewable energies, solar energy is one of the renewable sources in the world. This article conducts a bibliometric study on the topics; life cycle assessment (LCA) and photovoltaic solar energy, looking for publications that cover the topic and make a network map of the main authors cited through the evaluation of 354 articles. The research was carried out through bibliometric analysis in the Scopus database, from 1998 to 2020. The result of this work may contribute to new research in the area of life cycle assessment and photovoltaic solar energy, since bibliometric analysis allows to draw a list of the main publications based on the construction of a theoretical framework.

Keywords Life cycle assessment · Bibliometrics · Solar PV

1 Introduction

Throughout the world in recent decades, the concern with the environment has been increasingly highlighted, according to Haupt and Hellweg [1] due to the problems caused by human interference. The ability that human beings have to intervene in the environment to withdraw their livelihood and survival, allowed the exploration and consumption of resources without thinking about the conservation of the planet and its ecosystems, only due to environmental catastrophes, high levels of pollution and

W. de Paula Teixeira (✉)
Piracicaba Methodist University, Santa Bárbara d'Oeste - SP 13451-900, Brazil
e-mail: wilson.teixeira93@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_6

the verification of that the planet's capacity to recover was being exceeded is that a movement started in favor of the rational use of the planet's natural resources [2].

The need to reconcile economic efficiency with the conservation of natural resources and the preservation of existing ecosystems exposes the concept of sustainable development (SD) [3]. Being presented by the World Commission on Environment and Development in 1987 as "the ability of present generations to meet their needs without compromising the ability of future generations to meet their needs" [4] known as the "Our Common Future" report, a concept used until today when it comes to defining sustainable development.

This concept having gained strength in recent years, as well as the number of tools developed for managing and monitoring sustainable development [5]. Among these tools, the life cycle assessment (LCA) stands out, which aims to analyse systems, be it a product, service or process, from extraction of the raw material through its conception to its final disposal "from the cradle to the grave", quantifying the possible associated environmental impacts [6].

With this, the present work aims to identify the global characteristics of the literature associated with the theme ACV and photovoltaic solar energy, in order to present associations and trends that provide a foundation for future work.

2 Theoretical Framework

2.1 Photovoltaic Energy

Solar energy is an important alternative source of energy to fossil fuels and, theoretically, the most available source of energy on earth [7]. Through the photovoltaic effect, solar cells directly convert energy from the sun into electrical energy in a static, silent, non-polluting and renewable way [8].

Photovoltaic conversion is the direct transformation of sunlight into electricity in photovoltaic devices, since these devices are robust and simple in design, requiring very little maintenance, their biggest advantage is the construction as independent systems to provide outputs from microwatts to megawatts [8, 9].

The basic building block of PV (photovoltaic) devices is a semiconductor element known as a photovoltaic cell. When the cells are interconnected, the PV module is integrated with a number of additional components, for example, inverters, batteries, basic components and assembly systems [10].

Photovoltaic systems produce electricity without polluting the air during their operation and have a very low "carbon footprint" over their lifetime, providing superior environmental performance compared to traditional electricity generation based on fossil fuel technologies [11].

3 Methodology

3.1 Sample

The first phase of the research (Fig. 1) was responsible for defining the sampling of the analysis, according to Ramos and Oliveira [12]. The "Scopus" database was selected for data collection. The search terms used were: ("life cycle assessment LCA") AND ("photovoltaic solar energy"), where they were applied to the title, abstract and keywords fields. A total of 439 publications were extracted, and after refinement, 354 articles. To refine the research, the following exclusion criteria were applied.

Publication type: Only original articles and review articles were selected.

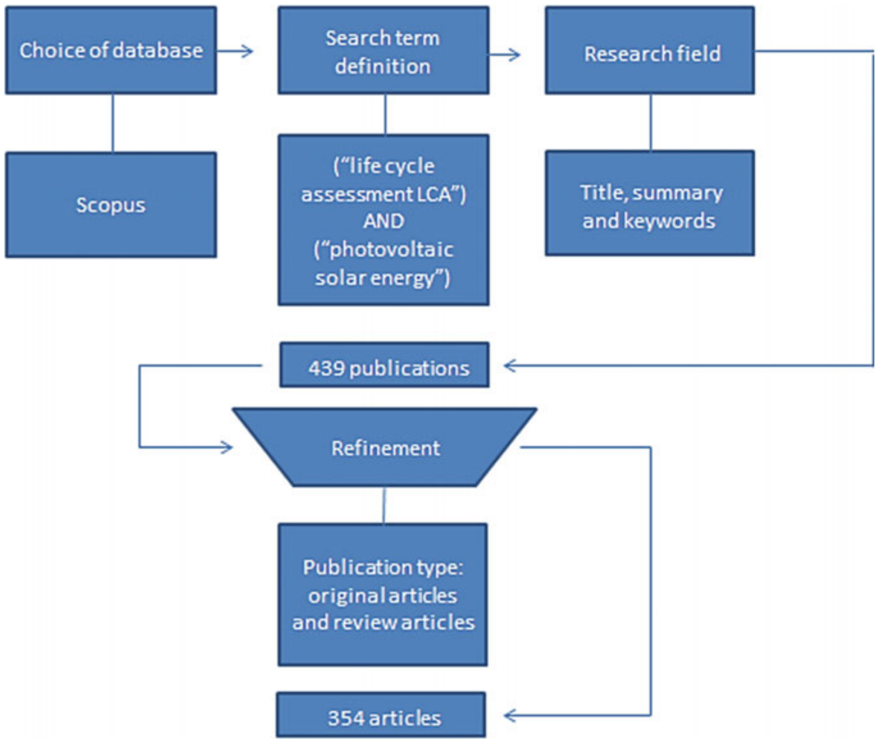


Fig. 1 Phase 1 (sample definition). Adapted from Ramos and Oliveira [12]

3.2 Data Analysis

For the second phase, with the sampling defined, all available metadata were imported, such as: abstract, authors, keywords, journal, references, number of citations, among other data. They were exported and later analysed using Microsoft Office Excel 2010 and Vos Viewer software. It was possible to extract the results sought in the work, such as: publications per year, journals with the largest number of publications, authors with the largest number of publications, most cited authors, institutions with the largest number of publications, countries with the largest number of publications, map of co -quotation and map of words co-occurrence.

4 Results and Discussion

Regarding the results of the survey with a sample of 354 articles, the first information extracted was the number of publications per year (Fig. 2). It is observed that the number of publications remains without much fluctuation until 2009, and from then on growing, until reaching a number of 78 publications in 2019, showing that there is a trend line, resulting from a possible maturation of this field of research.

314 different journals were found. The top 10 journals in terms of quantity of publications are shown in Table 1, with more than 50% of the total sample. The journals *Journal of Cleaner Production* and *Applied Energy* have the highest representation, with 37 and 28 publications respectively. Regarding the Impact Factor (IF) index, the periodical *Renewable And Sustainable Energy Reviews* stands out, which presented the highest index in 2018.

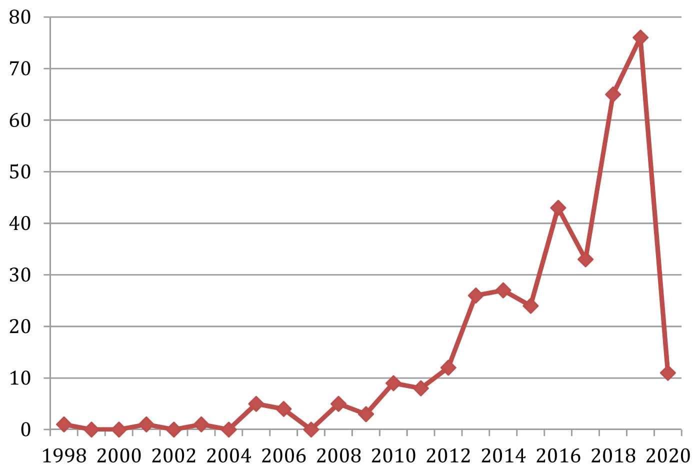


Fig. 2 Number of publications per year. Adapted from SCOPUS (2019)

Table 1 Analysis of the 10 main journals

Newspaper name	Quantity publications	%	IF - 2018	IF - last 5 years
Journal of cleaner production	37	10,45	6,395	7,051
Applied energy	28	7,91	8,426	8,558
Renewable and sustainable energy reviews	23	6,5	10,558	11,239
Progress in photovoltaics research and applications	19	5,37	6,34	6,355
Renewable energy	18	5,08	5,439	5,257
Energy	17	4,8	5,537	5,747
Solar energy	15	4,24	4,674	4,807
Solar energy materials and solar cells	15	4,24	6,019	5,105
Energies	14	3,95	2,707	2,99
International journal of life cycle assessment	11	3,11	4,868	5,524

Table 2 Analysis of the top 10 countries

Name of the country	Quantity publications	% of articles
United States	64	13,25
Italy	51	10,56
United Kingdom	44	9,11
Spain	37	7,66
China	33	6,83
France	22	4,55
Germany	20	4,14
Greece	18	3,73
Switzerland	16	3,31
Netherlands	15	3,11

The 354 articles were analysed according to their origin, geographic and institutional, resulting in 56 countries and 160 different institutions. With regard to countries, shown in Table 2, the top ten in terms of quantity of publications represent almost 70% of publications. The United States leads the list in relation to the number of publications (64), followed by Italy (51) and the United Kingdom (44) in third position.

Table 3 Analysis of the main institutions

Institution Name	Quantity publications
Chinese Academy of Sciences	12
University of Manchester	11
Universitat de Lleida	10
Department of Chemical Engineering and Analytical Science	9
Università degli Studi di Siena	8
Danmarks Tekniske Universitet	8
King Mongkuts University of Technology Thonburi	7
Università degli Studi di Palermo	7
Columbia University in the City of New York	7

Table 4 Analysis of the 10 main authors

Author's name	Quantity publications
Chemisana, D	9
Azapagic, A	8
Lamnatou, C	8
Espinosa, N	7
Gheewala, S.H	7
Basosi, R	6
Cellura, M	6
Krebs, F.C	6
Longo, S	6
Parisi, M.L	6

Due to the variety of institutions found in the sample, the majority with a low index of publications, it is inconclusive to cover the most representative portion of them. Given the above, only the nine main institutions were analysed in terms of quantity of publications, as shown in Table 3.

looseness-1With regard to the main authors, shown in Table 4, the top ten in terms of quantity of publications represent almost 20% of the publications. The author Chemisana, D. has the largest number of publications (9), followed by Azapagic, A. and Lamnatou, C. both with 8 publications.

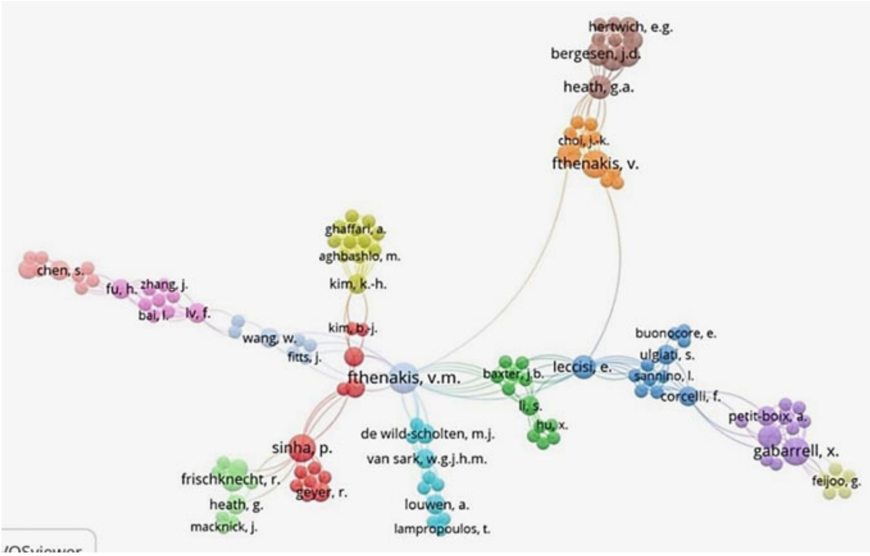


Fig. 3 Network map of the main authors mentioned

Through a cocitation analysis, in which the authors cited by the 354 articles in the sample, 1206 different authors were found. The analysis considers that when two authors are cited by the same article, they have a link and the set of these links form the chains of authors. Figure 3 shows the networks formed by the authors who were cited at least once within the sample, resulting in a total of 139 authors divided into 13 different streams, distinguished by colors. Regarding the relevance of the authors, the greater the circumference, the greater the number of citations.

The map resource was used to analyse the content of the articles, considering the words that occur in the title, in binary count, in which the occurrence in the article is verified, regardless of frequency. 1030 different words were found. Figure 4 shows the word map. This confirms that the publications address, in addition to LCA, the issues of environmental impact and photovoltaic solar energy, such as module, environmental impact, energy flow, solar PV, among others.

Table 5 shows the 10 most cited publications, including the average citation per year (CY) and journal name. With respect to publication sources, *Renewable and Sustainable Energy Reviews* tops the list, occurring twice. The most cited work was published by the journal *Renewable Energy*.

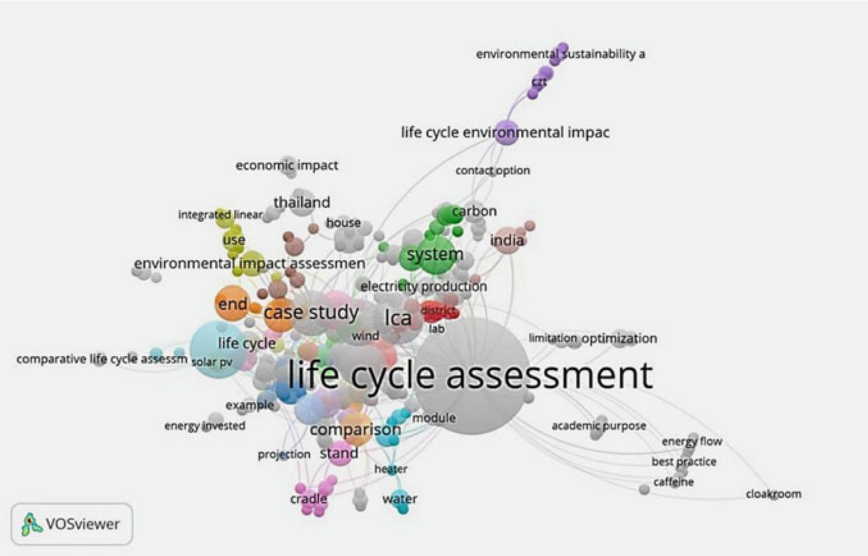


Fig. 4 Map of words co-order

5 Conclusion

Bibliometric analyses were carried out based on a sample of 354 articles covering the topic of LCA applied to photovoltaic solar energy, which allowed observing the growth in bibliometric terms. It is observed that the use of LCA as a tool to support environmental management is growing, both in terms of the number of publications and its relevance. The works were classified into 19 different subject categories, the majority of which are in the Energy area. The main journals found were: *Journal of Cleaner Production* and *Applied Energy*.

There are 10 authors who have the greatest influence in the literature, with Chemisana, D. being the main one. The country with the largest number of publications is the United States, while the most relevant institution is the Chinese Academy of Sciences, in China.

The result of this work may help further research in the field of photovoltaic solar energy and life cycle analysis, since bibliometric analysis allows drawing a network map based on the construction of the theoretical framework.

Table 5 10 Most cited publications

Year	Number of citations	CY	Publication	Periodical
2006	400	28,5	Dynamic life cycle assessment (LCA) of renewable energy technologies	Renewable energy
2013	279	39,9	Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems	Renewable and sustainable energy reviews
2013	255	36,4	Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations	Renewable and sustainable energy reviews
2015	230	46	Perovskite photovoltaics: Life-cycle assessment of energy and environmental impacts	Energy and environmental science
2015	222	44,4	Integrated life-cycle assessment of electricity-supply scenarios confirms global environmental benefit of low-carbon technologies	Proceedings of the national academy of sciences of the United States of America
2008	201	16,8	Life cycle assessment of photovoltaic electricity generation	Energy
2013	162	23,1	Life cycle water use for electricity generation: A review and harmonization of literature estimates	Environmental research letters
2006	149	10,6	Life cycle assessment study of solar PV systems: An example of a 2.7 kWp distributed solar PV system in Singapore	Solar energy
2012	134	16,8	Life cycle greenhouse gas emissions of crystalline silicon photovoltaic electricity generation: systematic review and harmonization	Journal of industrial ecology
2005	118	7,8	Energy, cost and LCA results of PV and hybrid PV/T solar systems	Progress in photovoltaics: Research and applications

Acknowledgements To the support provided by the PROSUP/CAPES program.

References

1. Haupt, M.: Hellweg, S.: Measuring the environmental sustainability of a circular economy. Environmental and Sustainability Indicators 1–2, 100005 (2019).
2. Li, Y., Li, Y., Kappas, M.: PAVAO-ZUCKERMAN, M.: Identifying the key catastrophic variables of urban social-environmental resilience and early warning signal. Environment International 113, 184–190 (2018).
3. Eustachio, J. H. P. P.: Caldana, A. C. F.: Liboni, L. B.: Martinelli, D. P.: Systemic indicator of sustainable development: Proposal and application of a framework. Journal of Cleaner Production 241, 118383 (2019).
4. WCED – World Comission on Environment and Development. Our Common Future. Oxford University Press, Oxford, (1987).
5. Caiado, R. G. G.: Dias, R. D.: Mattos, L. V.: Quelhas, O. L. G.: Filho, W. L.: Towards sustainable development through the perspective of ecoefficiency - A systematic literature review. Journal of Cleaner Production 165, 890–904 (2017).
6. Ludin, N. A.: Mustafa, N. I.: Hanafiah, M. M.: Ibrahim, M. A.: Teridi, M. A. M.: Sepeai, S.: Zaharim, A.: Sopian, K..: Prospects of life cycle assessment of renewable energy from solar photovoltaic technologies: A review. Renewable and Sustainable Energy Reviews 96, 11–28 (2018).
7. Desideri, U.: Zepparelli, F.: Morettini, V.: Garroni, E.: Comparative analysis of concentrating solar power and photovoltaic technologies: Technical and environmental evaluations. Applied Energy 102, 765–784 (2013).
8. Sampaio, P. G. V.: Gonzáles, M. O. A.: Photovoltaic solar energy: Conceptual framework. Renewable and Sustainable Energy Reviews 74, 590–601 (2017).
9. Parida, B.: Iniyan, S.: Goic, R.: A review of solar photovoltaic technologies. Renewable and Sustainable Energy Reviews 15, 1625–1636 (2011).
10. Aman, M. M.: Solang, K. H.: Hossain, M. S.: Badarudin, A.: Jasmon, G. B.: Mokhlis, H.: Bakar, A. H. A.: Kazi, S. N.: A review of Safety, Health and Environmental (SHE) issues of solar energy system. Renewable and Sustainable Energy Reviews 41, 1190–1204 (2015).
11. Yue, D.: You, F.: Darling, S. B.: Domestic and overseas manufacturing scenarios of silicon-based photovoltaics: Life cycle energy and environmental comparative analysis. Solar Energy 105, 669–678 (2014).
12. Ramos, M. O.: Oliveira, E. D.: Revisão Bibliométrica sobre a Manutenção Produtiva Total e o Pilar Saúde, Segurança e Meio Ambiente. In. Simpósio de engenharia, gestão e inovação. Águas de Lindoia, São Paulo (2019).

Analysing Plastic Cups Use: A Psychological Approach

Andressa D'Agostin, Amanda dos Santos Souza, Janine Fleith de Medeiros, and Ana Cristina Vendrametto Varrone Giacomini

Abstract Production and consumption of plastic, especially single-use ones, are seen today as one of the main environmental problems, since it is used for a very short time, takes hundreds of years to decompose, and the measures taken to reduce it have shown to be counterproductive, such as laws prohibiting its use. In this scenario, we investigate user behavior, analyzing young college students' perception facing plastic cups offer, specifically, drivers and barriers to non-adoption behaviors, through the Theory of Planned Behavior (TPB) and the Consumption Emotions Set scale (CES). A questionnaire, divided by blocks, was applied to southern-Brazilian university students (N = 502). For the data analysis we performed a general frequency description, followed by central tendency measurement (descriptive statistics), which evinces that students show favorable attitude and behavioral intention to disposable plastic cups non-use. Among the four emotions with higher frequencies, envy was a novelty verified in this study, along with guilt, frustration and worry. We propose practical and theorical implications based on our findings, followed by our study's limitations.

Keywords Environmental concern · Pro-environmental behavior · Emotion

1 Introduction

Plastic items are constant in contemporary society's daily life. The estimated annual global production in 2018 was 359 million tonnes [1]. A good part of these, around 40%, are produced to be used only once, being discarded almost immediately, such

A. D'Agostin (✉) · A. dos Santos Souza · J. F. de Medeiros · A. C. V. V. Giacomini
Universidade de Passo Fundo, Rodovia BR 285, km 292,7, S/n - São José, Passo Fundo, RS 99052-900, Brazil
e-mail: eng.andressadg@gmail.com

J. F. de Medeiros
Industrial Engineering Department, Universidade Federal do Rio Grande do Sul, Av. Osvaldo Aranha, 99, 5º Andar, Porto Alegre 90035-190, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_7

as straws, grocery bags, cups, among others. Regarding plastic cups, 720 million units are discarded every day in Brazil (262.8 billion annually), of which only 16% are recycled [2]. Production and consumption of plastic, especially single-use ones, are seen today as one of the main environmental problems [3, 4], since it is used for a very short time [5], takes hundreds of years to decompose [6], and the measures taken to reduce it have shown to be counterproductive, such as laws prohibiting its use [7, 8].

According to Tonglet et al. [9], the key to achieving sustainable waste management focuses on understanding waste minimization behavior. Therefore, there is a need for studies that enable a greater understanding of the factors that encourage people's engagement in behaviors that protect the environment and reduce impacts [10]. In this scenario, one issue that is worth investigating focuses on user behavior. Different studies emphasize that it is urgent to understand consumers' decision-making processes when buying and using in order to minimize waste generation and promote greater engagement in pro-environmental actions [11].

Theoretically, we know that human behavior is determined by different factors and can be measured or predicted by them. These constructs are influenced by other external factors, such as culture [12] and situational variables [13], or internal, such as beliefs [14], habits, past experiences, and emotions [10, 13, 15, 16]. In view of the above, we understand that the study of individual actions and their effects on the problem of garbage in the natural environment is fundamental to encourage environmentally appropriate behavior, as well as its activation. More than that, it tends to assist in the development of environmentally sustainable innovations, facilitating the adequacy and communication of requirements for the purchase and/or adoption of substitute products with a longer life cycle than disposable plastic cups.

2 Objectives

Our study aims to analyze young college students' perception facing plastic cups offer. Specifically, we investigate drivers and barriers to non-adoption behaviors.

3 Theoretical Background

To achieve the objective, the authors used as theoretical reference (i) the Theory of Planned Behavior (TPB) [17]; and (ii) Richins' [18] Consumption Emotions Set scale (CES).

Bamberg et al. [19] state that pro-environmental behavior can be induced by self-interest or pro-social reasons. Therefore, as the Theory of Planned Behavior embraces a construct that focuses on behavior's rational action, it is better applied in studies covering self-interest motivation. Azjen's Theory of Planned Behavior [17], an extension of Ajzen and Fishbein's Theory of Reasoned Action [20], has been one of the most influential theories in explaining and predicting a wide range of behaviors [21]. This theory considers as determinants of behavioral intentions: (i) attitudes; (ii) behavioral intention; (iii) subjective norm; (iv) awareness of the negative consequences; (v) perceived behavioral control; (vi) situational factors; and (vii) behavior.

(i) Attitude is the belief that a certain behavior or action will have a positive or negative effect on one's life, and the values this person ascribe to these consequences (result evaluation) [19]. (ii) Behavioral intention is seen as the only direct psychological behavioral determinant and it summarizes pros and cons one takes into account when assessing whether they should perform the behavioral option, or not [19, 22]. (iii) Subjective norm refers to the approval, or not, of a certain behavior by the social environment, as well as to what extent a person is influenced by their social surroundings [23]. In order to increase TPB's predictive power, researchers added another factor to it, (iv) awareness of negative consequences. It derives from Schwartz's [24] theory and stands for one's tendency to become aware of the consequences of their actions towards others. (v) Perceived behavioral control is one's perception of their skill (or the ease or difficulty) to perform a certain behavior [25, 26]. (vi) Situational factors may affect the relation between intention and behavior. They may weaken normative goals and thereby inhibit the effects of normative considerations and behavioral values as people want or need to prioritize other values or goals. On the positive side, situational factors can also strengthen normative goals (and/or weaken hedonic or earnings goals), making it more likely that people will act on account of biospheric values and thus promote pro-environmental actions [27]. Finally, (vii) behavior refers to the performed action.

Additionally, as emotions tend to predict attitudes towards pro-social actions such as pro-environmental behavior [28, 29], they should also be studied. We point out that the CES scale, compared to the Norm Activation Model (NAM) [24], shows a more embracing structure to measure emotions through decision-making processes related to consumption [30]. Furthermore, despite self-conscious emotions contemplated in NAM being ideal predictors of moral behavior, such as sustainable consumption, basic emotions (joy, sadness, anger and fear, for instance) also affect environmentally friendly decision-making processes, in addition to being great predictors of behavior [31], and should not be overlooked [32, 33].

Composed of 47 emotion descriptors, distributed over 17 factors, CES presents a comprehensive structure for measuring the emotions during purchase and consumption process [30], and includes positive and negative emotions. Studies have shown that both positive and negative emotions influence involvement in pro-environmental behavior. For example, anticipated negative emotions (such as feeling angry or frustrated) have reduced people's desire to use public transport and commit to recycling at home [15]. In addition, positive emotions (such as feeling happy or optimistic) proved to be important predictors of purchasing green products [34].

The influence of positive emotions on declared pro-environmental behavior is partially mediated by environmental concerns and the perceived effectiveness by the consumer [35]. In addition, they can be important in determining environmentally relevant behaviors. Bissing-Olson, Fielding and Iyer [10] demonstrated that pride in a behavior positively predicts future behavior. In fact, pride can increase according to the responsibility expressed by a group for environmental protection, while if the responsibility is for environmental damage, anger and guilt increase [36]. On the other hand, guilt, a negative emotion, can play a central role in encouraging pro-environmental behavior, like positive emotions [37]. Generically, we can say that guilt motivates a desire to repair and promote prosocial behavior.

4 Methods

In light of this study's objective, we opted to perform a descriptive research with a quantitative approach. The data collection instrument used was a questionnaire composed of blocks, aimed at identifying and diagnosing: (a) drivers and (b) barriers for plastic cup use; and (c) emotions towards it. In order to design blocks (a) and (b), we considered the TPB constructs applied in similar studies [9, 11, 19, 25, 34, 38, 39]. To assess emotions, after reverse translating CES, we rearranged the factors and descriptors according to the Brazilian context, since social and cultural aspects can interfere in the comprehension of emotional terms [40]. Moreover, due to our instrument design strategy, which encompassed emotions bipolarity (positive and negative), we added some antonyms to the original scale. Also, based on studies that found that guilt and pride have an interference in pro-environmental behavior [10, 36], we included them as factors in the data collection instrument (in CES, these emotions are descriptors in the "Other items" factor).

Cronbach's alpha, which states the instrument's reliability and the test's internal consistency, was 0.70, 0.83 and 0.95, respectively for each block. Values of 0.70 or 0.75 are frequently used as cutoff value for the Cronbach's alpha, therefore equal or higher values (closer to 1) are more reliable [41].

As for the research population sample, we focused our study on students from a southern-Brazilian university. In order to assure an acceptable number of responses, selection was made by convenience, a rather common approach in research involving the Theory of Planned Behavior [42]. After the validation of the answered instrument, there were a total of 502 respondents, of which: 70.7% (n = 355) were women, average age of 23.63 years old (sd = 5.71); 78.5% were undergraduate students (n = 394) (21.5% were graduate). Moreover, the number of participants in the survey is in line with Salant and Dillman's [43] suggestions who state that for studies of human dimensions, a sample of approximately 400 participants is generally adequate to generalize the results to a 95% confidence level with a margin of error of ±5%.

For data analysis, we performed a general frequency description, followed by central tendency measurement (descriptive statistics). Since our focus was on describing a behavioral tendency, this type of analysis is suitable [44].

5 Results

Table 1 summarizes the mapped drivers and barriers to disposable plastic cups non-adoption behavior. Variables were organized according to the TPB model. A five-point Likert scale was employed (where 1 stands for "totally disagree" and 5, "totally

Table 1 Expressed behavior towards disposable plastic cups use

	Planned behavior	Mean	SD
Attitude			
Driver	To stop using plastic cups on a daily basis means being concern with the environment	4.63	0.81
Driver	I believe that not using plastic cups means having a sustainable life style	3.79	1.15
Driver	It is wrong to use plastic cups because I am contributing to environmental pollution	4.07	1.46
Driver	I feel rewarded using a durable/reusable product	4.13	1.40
Driver	I believe that cups made of glass/acrylic/any durable and reusable material will replace plastic cups	4.44	0.81
Behavioral intention			
Driver	I want to ditch plastic cups in my everyday life	4.38	1.00
Driver	I plan not to use disposable plastic cups in my everyday life	4.10	1.17
Subjective norm			
Barrier	I use plastic cups because my classmates also use them	1.61	1.01
Driver	People around me (classmates, family) think I should stop using plastic cups	2.39	1.28
Driver	I am influenced by the media (social media, television, magazines, newspaper) to stop using disposable plastic cups	2.91	1.43
Awareness of negative consequences			
Driver	I am aware of the presence of chemical compounds in plastic cups that can leak into what I am drinking	3.66	1.37
Barrier	I know the problems caused by plastic, but I do not believe that plastic cups cause major impact	1.49	0.98
Perceived behavioral control			
Driver	It is easy not to use plastic cups	3.67	1.36
Barrier	When I use a plastic cup, I do not have to carry a cup/glass with me	3.27	1.57
Barrier	One of the biggest advantages of plastic cups is being able to take out	2.89	1.47
Barrier	I do not need to wash it after using (what saves water)	2.53	1.43
Barrier	It does not break, unlike glass	2.72	1.37
Situational factors			
Barrier	I use plastic cups when I buy a drink at the snack bar or at the university Convenience Store (convenience and handiness)	3.86	1.43
Behavior			
Barrier	I regularly use plastic cups because I have not found an alternative replacement yet	2.31	1.46

agree"). Based on the TPB, the constructs addressed in this study are: (i) attitude; (ii) behavioral intention; (iii) subjective norm; (iv) awareness of negative consequences; (v) perceived behavioral control; (vi) situational factors; and (vii) behavior.

Then, since TPB was criticized by some researchers for being exclusively focused on rational reasoning, ignoring the unconscious influences on behavior and the role of emotions in face of expected affective results [34, 45], we investigated emotions related to the use of disposable plastic cups in the third block of our study. We followed the cognitive theory of emotions [46], which states that for an emotion to occur, it relies on the cognitive interpretation of a physiological state. This cognitive evaluation determines which emotion should be experienced.

In this regard, the Consumption Emotions Set scale (CES) emerged from the need to assess consumption-related emotions, since before its development there was only frameworks of emotions based on psychology, which were not accurate to measure emotions related to consumer behavior [47–49]. Table 2 shows the results obtained.

Table 2 Respondents' emotional positioning towards the use of disposable cups

A	+A	0	+B	B
I feel angry to consume something served in a plastic cup	233	133	88	I feel peacefulness when consuming something in a plastic cup
Plastic cups make me feel discontent	296	147	45	Plastic cups make me feel content
I feel worried when I use plastic cups	351	79	46	I feel unconcerned when I use plastic cups
I feel sad when I notice there are plastic cups available	259	169	54	I feel joy when I notice there are plastic cups available
I fear using plastic cups	204	150	107	I trust in plastic cups' utility and functionality
I feel ashamed when I use plastic cups	252	213	28	I feel pride when I use plastic cups
I envy who doesn't use plastic cups	312	143	25	I sympathize with who uses plastic cups
I feel lonely when I use plastic cups	131	306	53	I feel welcomed when I use plastic cups
I hate plastic cups	272	162	55	I love finding plastic cups available
I am pessimist about plastic cups use	297	161	30	I am optimist about plastic cups use
I feel disappointed when I buy something served in a plastic cup	294	173	23	I feel enthusiasm when I buy something served in a plastic cup
I feel frustrated when I use plastic cups	306	152	34	I am positively surprised when I find plastic cups to use
I have contempt for plastic cups	260	210	22	I have passion for plastic cups
I feel guilty when I use plastic cups	327	143	22	I feel relieved when I use plastic cups
Using plastic cups makes me feel eager	220	250	24	Using plastic cups brings me serenity

6 Discussion

Responses signals that most respondents show attitude and behavioral intention that favors the non-use of plastic cups. This remark allows us to infer that the sampled students tend not to use plastic cups available in the commercial establishments in campus. The stronger a person's intention to perform the behavior, the more likely the behavior will be performed [50]. However, we also identified that situational factors, such as convenience and handiness, may reduce the positive effect of attitudes and behavioral intention, which results in the adoption of plastic cups (this may occur because the student is not carrying a silicon cup and/or a mug at the moment). Another point that supports the relevance of convenience and handiness is the expressions for the "Perceived Behavioral Control" construct: although most averages are lower than 3 on pro-environmental behavior inhibitory variables, we consider important the fact that the variable "When I use a plastic cup, I do not have to carry a cup/glass with me" showed a mean of 3.27 and standard deviation of 1.57.

In addition, the variable "I feel **rewarded** using a durable/reusable product" showed a mean of 4.13, which is in line with previous research [51]: people anticipate experiencing positive affective reward from prosocial behavior, also known as warm glow. Experiencing warm glow as a consequence of a pro-environmental attitude may instigate learning effects that lead to future behavior [51].

Frequent exposure to content about the environment in traditional media, such as TV and advertising, was positively related to environmental concerns and environmental knowledge [52]. However, in contrast to previous studies [23, 53], subjective norm - more specifically the influence of social networks and other media – did not play a significant role in students' decision making, which is not aligned with their attitude and intention, and would be a barrier to the dissemination and promotion of pro-environmental behavior.

Furthermore, regarding the second part of the study, in general, the university people preferred to position themselves closer to negative emotions, except for variables "loneliness/welcome" and "anxiety/serenity", in which the neutral option (represented by the position "0") obtained more responses. This means that a large part of the sample understands that the use of disposable plastic cups causes stress and displeasure [54]. This result corroborates with attitudes stated in the first block of the questionnaire, such as "To stop using plastic cups on a daily basis means being **concerned** with the environment" (4.63), "I feel **rewarded** using a durable/reusable product" (4.13) and "It is **wrong** to use disposable plastic cups because I am contributing to environmental pollution" (4.07). Attitudes result from three types of evaluative responses: cognitive, affective and behavioral [55].

Among the negative emotions with the most significant performance, we highlight concern, guilt, envy and frustration. Worry, frustration and, mainly, the feeling of guilt, have already been verified in other studies, and can be understood as emotions that predict behaviors associated with damage repair [36, 56, 57]. Frustration, along with helplessness and lack of control, may result from the feeling of living in a society that does not appear to care about plastic [58]. Envy, on the other hand, is a novelty verified in this study.

Envy is characterized by feelings of inferiority, desire and resentment [59]. It is a feeling that is often denied and masked by consumers [60]. Envy translates into regret for the evident success enjoyed by similars [61]. Therefore, it is considered a painful social emotion [62]. However, it can be an emotion that motivates change, especially to achieve public approval [59].

7 Conclusion

Analysing the results, it is possible to conclude that students show favorable attitude and behavioral intention to disposable plastic cups non-use. Additionally, by investigating the influence of emotions on the referred pro-environmental behavior, we understand that they can be drivers of environmentally sustainable attitudes. In this sense, we highlight the role of worry, guilt and envy. Therefore, we suggest that education and communication should explore these emotions to mobilize people to adopt green behaviors. However, as the results also show that questions related to situational factors could decrease the adoption of more ecologically suitable options, we suggest that the very commercial establishments propose alternatives to consumers, such as renting a cup, or proposing a price incentive for consumers who take away meals or to-go beverages in their own containers [21], for example.

Also, social research with stakeholders, and trial schemes, have shown to be an important step to achieve a state of readiness for transition when introducing policies, such as bans and fines. However, they work best if they are introduced with social attitudes and concerns (intrinsic motivations) in mind, which, psychologically, are a better fundament for long-term engagement in pro-environmental behaviors [58]. In this sense, the emotions mapped in this study could be representative of these motivations and could be applied in communication campaigns aiming social acceptance of new policies.

With regard to the study's limitations, we point out the impossibility to generalize the results obtained. University students usually present a higher knowledge and environmental awareness level than people who have not been to one [63]. Also, attitudes may vary according to the context in which they are expressed [64]. Hence, we propose the extension of the universe of research. In addition, for the manipulation of emotions to be carried out more effectively, we recommend the implementation of experimental studies, to verify which emotions are major determinants of the promotion of pro-environmental attitudes and behavioral intention.

References

1. Plastics Europe and EPRO (2019) Plastics—the Facts 2019. https://www.plasticseurope.org/en/resources/market-data
2. CEMPRE (2015) Review 2015. http://cempre.org.br/artigo-publicacao/artigos
3. Gall SC, Thompson RC (2015) The impact of debris on marine life. Mar Pollut Bull 92:170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041
4. 4. Xanthos D, Walker TR (2017) International policies to reduce plastic marine pollution from single-use plastics (plastic bags and microbeads): A review. Mar Pollut Bull 118:17–26. https://doi.org/10.1016/j.marpolbul.2017.02.048
5. Wagner TP, Toews P (2018) Assessing the Use of Default Choice Modification To Reduce Consumption of Plastic Straws. Detritus 4:113–121. https://doi.org/10.31025/2611-4135/2018.13734
6. Cózar A, Echevarría F, González-Gordillo JI, Irigoien X, Úbeda B, Hernández-León S, Palma ÁT, Navarro S, García-de-Lomas J, Ruiz A, Fernández-de-Puelles ML, Duarte CM (2014) Plastic debris in the open ocean. Proc Natl Acad Sci U S A 111:10239–10244. https://doi.org/10.1073/pnas.1314705111
7. Sun Y, Wang S, Li J, Zhao D, Fan J (2017) Understanding consumers' intention to use plastic bags: using an extended theory of planned behaviour model. Nat Hazards 89:1327–1342. https://doi.org/10.1007/s11069-017-3022-0
8. Wagner TP (2017) Reducing single-use plastic shopping bags in the USA. Waste Manag 70:3–12. https://doi.org/10.1016/j.wasman.2017.09.003
9. Tonglet M, Phillips PS, Read AD (2004) Using the Theory of Planned Behaviour to investigate the determinants of recycling behaviour: A case study from Brixworth, UK. Resour Conserv Recycl 41:191–214. https://doi.org/10.1016/j.resconrec.2003.11.001
10. Bissing-Olson MJ, Fielding KS, Iyer A (2016) Experiences of pride, not guilt, predict pro-environmental behavior when pro-environmental descriptive norms are more positive. J Environ Psychol 45:145–153. https://doi.org/10.1016/j.jenvp.2016.01.001
11. Corsini F, Gusmerotti NM, Testa F, Iraldo F (2018) Exploring waste prevention behaviour through empirical research. Waste Manag 79:132–141. https://doi.org/10.1016/j.wasman.2018.07.037
12. Martin M, Williams ID, Clark M (2006) Social, cultural and structural influences on household waste recycling: A case study. Resour Conserv Recycl 48:357–395. https://doi.org/10.1016/j.resconrec.2005.09.005
13. Boldero J (1995) The Prediction of Household Recycling of Newspapers: The Role of Attitudes, Intentions, and Situational Factors. J Appl Soc Psychol 25:440–462. https://doi.org/10.1111/j.1559-1816.1995.tb01598.x
14. Kok G, Siero S (1985) Tin Recycling: Awareness, Comprehension, Attitude, Intention and Behavior. J Econ Psychol 6:157–173
15. Carrus G, Passafaro P, Bonnes M (2008) Emotions, habits and rational choices in ecological behaviours: The case of recycling and use of public transportation. J Environ Psychol 28:51–62. https://doi.org/10.1016/j.jenvp.2007.09.003
16. Russell S V., Young CW, Unsworth KL, Robinson C (2017) Bringing habits and emotions into food waste behaviour. Resour Conserv Recycl 125:107–114. https://doi.org/10.1016/j.resconrec.2017.06.007
17. Ajzen I (1991) The Theory of Planned Behavior. Organ Behav Hum Decis Process 50:179–211
18. Richins M (1997) Measuring Emotions in the Consumption Experience. J Consum Res 24:127–146. https://doi.org/10.1086/209499
19. Bamberg S, Hunecke M, Blöbaum A (2007) Social context, personal norms and the use of public transportation: Two field studies. J Environ Psychol 27:190–203. https://doi.org/10.1016/j.jenvp.2007.04.001
20. Ajzen I, Fishbein M (1980) Understanding attitudes and predicting social behaviour. Prentice-Hall, Englewood Cliffs, NJ.

21. Ertz M, Huang R, Jo MS, Karakas F, Sarigöllü E (2017) From single-use to multi-use: Study of consumers' behavior toward consumption of reusable containers. J Environ Manage 193:334–344. https://doi.org/10.1016/j.jenvman.2017.01.060
22. Sheeran P (2002) Intention—Behavior Relations: A Conceptual and Empirical Review. Eur Rev Soc Psychol 12:1–36. https://doi.org/10.1080/14792772143000003
23. Botetzagias I, Dima AF, Malesios C (2015) Extending the Theory of Planned Behavior in the context of recycling: The role of moral norms and of demographic predictors. Resour Conserv Recycl 95:58–67. https://doi.org/10.1016/j.resconrec.2014.12.004
24. Schwartz SH (1977) Normative influences on altruism. Adv Exp Soc Psychol 10:221–279. https://doi.org/10.1016/S0065-2601(08)60358-5
25. Tonglet M, Phillips PS, Bates MP (2004) Determining the drivers for householder pro-environmental behaviour: Waste minimisation compared to recycling. Resour Conserv Recycl 42:27–48. https://doi.org/10.1016/j.resconrec.2004.02.001
26. Ohtomo S, Ohnuma S (2014) Psychological interventional approach for reduce resource consumption: Reducing plastic bag usage at supermarkets. Resour Conserv Recycl 84:57–65. https://doi.org/10.1016/j.resconrec.2013.12.014
27. Steg L, Bolderdijk JW, Keizer K, Perlaviciute G (2014) An Integrated Framework for Encouraging Pro-environmental Behaviour: The role of values, situational factors and goals. J Environ Psychol 38:104–115. https://doi.org/10.1016/j.jenvp.2014.01.002
28. Kim YJ, Njite D, Hancer M (2013) Anticipated emotion in consumers' intentions to select eco-friendly restaurants: Augmenting the theory of planned behavior. Int J Hosp Manag 34:255–262. https://doi.org/10.1016/j.ijhm.2013.04.004
29. Jiang X, Ding Z, Li X, Sun J, Jiang Y, Liu R, Wang D, Wang Y, Sun W (2020) How cultural values and anticipated guilt matter in Chinese residents' intention of low carbon consuming behavior. J Clean Prod 246:119069. https://doi.org/10.1016/j.jclepro.2019.119069
30. Laros FJM, Steenkamp JBEM (2005) Emotions in consumer behavior: A hierarchical approach. J Bus Res 58:1437–1445. https://doi.org/10.1016/j.jbusres.2003.09.013
31. Baumeister RF, Vohs KD, DeWall CN, Zhang L (2007) How Emotion Shapes Behavior: Feedback, Anticipation, and Reflection, Rather Than Direct Causation. Personal Soc Psychol Rev 11:167–203. https://doi.org/10.1177/1088868307301033
32. Hwang K, Kim H (2018) Are Ethical Consumers Happy? Effects of Ethical Consumers' Motivations Based on Empathy Versus Self-orientation on Their Happiness. J Bus Ethics 151:579–598. https://doi.org/10.1007/s10551-016-3236-1
33. Singh JJ, Garg N, Govind R, Vitell SJ (2018) Anger Strays, Fear Refrains: The Differential Effect of Negative Emotions on Consumers' Ethical Judgments. J Bus Ethics 151:235–248. https://doi.org/10.1007/s10551-016-3248-x
34. Koenig-Lewis N, Palmer A, Dermody J, Urbye A (2014) Consumers' evaluations of ecological packaging - Rational and emotional approaches. J Environ Psychol 37:94–105. https://doi.org/10.1016/j.jenvp.2013.11.009
35. Coelho F, Pereira MC, Cruz L, Simões P, Barata E (2017) Affect and the adoption of pro-environmental behaviour: A structural model. J Environ Psychol 54:127–138. https://doi.org/10.1016/j.jenvp.2017.10.008
36. Harth NS, Leach CW, Kessler T (2013) Guilt, anger, and pride about in-group environmental behaviour: Different emotions predict distinct intentions. J Environ Psychol 34:18–26. https://doi.org/10.1016/j.jenvp.2012.12.005
37. Graton A, Ric F, Gonzalez E (2016) Reparation or reactance? The influence of guilt on reaction to persuasive communication. J Exp Soc Psychol 62:40–49. https://doi.org/10.1016/j.jesp.2015.09.016
38. Ohtomo S, Hirose Y (2007) The dual-process of reactive and intentional decision-making involved in eco-friendly behavior. J Environ Psychol 27:117–125. https://doi.org/10.1016/j.jenvp.2007.01.005
39. Hartley BL, Pahl S, Veiga J, Vlachogianni T, Vasconcelos L, Maes T, Doyle T, d'Arcy Metcalfe R, Öztürk AA, Di Berardo M, Thompson RC (2018) Exploring public views on marine litter in Europe: Perceived causes, consequences and pathways to change. Mar Pollut Bull 133:945–955. https://doi.org/10.1016/j.marpolbul.2018.05.061

40. Chentsova-Dutton YE, Lyons SH (2016) Different Ways of Measuring Emotions Cross-Culturally. Elsevier Ltd
41. Christmann A, Van Aelst S (2006) Robust estimation of Cronbach's alpha. J Multivar Anal 97:1660–1674. https://doi.org/10.1016/j.jmva.2005.05.012
42. Ioannou T, Zampetakis LA, Lasaridi K (2013) Psychological determinants of household recycling intention in the context of the theory of planned behaviour. Fresenius Environ Bull 22:2035–2041
43. Salant, P Dillman DA (1996) How to conduct your own survey. Wiley, New York.
44. Malhotra NK (2019) Pesquisa de Marketing: uma orientação aplicada, 7th ed. Bookman
45. Sniehotta FF, Presseau J, Araújo-Soares V (2014) Time to retire the theory of planned behaviour. Health Psychol Rev 8:1–7. https://doi.org/10.1080/17437199.2013.869710
46. Lazarus RS (1991) Progress on a cognitive-motivational-relational theory of emotion. Am Psychol. https://doi.org/10.1037/0003-066X.46.8.819
47. Mehrabian A, Russell JA (1974) An approach to environmental psychology. The MIT Press, Cambridge, MA
48. Izard CE (1977) Human Emotions. Plenum, New York
49. Plutchik R (1980) A language for the emotions. Psychol Today 13:68–78
50. Graham-Rowe E, Jessop DC, Sparks P (2015) Predicting household food waste reduction using an extended theory of planned behaviour. Resour Conserv Recycl 101:194–202. https://doi.org/10.1016/j.resconrec.2015.05.020
51. Hartmann P, Eisend M, Apaolaza V, D'Souza C (2017) Warm glow vs. altruistic values: How important is intrinsic emotional reward in proenvironmental behavior? J Environ Psychol 52:43–55. https://doi.org/10.1016/j.jenvp.2017.05.006
52. Lee K (2011) The role of media exposure, social exposure and biospheric value orientation in the environmental attitude-intention-behavior model in adolescents. J Environ Psychol 31:301–308. https://doi.org/10.1016/j.jenvp.2011.08.004
53. Fan B, Yang W, Shen X (2019) A comparison study of 'motivation–intention–behavior' model on household solid waste sorting in China and Singapore. J Clean Prod 211:442–454. https://doi.org/10.1016/j.jclepro.2018.11.168
54. Watson D, Clark LA, Tellegen A (1988) Development and validation of brief measures of positive and negative affect: The PANAS scales. J Pers Soc Psychol 54:1063–1070. https://doi.org/10.1037/0022-3514.54.6.1063
55. Rosenberg MJ, Hovland CI (1960) Cognitive, affective, and behavioral components of attitudes. In: Hovland, CI, Rosenberg, MJ (eds.) Attitude Organization and Change: An Analysis of Consistency among Attitude Components. New Haven, CT: Yale University Press, pp. 1–14.
56. Tangney JP, Stuewig J, Mashek DJ (2007) Moral Emotions and Moral Behavior. Annu Rev Psychol 58:345–372. https://doi.org/10.1146/annurev.psych.56.091103.070145
57. Onwezen MC, Antonides G, Bartels J (2013) The Norm Activation Model: An exploration of the functions of anticipated pride and guilt in pro-environmental behaviour. J Econ Psychol 39:141–153. https://doi.org/10.1016/j.joep.2013.07.005
58. Pahl S, Wyles KJ, Thompson RC (2017) Channelling passion for the ocean towards plastic pollution. Nat Hum Behav 1:697–699. https://doi.org/10.1038/s41562-017-0204-4
59. Parrott WG, Smith RH (1993) Distinguishing the Experiences of Envy and Jealousy. J Pers Soc Psychol 64:59–77. https://doi.org/10.1037/0022-3514.64.6.906
60. Medeiros JF de, Sampaio CH, Perin MG (2010) Fatores emocionais no processo de tomada de decisão de compra. Psico 41:439–446
61. Elster J (1991) Envy in social life. In: Zeckhauser R (ed) Strategy and Choice. MIT Press, Cambridge, MA, pp 49–82
62. Dickinson JL, Crain RL, Reeve HK, Schuldt JP (2013) Can evolutionary design of social networks make it easier to be "green"? Trends Ecol Evol 28:561–569. https://doi.org/10.1016/j.tree.2013.05.011

63. Zhang Y (2013) The state of university students' environmental awareness and its solution. J Ningbo Inst Educ 4:37–40
64. Ajzen I, Fishbein M (2000) Attitudes and the Attitude-Behavior Relation: Reasoned and Automatic Processes. Eur Rev Soc Psychol 11:1–33. https://doi.org/10.1080/14792779943000116

Barriers to the Diffusion of Renewable Energies: Literature Review

Luiza de Barros Zamparetti, Anny Key de Souza Mendonça, Thaís Guerra Braga, Gabriel de Andrade Conradi Barni, and Antonio Cezar Bornia

Abstract This article aims to analyze and synthesize the principal barriers in the way of the implementation of the renewable energies through a literature review. After doing an bibliometric analysis ant selecting 48 articles that satisfied the choosing theme, 38 barriers were found, which were divided into 4 categories, them being: Economics, Technical e Technological, Political and Social. After a thorough analysis of each category, it was possible to observe that each barrier generates different impacts in each country, depending of their development and climatic conditions, and that all of them relate and impact each other, intensifying themselves and making the diffusion of these energies even more difficult.

Keywords Renewable energy · Niche · Cities · Countries · Barriers

L. de Barros Zamparetti
Department of Control and Automation Engineering, Federal University of Santa Catarina, Florianópolis, SC, Brazil
e-mail: lzamparetti@gmail.com

A. K. de Souza Mendonça (✉) · T. G. Braga · G. de Andrade Conradi Barni · A. C. Bornia
Department of Production and Systems Engineering, Federal University of Santa Catarina, Florianópolis, SC, Brazil
e-mail: anny.mendonca@posgrad.ufsc.br

T. G. Braga
e-mail: thais.braga@posgrad.ufsc.br

G. de Andrade Conradi Barni
e-mail: barni.gabriel@posgrad.ufsc.br

A. C. Bornia
e-mail: cezar.bornia@ufsc.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_8

1 Introduction

The environment has become a featured object among worldwide discussions. With the increase of greenhouse gases and the confirmation of the possibility of fossil resources depletion, alternative options have been increasingly searched and studied [1].

Ensuring that the entire population has access to electricity is essential and a challenge [2]. However, the world needs to expand access to electricity and also transition from an energy system dominadsted by fossil fuels to renewable sources, due to the environmental impact and the depletion of fossil fuel reserves.

Generating electricity from renewable sources, such as hydroelectric, wind, solar photovoltaic, biomass, geothermal and tidal energy, has been a challenge and the goal of many countries. These sources are widely available and their use for power generation does not produce pollution by burning fossil fuels, emissions of greenhouse gases or radiation, as occurs, for example, in thermal and nuclear power plants.

According to [1], the diffusion and adoption of new technologies from renewable sources have been of great interest to scientists and researchers from different disciplines. A justification for the time interval between the invention and the large-scale diffusion of a technology can be found by looking at the barriers [3]. Many barriers need to be addressed before large-scale diffusion is possible. Also, despite its undeniable importance, studies about renewable energies are not still priority in several countries, restraining the quantity of available examples and information.

This work aims to analyzes these barriers for the implementation and diffusion of renewable energies, based on a literature review of articles published in the last 5 years, with the objective of identifying the researches that address the theme and the types barriers to the insertion of renewable energy technologies in the market.

2 Methodological Procedures

As a method for this article, a bibliographic review of the literature was conducted, searching for academic articles that addresses the barriers, challenges or constraints to the implementation of renewable energies.

A six-step process was used to select and retrieve the articles: (i) Explore the bibliography; (ii) selection of the electronic database; (iii) identification of keywords for the research; (iv) study exclusion criteria; (v) revision of the title, abstracts and keywords of the articles obtained; (vi) review of the full text of the selected articles [4].

Research of the articles to make the bibliographical portfolio was made through the CAPES periodicos portal in Scopus and Web of Science databases. Scopus and Web of Science databases were selected due to the presence, at embassies, of documents related to sustainability and management. The search term utilized was: (TS = ((“renewable* energ*”) AND (niche OR city OR cities OR countr*)) AND TI = (barrier* OR constraint* OR challenge*)), that is, articles that had the terms "("renewable* energ*") AND (niche OR city OR cities OR countr*)" in the title, abstract or keywords, and some of the terms "(barrier* OR constraint* OR challenge*)" in the title were searched.

The first database resulted in 204 references, while the second, 276. References were imported at Mendeley software, which allowed the exclusion of 147 duplicate references, resulting in 333 articles. After that, the title and summary of these 333 references were analyzed to eliminate those that were not aligned with the objective of the research that is to collect the barriers and challenges of the implementation of renewable energies. After this selection, 48 references were reestablished for the composition of the bibliographical portfolio (BP).

The 48 articles of the BP were read by one of the authors in a first round in order to make sure that they were really aligned with the research objective. After this first round, the authors met and the aspects to be collected from the reading of the articles were defined, it was decided to analyze the types of barriers mentioned, the type of energy source and the country studied in the articles, when present. In the second round of readings, the articles were read by 4 researchers, and in this round each one extracted from the articles the aspects defined in the previous step, generating 4 files with the main elements of each article. The 4 files were compared and there were no significant discrepancies between them, which would generate the need for a re-reading of any of the articles. Having the definition of a method of extracting concepts and elements from articles a priori was an important step for the convergence of analyzes between researchers. Finally, the files were joined generating a single base file for being analyzed by the authors.

From the systematic analysis of the articles, the authors propose a framework that organizes the barriers in 4 major classes, and points out various types of barriers correlated to each of the classes. This theoretical framework is a source of information for directing actions focused on resolving each type of barrier, in order to enable greater diffusion of renewable energies in the world. This framework is presented and analyzed in the following section.

3 Results and Discussion

This section presents an analyzes of the 48 references that form the bibliographic portfolio (BP). The 48 scientific documents were mostly written in English by 167 authors and co-authors, with 11 articles being produced by only one author. They have 369 keywords, were produced by 73 different institutions, 7 of which are private or governmental companies, in 29 countries and published in 32 periodicals, annals of events or books.

Fist, Fig. 1 shows from which countries are the authors that published the articles. The darker the blue, the greater the number of authors from that country. The red lines show the co-authorship lines between countries. It is possible to analyze that research poles are still centered, having authors especially from developed and in development countries, with great focus on Europe and Asia.

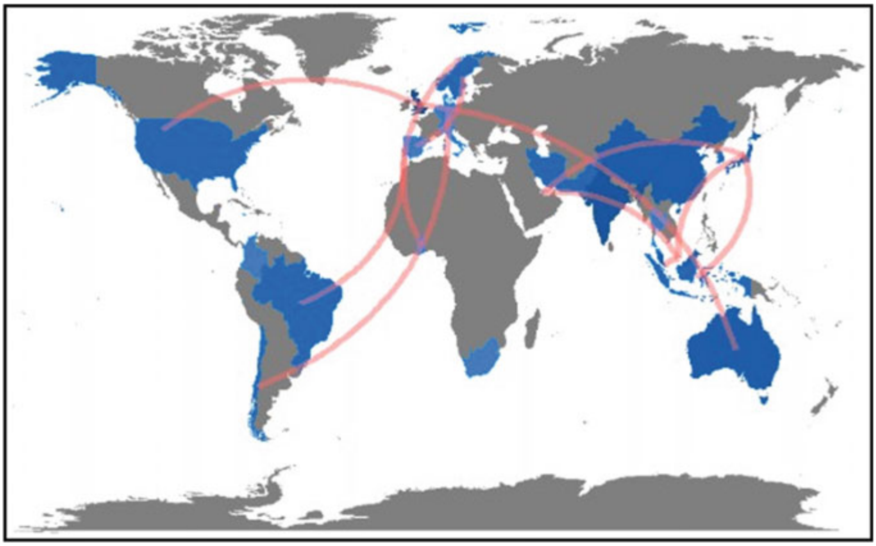


Fig. 1 Collaboration map of article production between countries

The country with the most authors publishing on the topic is Malaysia with 22 authors, followed by India and the United Kingdom, both with 12 authors each. Figure 1 shows an important co-authorship network between European countries, and another network formed between Asian countries. Brazil has 3 researchers as co-authors of articles whose main author is from Portugal.

As for the countries that are baseline for the studies, the trend is not the same shown by the affiliation country of the author. Malaysia is study topic of only one paper, India of 3 papers and there is no study focused on the United Kingdom. The distribution of the studies by region is shown in Fig. 2 aggregated by continent. The continent most researched is Asia with 21 appearances.

The articles present researches of different types of renewable energies, as shown in Fig. 3. Among the most researched energies are: biomass [5, 6], onshore wind [7], offshore wind [3], solar [5] and geothermal [8]. It's important to notice that 23 of the articles (27%) does not present research about one specific type of energy, being more theoretical papers. That are also some papers from the BP that study more than one type of energy in order to make comparative analysis.

Table 1 presents a framework that synthesizes the barriers for the diffusion of renewable energies quoted in the articles of the bibliographic portfolio. These barriers were grouped into 4 principal classes, obtained by importance shown in most articles: economics, technical and technological, political and social. In the central column of Table 1, a more detailed analysis of the types that configure each class of barriers. The right column of Table 1 presents the articles that make reference to each type of barrier.

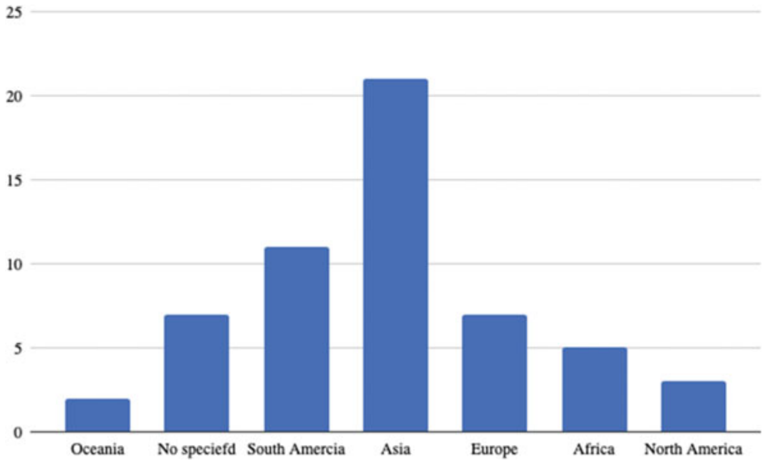


Fig. 2 Number of appearances of researches focuses in specified countries, aggregated by continent

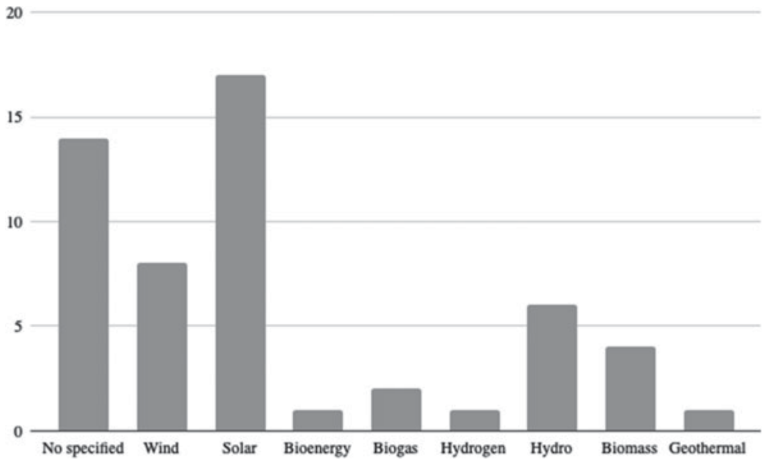


Fig. 3 Number of articles that studies each type of renewable energy

3.1 Financial Barriers

Despite the big innovations in the field of renewable energies, there is still a path to make clean energies, indeed, accessible. One of the major problems for achieving this objective is the financial barriers, which has not been cited in only 3 articles of the BP. Even having a bigger impact in underdeveloped and in developing countries, the economic obstacles have been revealed to be relevant in most countries studied by the articles [9]. For the developed countries studied the most critical financial barrier is the cost of renewable energy that is not yet competitive between the cost of

Table 1 List of barriers by category

Classes of barriers	Types of barriers	Articles
Economics	High initial investment costs	[9–19]
	Cos of system and technologies	[10, 19–27]
	Lack of financial support (institutions)	[11, 13, 17, 19, 20, 25, 27–31]
	Lack of financial policies	[22, 25, 27, 28, 32, 33]
	Insufficient fund (limited access to capital)	[19, 21, 22, 27, 33, 34]
	Obstacles for private investment	[11, 12, 23, 25, 34–36]
	Late financial return	[25, 31, 34]
	Expensive studies	[37]
	Small market	[34]
Technical and technologic	Lack of infrastructure and/or logistic	[11, 13, 22, 25, 26, 28, 31, 34, 35, 38]
	Lack or research	[20, 26, 28, 29, 31, 32, 35, 37]
	Lack of technologies and/or materials	[13, 16, 18, 21, 23, 25, 28, 31, 32, 34, 35, 37, 39]
	Lack of manpower (maintenance included)	[11, 18, 20, 21, 28, 31, 32, 35]
	Lack of documentation	[11, 16, 18–20, 26, 28, 31, 33]
	Lack of similar systems	[18, 32, 34]
	Climate changes	[37]
	Low efficiency	[13, 31, 32, 40]
	Competitiveness from fossil fuels	[20, 23, 25, 26, 33, 35, 41, 42]
	Need of large areas (implementation)	[11, 13, 43, 44]
	Problems in shift of energies	[28, 34, 41]
	Implementation since beginning of project	[16]
	Transportation problems	[29]
Political	Political instability	[19, 26, 31, 34, 36]
	Companies disagreements	[25, 38, 40, 45]
	Lack of public support	[16, 18, 23, 25, 29, 37, 46]
	Lack of policies	[11, 13, 16, 25, 26, 32–35, 37, 38, 40, 46]

(continued)

Table 1 (continued)

Classes of barriers	Types of barriers	Articles
	Complex institutional procedures	[11, 19, 23, 28, 31, 32, 34, 35, 37, 46]
	Non-defined responsibilities	[11, 18, 34, 36, 40]
	Lack of dissemination of information	[18]
	Insufficient resources	[13]
	Commercialization barriers	[33]
	Lack of knowledge between authorities	[34]
Social	Lack of knowledge of its importance	[11, 13, 18, 21, 23, 25, 26, 32, 34, 35, 38, 41, 46]
	Social insecurity	[29, 31]
	Costs	[21, 35]
	Preference for traditional	[18]
	Discomfort of nearby communities	[19]

fossil fuels that are already deployed [23, 34, 36, 47]. Either for the lack of large-scale production or the lack of specialized companies in the improvement and optimization of the needed materials, the cost of renewable systems becomes higher than fossil's [17, 18].

As for the underdeveloped countries the financial barriers comprehend the lack of investiments either from private electrical sector [35] and public [28].

In terms of cost for implementation, because they are relatively new technologies the necessary materials for installation are of difficult access several times and high costs [10]. Besides, the high costs of initial investment [17] and the late financial return [48] generates uncertainties for potential investors, mainly those who aren't aware of the long-term benefits of renewable energies [48].

Another problem related to its cost is that in many countries governments still gives subsides for fossil fuel production, an in this way they are cheaper and more competitive than renewable energies [12, 36, 37].

The lack of financial support and institutions focused on the area [22, 34, 46] is also shown as barrier for its development, and these institutions, when exist, are usually inefficient and ineffective, making the access to the capital difficult and making many projects unfeasible due to lack of funds [11, 20, 41].

3.2 Technical and Technological Barriers

The lack of infrastructure [21] and of requested technologies [10, 16] were two of the most technical problems mentioned. Renewable energies demand specific materials and technologies, which are not available in all countries, therefore many of them depend on the import of products [19]. Besides, even the countries who possess the means to manufacture the necessary parts still don't produce them in large scales, making them more expensive and their access even more difficult.

For being a new area, the number of researches and already installed systems are still low [16] and therefore, the data and documentations are also limited [36], which brings more doubts about the real cost, capacity and installation of these energies. This limited information also becomes a problem for when educating new professionals in the area, causing the lack of manpower [39] to be another big technical gap. Also, there is still no real estimative of the costs related to maintenance of the energy generation stations [17, 29] and high qualified employees for maintenance [49].

The competitiveness of fossil fuels is another big challenge. As it is already widely used, efficient and have its costs lower [17], the shift for renewable energies is seen as too risky, to the point that it's not worth it compared to an already stable and safe energy. The infeasibility of certain renewable energies also makes them less attractive: Energies like wind and hydroelectric demand specific environments and climate conditions, and can present efficiency changes according to the weather and time of the year [33]. Also, researchers point out the problem of physical space necessary for the implementation of certain types of energy as solar, that request large areas for panels in order of a 100% renewable matrix [40].

3.3 Political Barriers

Due to the high costs and difficulties in the implementation (which include the shift from fossil fuels to clean energies), renewable energies are not attractive for investors and companies [13]. Because of that, literature point out that it is important that government incentives exist, with the objective of stimulating and encouraging investments, research and also to facilitate the implementation of these systems [1, 43].

The lack of policies and institutions focused on renewable energies [15, 30] was one of the most mentioned barriers, as well as the large number of complex institutional procedures existing in the process of implementation [19, 50]. Besides, in several countries the responsibilities towards these energies are not clear, such as supervision, maintenance and necessary documentation.

Not only the lack of policies, but also the lack of information dissemination becomes an obstacle [16]. In countries where the population doesn't have knowledge about renewable energies, there is a lack of divulgation by the government.

The political instability, especially in undeveloped countries, has shown itself to be an extremely relevant problem [26, 32]. Several articles that leveled the importance of the existing barriers quoted political instability as being the main general barrier in the way of the installation of renewable energies [18].

3.4 Social Barriers

In several countries the lack of knowledge and information of the population about renewable energies [9, 51] was quoted as being one of the barriers with major impacts. There is a low acceptance and insecurity from society [32], either for not knowing the importance of having clean energy, the advantages of it or how these energies work. Thais makes much more difficult to make renewable energies projects feasible. In specific countries, the preference for traditional also impacts the population, as is the case in Sub-Saharan Africa, where they prefer a wood burning stove than changing for a more ecological way as the biogas [16].

4 Conclusion

From the study of the article of the bibliographic portfolio and the construction of the framework that systematizes the classes and types of barriers to the implementation of renewable energies, it was possible to verify that each barrier has different impacts in each country, showing that it is not suitable to have the same approach for all the situations. Besides, all the barriers relate and impact each other, as pointed out below:

Financial—The high initial costs make the development of needed material more difficult, generates low incentives for the government to invest in these technologies and discourages the population to ask for more renewable options.
Technical and Technological—The lack of specialized manpower and companies focused on renewable energies increases the costs of implementation and research, which causes most countries to resort to the importation of several materials. This avoids the population of having knowledge about the existence and functioning of clean energies, bringing preconceptions and insecurities.
Political—The lack of investments of the government towards renewable energies causes delays in the projects, research and even in its implementation. It also influences directly in the disinformation of the population about the importance of the subject, decreasing even more the research about the theme.
Social—The misinformation of the people causes in less availability of manpower for work and search about renewable energies, which ends up amplifying all the other barriers.

Given the encountered barriers, it is suggested for future research to understand how they can be overcome through empirical studies about the developed countries that have been living the transition of their energetic matrix for a mainly renewable basis. It is important to highlight that for this energetic matrix change to happen, society, financial entities, universities, research institutions and the government have responsibilities and important roles to be played.

References

1. Curtius, H.C., *The adoption of building-integrated photovoltaics: barriers and facilitators.* Renewable Energy, 2018. **126**: pp. 783–790.
2. BANK, W., *Global Tracking Framework 2017: Progress Towards Sustainable Energy*. World Bank, Washington, DC, April. https://doi.org/10.1596/978-1-4648-1084-8 *License: Creative Commons Attribution CC BY 3.0 IGO*. 2017.
3. Dedecca, J.G., R.A. Hakvoort, and J.R. Ortt, *Market strategies for offshore wind in Europe: A development and diffusion perspective.* Renewable and Sustainable Energy Reviews, 2016. **66**: pp. 286–296.
4. Thomé, A.M.T., R.L. Hollmann, and L. Carmo, *Research synthesis in collaborative planning forecast and replenishment.* Industrial Management & Data Systems, 2014. **114**(6): pp. 949–965.
5. Elmustapha, H., T. Hoppe, and H. Bressers, *Comparing two pathways of strategic niche management in a developing economy; the cases of solar photovoltaic and solar thermal energy market development in Lebanon.* Journal of cleaner production, 2018. **186**: pp. 155–167.
6. Tani, A., *A Strategic Niche Management approach for shaping bio-based economy in Europe.* Open Agriculture, 2018. **3**(1): pp. 98–109.
7. Bauknecht, D., G. Brunekreeft, and R. Meyer, *From niche to mainstream: The evolution of renewable energy in the German electricity market*, in *Evolution of Global Electricity Markets.* 2013, Elsevier. pp. 169–198.
8. DiEnna Jr., J.P. *Geothermal heat pumps—more than a niche.* in *Green Energy Times*. 2016.
9. Arshad, M. and B. O'Kelly, *Global status of wind power generation: theory, practice, and challenges.* International Journal of Green Energy, 2019. **16**(14): pp. 1073–1090.
10. Chakraborty, S., P. Sadhu, and U. Goswami, *Barriers in the advancement of solar energy in developing countries like India.* Problemy Ekorozwoju–Problems Of Sustainable Development, 2016. **11**(2): pp. 75–80.
11. How, B.S., et al., *An outlook of Malaysian biomass industry commercialisation: Perspectives and challenges.* RENEWABLE & SUSTAINABLE ENERGY REVIEWS, 2019. **113**.
12. Khan, Z. and A.A. Khan, *Current Barriers to Renewable Energy Development in Trinidad and Tobago.* Strategic Planning for Energy and the Environment, 2017. **36**(4): pp. 8–23.
13. Ma, L., J. Yu, and L. Zhang, *An analysis on barriers to biomass and bioenergy development in rural China using intuitionistic fuzzy cognitive map.* Energies, 2019. **12**(9).
14. Polzin, F., *Mobilizing private finance for low-carbon innovation—A systematic review of barriers and solutions.* Renewable & Sustainable Energy Reviews, 2017. **77**: pp. 525–535.
15. Rezaee, M.J., S. Yousefi, and J. Hayati, *Root barriers management in development of renewable energy resources in Iran: An interpretative structural modeling approach.* Energy Policy, 2019. **129**: pp. 292–306.
16. Rupf, G.V., et al., *Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal.* Renewable & Sustainable Energy Reviews, 2015. **52**: pp. 468–476.
17. Seetharaman, et al., *Breaking barriers in deployment of renewable energy.* Heliyon, 2019. **5**(1).
18. Shah, S.A.A., Y.A. Solangi, and M. Ikram, *Analysis of barriers to the adoption of cleaner energy technologies in Pakistan using Modified Delphi and Fuzzy Analytical Hierarchy Process.* Journal of Cleaner Production, 2019. **235**: pp. 1037–1050.

19. Sukamongkol, Y. *Barriers of the solar PV rooftop promoting in Thailand*. Energy Engineering Program, Faculty of Engineering, Ramkhamheang University, Bangkok, Thailand: Institute of Electrical and Electronics Engineers Inc.
20. Diógenes, J.R.F., J. Claro, and J.C. Rodrigues, *Barriers to onshore wind farm implementation in Brazil.* Energy Policy, 2019. **128**: pp. 253–266.
21. Fenton, P. and W. Kanda, *Barriers to the diffusion of renewable energy: studies of biogas for transport in two European cities.* Journal of Environmental Planning and Management, 2017. **60**(4): pp. 725–742.
22. Haas, J., et al., *Sunset or sunrise? Understanding the barriers and options for the massive deployment of solar technologies in Chile.* Energy Policy, 2018. **112**: pp. 399–414.
23. Karakaya, E. and P. Sriwannawit, *Barriers to the adoption of photovoltaic systems: The state of the art.* Renewable & Sustainable Energy Reviews, 2015. **49**: pp. 60–66.
24. Granoff, I., J.R. Hogarth, and A. Miller, *Nested barriers to low-carbon infrastructure investment.* Nature Climate Change, 2016. **6**(12): pp. 1065–1071.
25. Saculsan, P.G. *Analysis of the Constraints in the Renewable Energy Sector within a Multi-level Energy Transition Perspective (MLP): The Case of the Philippines.* Kyoto University, Kyoto, Japan: Institute of Physics Publishing.
26. Ullah, K., M.S. Raza, and F.M. Mirza, *Barriers to hydro-power resource utilization in Pakistan: A mixed approach.* Energy Policy, 2019. **132**: pp. 723–735.
27. Wyllie, J.O.Y., E.A. Essah, and E.L. Ofetotse, *Barriers of solar energy uptake and the potential for mitigation solutions in Barbados.* Renewable and Sustainable Energy Reviews, 2018. **91**: pp. 935–949.
28. dos Santos Carstens, D.D. and S.K. da Cunha, *Challenges and opportunities for the growth of solar photovoltaic energy in Brazil.* ENERGY POLICY, 2019. **125**: pp. 396–404.
29. Sato, T., et al. *A Challenge for Sustainable Electrification, Respecting the Local Tradition in Ciptagelar Village, West Java, Indonesia: Complementary Approach with a Private Company.* Institute of Decision Science for A Sustainable Society, Kyushu University, Fukuoka, 819-0395, Japan: Elsevier Ltd.
30. Shah, S.A.A. and Y.A. Solangi, *A sustainable solution for electricity crisis in Pakistan: opportunities, barriers, and policy implications for 100% renewable energy.* Environmental Science and Pollution Research, 2019.
31. Thapar, S., S. Sharma, and A. Verma, *Analysis of factors impacting wind and solar sectors—Challenges to sustainable development (Four Country Study).* Sustainable Development, 2019. **27**(3): pp. 481–511.
32. Ghimire, L.P. and Y. Kim, *An analysis on barriers to renewable energy development in the context of Nepal using AHP.* Renewable Energy, 2018. **129**: pp. 446–456.
33. Morales, S., et al., *An overview of small hydropower plants in Colombia: Status, potential, barriers and perspectives.* Renewable and Sustainable Energy Reviews, 2015. **50**: pp. 1650–1657.
34. Garcia, D.A., *Analysis of non-economic barriers for the deployment of hydrogen technologies and infrastructures in European countries.* International Journal Of Hydrogen Energy, 2017. **42**(10): pp. 6435–6447.
35. Anantharajah, K., *Governing climate finance in Fiji: Barriers, complexity and interconnectedness.* Sustainability (Switzerland), 2019. **11**(12).
36. Mokhtar, A. *Challenges of retrofitting affordable housing to net-zero carbon in the United Arab Emirates.* American University of Sharjah, Sharjah, United Arab Emirates: Institute of Physics Publishing.
37. Manaf, I.S.A., et al., *A review for key challenges of the development of biodiesel industry.* Energy Conversion and Management, 2019. **185**: pp. 508–517.
38. Arshad, M. and B. O'Kelly, *Global Status of Wind Power Generation: Theory, Practice and Challenges (pg 1, 2019).* International Journal of Green Energy, 2019. **16**(14): p. 1379.
39. Sindhu, S., V. Nehra, and S. Luthra, *Identification and analysis of barriers in implementation of solar energy in Indian rural sector using integrated ISM and fuzzy MICMAC approach.* Renewable and Sustainable Energy Reviews, 2016. **62**: pp. 70–88.

40. Gunther, M., *Challenges of a 100% renewable energy supply in the Java-Bali grid.* International Journal of Technology, 2018. **9**(2): pp. 257–266.
41. Okafor, A.O. and J.T. Martins, *Institutional stakeholder perceptions of barriers to Green IT policy in Nigeria.* International Journal of Technology Management and Sustainable Development, 2017. **16**(1): pp. 71–95.
42. Olowu, T.O., et al., *Future Challenges and Mitigation Methods for High Photovoltaic Penetration: A Survey.* ENERGIES, 2018. **11**(7).
43. Cheraghi, S., S. Choobchain, and E. Abbasi, *Investigation of entrepreneurship development barriers in the field of renewable energies technologies in developing countries: A case of iran.* International Journal of Scientific and Technology Research, 2019. **8**(3): pp. 160–170.
44. Linnerud, K. and E. Holden, *Investment barriers under a renewable-electricity support scheme: Differences across investor types.* Energy, 2015. **87**: pp. 699–709.
45. Chakraborty, S., P.K. Sadhu, and U. Goswami, *Barriers in the Advancement of Solar Energy in Developing Countries like India.* Problemy Ekorozwoju, 2016. **11**(2): pp. 75–80.
46. Desgain, D. and J. Haselip, *Barriers to the Transfer of Low-carbon Electricity Generation Technologies in Four Latin American Countries.* Energy Sources Part B-Economics Planning and Policy, 2015. **10**(4): pp. 348–360.
47. Jamil, M., F. Ahmad, and Y.J. Jeon, *Renewable energy technologies adopted by the UAE: Prospects and challenges—A comprehensive overview.* Renewable and Sustainable Energy Reviews, 2016. **55**: pp. 1181–1194.
48. Karatayev, M. and S. Hall, *Integration of wind and solar power in Kazakhstan: Incentives and barriers.* 2017, Taylor and Francis: School of Geography, University of Nottingham, UK, pp. 65–89.
49. Yaqoot, M., P. Diwan, and T.C. Kandpal, *Review of barriers to the dissemination of decentralized renewable energy systems.* Renewable & Sustainable Energy Reviews, 2016. **58**: pp. 477–490.
50. Nasirov, S., C. Silva, and C.A. Agostini, *Investors' perspectives on barriers to the deployment of renewable energy sources in Chile.* Energies, 2015. **8**(5): pp. 3794–3814.
51. Murombo, T., *Legal and policy barriers to renewable and sustainable energy sources in South Africa.* Journal of World Energy Law and Business, 2016. **9**(2): pp. 142–165.

Organizational Performances of Distributed Generation in Brazil Electric Utilities: A Balanced Scorecard Perspective

Carmen B. Rosa, Julio Cezar M. Siluk, Paula D. Rigo, Graciele Rediske, Heloísa P. Burin, and Leandro Michels

Abstract The transformation of the electricity sector towards a more diversified and sustainable electricity production has increase the importance of distributed generation. In Brazil, the electric power generation systems connected to the electric grid near the load center grow through the compensation of credits, a model that was only possible after ANEEL Normative Resolution. Although the systemic benefits associated with the expansion of distributed generation are evident, regarding the electric utilities is important to assess the challenges arising from the increased diffusion rate of these facilities. Given this scenario, for the utilities to achieve adequate performance and defend strategic positions in the electricity market, it is necessary to know and understand the dynamics of the business permeated by indicators capable of measuring and evaluating, in fact, their specific reality. Therefore, in this article, the use of a performance measurement system was developed based on the Balanced Scorecard precepts. Thirty-two objectives were selected through the methodology that associated with the Delphi method and allocated to the BSC divided into four traditional perspectives: Financial, Customer, Internal Process, and Learning and Growth.

Keywords Balanced scorecard · Organizational performances · Distributed generation

C. B. Rosa (✉) · J. C. M. Siluk · P. D. Rigo · G. Rediske · H. P. Burin
Production Engineering Postgraduate Program, Federal University of Santa Maria (UFSM), Santa Maria 97105-900, Brazil
e-mail: carmen.b.rosa@ufsm.br

L. Michels
Electrical Engineering Postgraduate Program, Federal University of Santa Maria (UFSM), Santa Maria 97105-900, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_9

1 Distributed Generation in Brazil

The search for development increasingly brings the current scenario closer to the depletion of natural resources aimed at generating electricity [1]. The transition to a mixed energy system with more significant renewable sources is underway, supported by technological advances and demand projections [2]. Electric power systems have traditionally been designed hierarchically, where large centers produce energy, transmission systems transport the energy generated in high voltage to consumers distributed in low voltage. However, in recent decades, many countries have started the process of liberalizing their electrical systems and opening access to transmission and distribution grid [2].

Distributed Generation (DG) represents the new configuration for the electricity sector [3]. According to the Resolution of the National Electric Energy Agency (ANEEL) 482/2012 the literal definition of DG means generation of electricity that is injected directly into the distribution electric utilities grid [3]. The environmental appeal that DG has acquired in recent years does not derive directly from the concept of distributed generation, however it is a construction, varying from a myriad of factors, such as the location of the grid, the voltage level, the resource and the technology used to generate electricity, installed capacity, environmental impact and economic aspects [4].

Despite Brazil being the fifth largest country in the world in territorial area, with some remote regions, historically the country has never benefited from decentralized electrical systems and chose to build large hydroelectric plants and extend long transmission lines [5]. Only recently, with environmental pressure and the impossibility of investing in expanding the centralization of power generation by water sources, the Brazilian government is turning its attention to the distributed generation. The DG has an important impact on the entire power transmission and distribution system as it changes the design of the current system and becomes a key issue of high criticality [6]. The resolution proposed the creation of an energy compensation system, the Net Metering. The owner of a small renewable source generator (Wind, Photovoltaic Systems, Biomass, Small Hydroelectric Plants) does not need to consume all the energy produced at the time of generation, because they will be able to inject into the power grid to receive kWh credits on the bill [4]. The regulatory agency published ANEEL Normative Resolution 687/2015, in this regulatory, microgeneration is characterized by an installed power of less than or equal to 75 kW, and minigeneration is characterized by an installed power of greater than 75 kW and less than or equal to 5 MW [7].

The photovoltaic energy (PV) represents over 88% of the distributed generation in the country. The scenario of PV in Brazil constitutes promising expectations, due to the advantageous geographic location—with almost all its territory located in tropical range—to capture solar energy, where the degree of incidence of solar rays in this region is almost perpendicular, favoring the high levels of solar irradiation [8]. The average annual irradiation in Brazil varies between 1200 and 2400 kWh/m^2/year, being above the average of Europe [8]. With all this potential for generation of energy from the solar source, according to the records of the ANEEL, the country presented a total of installations of small-scale power generation solar systems in Brazil in November 2019 of 144,209, which corresponds to 1.67 GW of power [9].

The advance of distributed generation implies transformations in the electricity sector and especially in the distribution segment. This large insertion of DG and Prosumers (Producers + Consumers) in distribution systems has led to a major change in the traditional electricity business model, as the consumer becomes part of its traditional value chain, offering new services such as voltage control services, system information, rapid demand response, storage capacity, and more [10]. However, this generation diffusion dynamics, focused on the most representative source, photovoltaic solar, tends to have significant impacts on the electricity sector.

The current transition of the electricity utility structure to a new model is being driven by economic and technological forces that will ultimately drive change [2]. In 1982, Lovins and Lovins [11] developed a framework that showed how utilities can change from "sellers of kilowatt-hours to funders of lower-cost energy investments". More recently, De Fusco et al. [12], Facchinetti et al. [13] proposed conceptual frameworks for emerging models of energy utility companies and business innovations. Helms [14] identified the shift from tangible to intangible assets as the most important barrier for utilities to become energy service providers. Burger and Luke [15] state in their study that regulatory factors are more important than technological factors in driving a shift to distributed energy resources. Finally, Richter identifies 10 factors for utilities to invest in these technologies, such as marketing and public relations [16].

In general, the conclusions of the surveys developed with the aim of explaining the scenario of European utilities bring good reflections for the moment of utilities in Brazil, from the perspective of DG management. The DG in Brazil is inserted in a moment of ideation, mainly because it is exponentially expanding, which forces electric utilities to perform their processes with maximum efficiency. In view of this scenario, for companies defend strategic positions in the electricity market, it is necessary to know and understand the dynamics of the actors in the business allocated in performance models capable of measuring and evaluating specific reality.

1.1 Balanced Scorecard: Theoretical Background

The Balanced Scorecard (BSC) emphasizes on performance measurement and evaluation of the defined strategies deployed by the organization. BSC technique was developed by Kaplan and Norton [17] as a strategic performance management tool to help decode organizational strategies into actions plans. The multidimensional BSC framework comprises four perspectives—Financial, Clients, Internal Processes and Learning and Growth—scorecard strategies contribute to the implementation of a consistent strategy. Executives use the BSC as an organizational tool for important management processes: establishment of individual and team goals, remuneration and allocation of resources, planning, budget feedback and strategic learning [18].

The Sánchez-Ortiz research's et al. [18] reflects the BSC's ability to adapt and model, showing how it can be used to analyze and define the strategic objectives followed by the five major electricity generation and distribution companies in Spain from the strategies and objectives of each electric power company identified individually, without focus in DG.

In this study, the concept of BSC is used for the design of an organizational performance measurement model to support the management of DG in electric power utilities in Brazil. The essence of the BSC implies the decision of organizations based on the requirements of the strategy, hence the term organization focused on strategy. The use of the original model of the BSC for a public or regulated organization should establish perspectives that adjust more to its reality, always maintaining a logical relationship of cause and effect.

2 Methodological Structure Proposed

The methodology proposed for this study is based on three phases, according to the Fig. 1.

Systematic literature reviews, whether quantitative or qualitative, are important tools for drawing conclusions from large bodies of research, enabling advancement of scientific theory and evidence-based practice [19]. The systematic review started with the elaboration of the protocol reproduction strategy based on the identification of the determined study theme from the execution of primary studies and was divided into three keywords: distributed generation, business, utilities. The search was without time frame, as it is a recent term and aims to verify the evolution of publications. The search terms were investigated in the databases Scopus and Web of Science. The advanced search in the Scopus base considered the filter: TITLE-ABS-KEY (utilities AND "Distributed generation" AND "business"). A total of 126 articles were found with search specifications. The database Web of Science performed the search based on the selection: TS: (utility*AND Distributed generation AND business), a total of 46 articles were found.

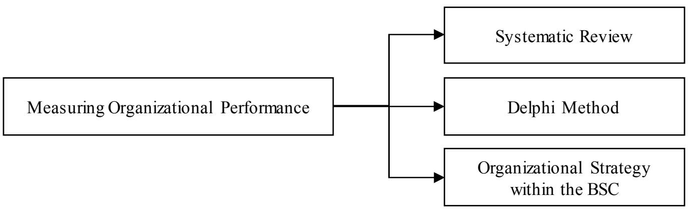


Fig. 1 Schematic representation of the methodological structure

The metadata for 172 articles have been added to the software Mendeley®, 61 were duplicate articles. The selection and extraction of the relevant data from the 111 articles took place by reading all the publications in full. However, 61 studies were selected that were aligned with the research question. The compilation of the results of the bibliographic research together with the documentary research was structured in objectives allocated in the four perspectives of the BSC.

The second phase of the research was with the construction of a structured semi-open questionnaire, which was sent to six specialists in the area of DG (three representatives of electric utilities, two researchers in the area and one representative from ANEEL) the in order to verify the opinion against the selected objectives. The Delphi method was used evaluation of the returned questionnaires, this method is an appropriate approach to analyze the opinions of experts to achieve an understanding of future developments and to aggregate opinions and judgments in a context of collective decision. The appropriate selection of respondents from the survey instrument is a key stage in the design of the Delphi method. The recruitment of participants is usually informed by the level of their domain knowledge in the relevant topic area [20]. In terms of the number of panelists needed, the suggested range is: 5–20, not >50 [20].

Subsequent to the evaluation of the return of the Delphi instrument, it was possible to refine the objectives and validate their subdivision from the perspective of the BSC. Such refinement allowed the previous construction of a model for monitoring the organizational performance of the generation distributed in the electric utilities. At this point, the research objective is resumed and the result obtained satisfies the research problem defined in the introductory section of this study.

3 Results and Discussion

3.1 Application of BSC in Distributed Generation in Electric Utilities

In view of the objective of the study, the selection of objectives consisted of a critical reading of the articles selected through the protocol of systematic literature review, in addition to the complement of the document search in technical notes and regulatory standards of the electric sector in Brazil. The Table 1 presents the objectives most important to characterize the dimension that indicates how the transformation of the strategy results in economic success.

To illustrate the financial dimension, Alhamwi et al. [38] distributed indicators that provide a return on capital employed. The research of Figge et al. [23] was concerned with characterizing how the transformation of the strategy can result in economic success, defining economic success as greater profitability. In international scenario, Richter [27] argues that the increase in electricity generation by individuals leads to a decreasing demand for electricity from energy distribution companies

Table 1 Objectives selected for financial perspective

Goal	Question to be answered?	Authors
Improve profitability by installing microgeneration and mini-generation	Is the organization profitable?	[21–27]
Decrease costs associated with checking micro and mini-generation projects	Is the cost target reached?	[22, 24, 27–32]
Reduce operating costs for microgeneration and mini-generation	Is the cost target reached?	[22, 24, 27–32]
Reduce costs with rework in the distributed generation sector	Is the cost target reached?	[21, 33, 34]
Reduce costs with distributed generation in the legal department	Is the impact of legal processes linked to DG calculated?	[18, 35, 36]

and, consequently, to the erosion of their revenues. In general, the identification of the objectives allocated in the financial perspective associated the reality of the management of DG in the utilities with the need to guarantee economic sustainability.

The Table 2 presents the objectives associated with the second perspective of the BSC, the dimension of the customers.

How efficient management of stakeholders in the electricity utility business is necessary for the organization's long-term profitability and survival in the market [44], the second perspective includes the company's external stakeholders, in particular customers. This approach makes it possible to articulate the strategy of customers and markets towards the financial results desired by the organization. In fact, the BSC allows us to understand how the integration of customer aspects can contribute to economic performance.

Table 3 identifies the objectives associated with the third perspective of the BSC, the dimension of Internal Processes.

It is known that the use of BSC can represent and provide strategies according to each business, instead of offering the simple combination of financial and non-financial indicators classified by individual categories [56]. According to the authors' arguments about the perspective of internal processes, organizational skills, and learning contribute to the organization's ability to implement internal business processes so that, finally, value creation can take place.

The fourth perspective of the BSC involves measuring the performance of key elements of the organization's ability to compete, improve processes and, ultimately, create value, describe in Table 4.

According to the authors Farooq and Hussains [60] this perspective is the backbone of a successful BSC, as it involves employee skills, motivation, and information systems. All authors mentioned in Table 4 define that greater motivation and employee satisfaction are a key factor in the success of a corporate strategy. The essence of the BSC implies the insertion of the organization's strategy at the center of management processes.

Table 2 Objectives selected for customers' perspective

Goal	Question to be answered?	Authors
Map customers with micro-generation systems	Are all micro-generation customers georeferenced?	[6, 39, 40]
Map customers with mini-generation systems	Are all mini-generation customers georeferenced?	[6, 39, 40]
Comply with the deadlines for connecting the system to the power grid as established by ANEEL	Does the utilities comply with the deadlines established by ANEEL?	[5, 37, 41–43]
Strengthen the utilities's image to stakeholders	Is the utilities's image satisfactory?	[18, 44, 45]
Promote energy efficiency campaigns targeting residential, commercial and industrial customers	Does the utilities promote energy efficiency campaigns?	[46–48]
Promote greater clarity in the relationship of the generation distributed between the utilities and customers	Does the utilities establish clarity in the relationship with DG customers?	[18, 37, 45, 49]
Periodically control customers with remote self-consumption	Is there a periodic control of customers with remote self-consumption?	[6, 39, 40, 50]
Periodically control customers with multiple consumer units	Is there a periodic control of customers with multiple consumer units?	[6, 39, 40, 50]
Periodically control customers with shared generation	Is there a periodic control of customers with shared generation?	[6, 39, 40, 50]
Ensure microgeneration and mini-generation customer satisfaction	Does the utilities guarantee its customer's satisfaction with DG?	[18, 49]

Once the search for objectives is finished, the Delphi method was designed to improve a group's access to multiple interpretations and views on the topic under discussion. The Delphi instrument was designed in the format of Fig. 2 to instruct specialists to answer a sequence of questions about the adequacy of each objective allocated in the respective four perspectives of the BSC.

The consensus verification was achieved in the first round of the Delphi instrument's application to the six specialists. The instrument returned according to Fig. 3.

The six reports of the specialists were translated graphically and treated through content analysis. There was full consensus on the adequacy of 31 of the 33 objectives allocated in the four perspectives of the BSC. The incongruity of objective 1.1 was verified by 67% of the experts, their opinion was asserted through the interpretation of the business model of the electric energy utilities in Brazil. With that, the decision was made to exclude objective 1.1 from the proposed BSC model. Regarding objective 3.1, this was indicated by an expert as inadequate because it does not cover aspects

Table 3 Objectives selected for internal processes perspective

Goal	Question to be answered?	Authors
Periodically calculate the occupancy rate of employees responsible for micro and mini-generation	Is there DG process control through a workflow known to everyone at the dealership?	[52, 53]
Standardize service to microgeneration and mini-generation customers when requesting access	Is there a standardization in the requests for access to DG customers?	[6, 54–56]
Standardize service to microgeneration and mini-generation customers in the evaluation of projects and connection of the system to the electricity grid	Is there a standardization in the assessments and connection of the DG system in the electric grid?	[6, 54–56]
Control all distributed generation processes in the company through the disclosure of a workflow	Control all distributed generation processes in the company through the disclosure of a workflow	[51, 52, 54]
Guarantee the quality of access of the microgeneration and mini-generation system to the electricity grid	Does the utilities guarantee quality in the DG system's access to the power grid?	[18, 55, 57]
Provide service that ensures greater clarity to DG consumers about their duties to the quality and safety of the electrical grid	Does the utilities offer clarity to the consumer of DG in defining its duties towards the quality and safety of the electric grid?	[19, 56, 57]
Record the technical inconsistencies of the micro-generation and mini-generation projects in order to generate a database to report recurring practices	Is there a record of technical inconsistencies in DG projects in a database?	[6, 54–56]
Standardize the technical evaluations of microgeneration and mini-generation projects	Is there a standardization in the technical evaluations of DG projects?	[6, 54–56]
To be a reference in services in the microgeneration and mini-generation sector	Does the utilities consider itself a reference in service in the DG sector?	[56, 57, 60]
Ensure continuous improvement in the efficiency of distribution and commercialization of electricity by distributed generation	Does the utilities guarantee continuous improvement in the efficiency of the distribution and sale of electricity by DG?	[18, 57]
Propose synergy projects with other electricity supply companies to identify levers for improvement	Does the utilities propose synergy projects in DG with other electricity utilities?	[18]
Ensure effort in R&D&I in the area of distributed generation	Does the utilities guarantee effort in R&D&I in the DG area?	[18, 52]

Table 4 Selected objectives for learning and growth perspective

Goal	Question to be answered?	Authors
Develop skills in microgeneration and mini-generation	Does the utilities develop skills in the DG area?	[44, 59]
Create employee awareness to act responsibly	Does the utilities create awareness among employees to act responsibly?	[6, 58, 60]
Motivate employees to improve results	Does the dealership motivate employees in search of better results in DG?	[6, 44, 60]
Provide empowerment and alignment of micro and mini-generation employees	Does the utilities propose empowerment and alignment of DG employees?	[58, 60]
Propose workforce recycling	Does the utilities propose workforce recycling?	[6, 24, 58]
Promote computerization of employees	Does the utilities propose computerization of DG employees?	[44, 60]

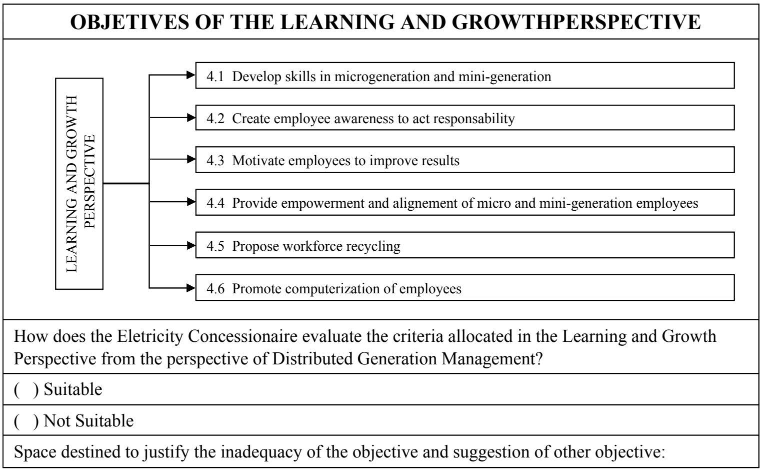


Fig. 2 Delphi instrument—learning and growth perspective

Specialist: Electric Utility 2

Return date of the Delphi Questionnaire: September 23, 2019 at 3:37 pm

Evaluation summary: Review the objective criterion 1.1.

Comments: Dear, questionnaire answered. I understand that in other contexts it is feasible to make GD profitable by offering services, in Brazil, to make GD profitable would be to better manage "costs and investments, and this is configured in objetives 1.2 and 1.3".

Fig. 3 Example expert response to Delphi instrument that go beyond the occupancy rate of DG employees. For this purpose, the criterion was replaced by: *3.1—Periodically calculating the Index of Global Operating Income (IROG) for microgeneration and mini-generation services*. The justification for such an agreement decision, without the need for another round to establish consensus, is that the initial proposal to calculate only the occupation of employees is directly associated with the calculation of the overall operating income, which also considers the efficiency of the equipment for planning the activities that make up the DG process at the utilities.

The set of objectives identified by the systematic literature review and submitted to the experts' evaluation comprised the methodization of a model based on the BSC. The research relevance was justified by the situation of the continuous evolution of the electric sector in Brazil. Since it was necessary to acquire new contours, especially concerning that necessary knowledge of state of the art to understand the management practices of distributed generation in electricity utilities, as well as to design and build new artifacts that aim to contribute to the organizational performance for the advancement of DG in Brazil.

Finally, the research contributions are beyond the interests of the utilities, which can be extendable to the: regulatory agency interest, in the construction of a metric to evaluate the utilities performance in the segment of microgeneration and mini-generation; researchers interest, with the gaps identification in technical and managerial studies; and, customer interest, with the partnership disclosure between universities and electric utilities for the benefit of the sector development to guide future regulatory balance decisions, in order to guarantee customer satisfaction.

4 Conclusions and Implications

The study focuses on the development of a useful model organizational support DG management in Brazil's Electric Utilities. The application of BSC has substantially contributed to the understanding of a framework that incorporates essential elements of decision making pertinent to develop distributed generation.

The utilities do not recognize microgeneration and mini-generation as an independent process in the company. There is not a sequence of activities carried out in a standardized way, aiming at generating results for the customer, from the beginning of the access request to the delivery of the product (the connection of the system to the power grid). However, there was an interest of all managers who contacted face-to-face meetings to build a DG sector standardization supported by the deliveries of this study.

This decision was a consequence of the utilities perception that ANEEL, in the short term, will require an efficient positioning of DG in companies, mainly with approval of the increase in costs related to the use of the distribution grid and the charges in the tariff paid by consumers who have a distributed generation system. It is also worth noting that the limitations of the research are the degree of importance of each objective. This can be differentiated with the use of a Multiple-criteria decision-making in order to effectively measure the performance of DG management in electric power utilities of Brazil.

Acknowledgements The authors thank INCTGD, CAPES, CNPq and FAPERGS for the financial support received for the development of this work. Michels and Siluk was supported by a research grant of CNPq—Brasil. The present work was carried out with the support of the INCTGD and the financing agencies (CNPq process 465640/2014-1, CAPES process No. 23038.000776/2017-54 and FAPERGS 17/2551-0000517-1).

References

1. Khoodaruth, A., Oree, V.: Exploring options for a 100% renewable energy system in Mauritius by 2050. Utilities Policy (44), 38–49 (2017).
2. Brummer, V.: Of expertise, social capital, and democracy: Assessing the organizational governance and decision-making in German Renewable Energy Cooperatives. Energy Research & Social Science (37), 111–121 (2018).
3. Bayod-Rújula, A.: Future development of the electricity systems with distributed generation. Energy (34), 377–383 (2009).
4. BRASIL, Agência Nacional de Energia Elétrica (ANEEL): Resolução Normativa no. 482, de 17 de abril de 2012.
5. De Faria, H., Trigoso, F.B.M., Cavalcanti, J.A.M: Review of distributed generation with photovoltaic grid connected systems in Brazil: Challenges and prospects. Renewable and Sustainable Energy Reviews (75), 469–475 (2017).
6. Picciariello, A., Vergara, C., Reneses, J.: Electricity distribution tariffs and distributed generation: Quantifying cross-subsidies from consumers to prosumers. Utilities Policy (37), 23–33 (2015).
7. BRASIL, Agência Nacional de Energia Elétrica (ANEEL): Resolução Normativa no. 687, de 24 de Novembro de 2015.
8. Pereira, E.B., Martins, F.R., Gonçalves, A.R., Costa, R.S., Rutter, R., Tiepoldo, G.M.: Atlas Brasileiro de Energia Solar; 2nd edn. INPE, São José dos Campos (2017).
9. BRASIL, Homepage https://app.powerbi.com/view?r=ey, last accessed 2019/12/16
10. Daza, E.: Determinação de arranjos regulatórios e econômicos para viabilizar investimentos em sistemas de armazenamento de energia em redes de distribuição de energia elétrica. Tese de Doutorado, Programa de Pos-Graduação em Engenharia Elétrica. Universidade Federal de Santa Maria (2018).
11. Lovins, A.B., Lovins, L.H.: Electric utilities: Key to capitalizing the energy transition. Technological Forecasting and Social Change (22), 153–166 (1982).
12. De Fusco, L.; Lorenzi, G.; Jeanmart, H.: Insight into electric utility business models for high-share renewables and storage integration. In: Proceedings of the 2016 13th International Conference on the European Energy Market, pp. 1–5. IEEE (2016).
13. Facchinetti, E., Sulzer, S.: General Business Model Patterns for Local Energy Management Concepts. Frontiers in Energy Research (4) (2016).
14. Helms, T.: Asset transformation and the challenges to servitize a utility business model. Energy Policy (91), 98–112 (2016).
15. Burger, S.P., Luke, M.: Business models for distributed energy resources: A review and empirical analysis. Energy Policy (109), 230–248 (2017).
16. Richter, M.: Business model innovation for sustainable energy: how German municipal utilities invest in offshore wind energy. International Journal of Technology Management (63) (2013).

17. Kaplan, R.S., Norton, D.P.: The Balanced Scorecard—Measures That Drive Performance. 1st edn. H.B, Boston (1992).
18. Sánchez-Ortiz, J., García-Valderrama, T., Rodríguez-Cornejo, V.: Towards a balanced scorecard in regulated companies: A study of the Spanish electricity sector. The Electricity Journal (29), 36–43 (2016).
19. Şener, Ş.E.C., Sharp, J.L., Anctil, A.: Factors impacting diverging paths of renewable energy: A review. Renewable and Sustainable Energy Reviews (81), 2335–2342 (2018).
20. Powell, C.: The Delphi Technique: myths and realities. Journal of advanced nursing (4), 376–382, (2003).
21. Nicoletti Junior, A., de Oliveira, M.C., Helleno, A.L.: Sustainability evaluation model for manufacturing systems based on the correlation between triple bottom line dimensions and balanced scorecard perspectives. Journal Cleaner Production (190), 84–93 (2018).
22. Antolín-López, R., Delgado-Ceballos, J., Montiel, I.: Deconstructing corporate sustainability: a comparison of different stakeholder metrics. Journal Cleaner Production (136), 5–17 (2016).
23. Figge, F., Hahn, T., Schaltegger, S., Wagner, M.: The Sustainability Balanced Scorecard—linking sustainability management to business strategy. Business Strategy and the Environment (11) 269–284 (2002).
24. Dinçer, H., Hacıoğlu, Ü., Yüksel, S.: Balanced scorecard based performance measurement of European airlines using a hybrid multicriteria decision making approach under the fuzzy environment. Journal of Air Transport Management (63), 17–33 (2017).
25. Buyya, R., Sulistio, A.: Service and utility oriented distributed computing systems: Challenges and opportunities for modeling and simulation communities. In: 41st ANNUAL SIMULATION SYMPOSIUM, pp. 68–81. IEEE, USA (2008)
26. Kamali, M., Hewage, K.: Development of performance criteria for sustainability evaluation of modular versus conventional construction methods. Journal Cleaner Production (142), 3592–3606 (2017).
27. Richter, M.: German utilities and distributed PV: How to overcome barriers to business model innovation. Renewable Energy (55), 456–466 (2013).
28. Hsu, C.-W., Hu, A.H., Chiou, C.-Y., Chen, T.-C.: Using the FDM and ANP to construct a sustainability balanced scorecard for the semiconductor industry. Expert Systems with Applications (38), 12891–12899 (2011).
29. Azevedo, S.G.: Accelerating the transition towards sustainability dynamics into supply chain relationship management and governance structures. Journl Cleaner Production (112), 1813–1823 (2016).
30. Windmark, C., Andersson, C.: Cost assessment of a production system: A method targeting a product's aggregated value stream costs. Procedia Manufacturing (25), 231–238 (2018).
31. Sioshansi, F.P.: Electricity utility business not as usual. Economic Analysis and Policy (48), 1–11 (2015).
32. Love, P.E.D., Smith, J.; Ackermann, F., Irani, Z.: Making sense of rework and its unintended consequence in projects: The emergence of uncomfortable knowledge. International Journal of Project Management (37), 501–516 (2019).
33. Jaber, M.Y., Guiffrida, A.L.: Learning curves for imperfect production processes with reworks and process restoration interruptions. European Journal of Operational Research (189), 93–104 (2008).
34. Heldeweg, M.A.: Legal regimes for experimenting with cleaner production—Especially in sustainable energy. Journal Cleaner Production (169), 48–60 (2017).
35. BRASIL, Agência Nacional de Energia Elétrica (ANEEL), Módulo 3 PRODIST -Acesso ao Sistema de Distribuição (2016).
36. Hansen, E.G., Lüdeke-freund, F., Quan, X.I., West, J.: Beyond Technology Push vs Demand Pull: The Evolution of Solar Policy in the U.S. Germany and China. In: Proceedings of the TECHNOLOGY ENGINEERING MANAGEMENT CONFERENCE, pp. 1–6, IEEE, USA (2017).
37. Maria Jebamalai, J., Marlein, K.; Vandevelde, L.: An automated GIS-based planning and design tool for district heating: Scenarios for a Dutch city. Energy (183), 487–496 (2019).

38. Alhamwi, A., Medjroubi, W., Vogt, T., Agert, C.: Development of a GIS-based platform for the allocation and optimisation of distributed storage in urban energy systems. Applied Energy (251), 223–289 (2019).
39. BRASIL, Agência Nacional de Energia Elétrica (ANEEL), Cadernos Temáticos: Micro e Minigeração Distribuída—Sistema de compensação de energia elétrica. (2016)
40. Gucciardi Garcez, C.: Distributed electricity generation in Brazil: An analysis of policy context, design and impact. Utilities Policy (49), 104–115(2017).
41. Jannuzzi, G. de M., Melo, C.A.: Grid-connected photovoltaic in Brazil: Policies and potential impacts for 2030. Energy for Sustainable Development (17), 40–46 (2013).
42. Journeault, M.: The Integrated Scorecard in support of corporate sustainability strategies. Journal Environmental Management (182), 214–229 (2016).
43. Garlet, T.B., Ribeiro, J.L.D., de Souza Savian, F., Mairesse Siluk, J.C.: Paths and barriers to the diffusion of distributed generation of photovoltaic energy in southern Brazil. Renewable and Sustainable Energy Review. (111), 157–169 (2019).
44. Sebastian Oliva, H.: Residential energy efficiency and distributed generation—Natural partners or competition? Renewable and Sustainable Energy Review (76), 932–940 (2017).
45. Alqahtani, B.J., Patiño-Echeverri, D.: Combined effects of policies to increase energy efficiency and distributed solar generation: A case study of the Carolinas. Energy Policy (134), 112–135 (2019).
46. Lund, P.D., Lindgren, J., Mikkola, J., Salpakari, J.: Review of energy system flexibility measures to enable high levels of variable renewable electricity. Renewable and Sustainable Energy Review (45), 785–807 (2015).
47. Sioshansi, F., Guimarães, L.N.: Challenges to the Promotion of Distributed Energy Resources in Latin America: A Brazilian Case Study. Consumer, Prosumer, Prosumager (198), 235–258 (2019).
48. Jamal, T., Urmee, T., Calais, M., Carter, C.: Technical challenges of PV deployment into remote Australian electricity networks: A review. Renewable and Sustainable Energy Review (77), 1309–1325, (2017).
49. Dinçer, H., Yüksel, S., Martínez, L.: Balanced scorecard-based analysis about European energy investment policies: A hybrid hesitant fuzzy decision-making approach with Quality Function Deployment. Expert Systems with Applications (115), 115–152 (2019).
50. Dinçer, H.; Yüksel, S. Multidimensional evaluation of global investments on the renewable energy with the integrated fuzzy decision-making model under the hesitancy. International Journal of Energy Research (43), 1775–1784 (2019).
51. Ekoe A Akata, A.M., Njomo, D., Agrawal, B.: Assessment of Building Integrated Photovoltaic (BIPV) for sustainable energy performance in tropical regions of Cameroon. Renewable and Sustainable Energy Review (80), 1138–1152 (2017).
52. Agrawal, S., Singh, R.K., Murtaza, Q.: Outsourcing decisions in reverse logistics: Sustainable balanced scorecard and graph theoretic approach. Resources, Conservation and Recycling (108), 41–53 (2016).
53. Xia, D., Yu, Q., Gao, Q., Cheng, G.: Sustainable technology selection decision-making model for enterprise in supply chain: Based on a modified strategic balanced scorecard. Journal Cleaner Production (141), 1337–1348 (2017).
54. Rabbani, A., Zamani, M., Yazdani-Chamzini, A., Zavadskas, E.K.: Proposing a new integrated model based on sustainability balanced scorecard (SBSC) and MCDM approaches by using linguistic variables for the performance evaluation of oil producing companies. Expert Systems with Applications (41), 7316–7327 (2014).
55. Kayaga, S.M., Kingdom, W., Jalakam, A.: Organisational design for improved performance of urban water utilities in developing countries. Utilities Policy (50), 49–59 (2018).
56. Acuña-Carvajal, F., Pinto-Tarazona, L., Barros-Castro, R., Palacio, K.: An integrated method to plan, structure and validate a business strategy using fuzzy DEMATEL and the balanced scorecard. Expert Systems with Applications (122), 351–368 (2019).
57. Picciariello, A.; Vergara, C.; Reneses, J.; Frías, P.; Söder, L. Electricity distribution tariffs and distributed generation: Quantifying cross-subsidies from consumers to prosumers. Utilities Policy (37), 23–33 (2015).

58. Mendes, P., Santos, A.C., Perna, F., Ribau Teixeira, M.: The balanced scorecard as an integrated model applied to the Portuguese public service: a case study in the waste sector. Journal Cleaner Production (24), 20–29 (2012).
59. Tubis, A., Werbińska, S.: Balanced Scorecard use in Passenger Transport Companies Performing at Polish Market. Procedia Engineering (187), 538–547 (2017).
60. Farooq, A., Hussain, Z.: Balanced scorecard perspective on change and performance: a study of selected Indian companies. Procedia—Social and Behavioral Sciences (24), 754–768 (2011).

EPQ Model with Partial Backordering Considering Environmental Aspects and Stochastic Demand

Maria Angélica Silva, Itaiane de Paula, and Adriana Leiras

Abstract Due to the great concern with sustainable development, new Economic Production Quantity (EPQ) models are no longer restricted only to traditional economic issues. However, they also focus on sustainability issues, especially regarding environmental aspects. However, the studies addressing the EPQ models together with sustainable issues, remain poorly explored in the literature. Still, these theoretical EPQ models mostly consider essential aspects which simplify the real-life conditions, such as deterministic demand. Thus to fill this gap, the present paper proposes an EPQ model with partial backorder considering environmental issues and stochastic demand, addressing, therefore, more realistic aspects of the real world. To find the optimal solution, we solve the maximisation problem, and we provide a numerical example with sensitivity analysis. We conclude that demand is the parameter that most affects the total profit.

Keywords EPQ · Environmental aspects · Stochastic demand

1 Introduction

The Economic Order Quantity (EOQ) proposed by Harris [1] is the first in the literature on inventory management that seeks to minimise the costs (see [2]). From this model, several extensions have emerged, such as the Economic Production Quantity (EPQ), idealised by Harris [3]. Subsequently, various researchers have expanded these initial models, as Taft [4] for EOQ, and Camp [5] and Wilson [6] for EPQ.

M. A. Silva (✉) · I. de Paula · A. Leiras
Pontifical Catholic University of Rio de Janeiro—PUC-Rio, Rua Marquês de São Vicente, 255, Rio de Janeiro, Brazil
e-mail: mari_angelicags_94@hotmail.com

I. de Paula
e-mail: itaianedepaula@outlook.com.br

A. Leiras
e-mail: adrianaleiras@puc-rio.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_10

One of the most common assumptions of the EPQ/EOQ models considers the possibility of shortages, which is one of the main issues in inventory management [7]. In this scenario, it is up to the customers to choose to wait or not for receiving the orders in the next period. If the customer decides to hold—and receive their orders in the upcoming period—the orders become backorders. Otherwise, if only some customers are willing to wait, we have partial backorders and lost sales for those who are not willing to wait.

Fabrycky and Banks [8] and Ali [9], respectively, developed the first extensions of EOQ-PBO and EPQ-PBO, which have omitted the numerical expressions used. Thus, Montgomery, Bazaraa and Keswani [10] and Rosenberg [11] were the first to demonstrate the mathematical resolution for EOQ-PBO. These models include fixed costs per unit and established annually backorder costs. Park [12] also studied the EPQ-PBO model, but the author did not consider the fixed price per unit.

Subsequently, Mak [13] creates the first extension of EPQ-BPO, in which the lack of stock is partial. Zeng [14] also considers EPQ-BPO identifying the conditions under which the applications with incomplete delays exceed the total demands with lag. Pentico and Drake [7] use the same cost structures of Park [12] for EOQ-BPO, including a missing fixed cost per unit. Bera et al. [15], Taleizadeh and Pentico [16], and Salehi and Taleizadeh [17] are examples of other researches that propose extensions to the EOQ-PBO model. Cunha et al. [18] develop an EPQ-PBO model, addressing other variables with impacts on the total cost and Taleizadeh et al. [19] consider sustainable aspects together with the partial backorder.

As to the use of stochastic demand, many papers present this type of extension to the basic model of EOQ (see [20–22]) and EPQ (see [23]). Further research analysing the use of stochastic demand in EPQ models was carried out, as they represent the majority of current market demands (see [24]). Kumar et al. [25] address orders with partial delays, and Digiesi et al. [26] consider sustainability aspects. Ribas et al. [27] use three mathematical models to deal with internal and external uncertainties, for operational planning of oil refineries, based on stochastic programming and robust programming. Leiras et al. [28] propose linear programming models to integrate the tactical and operational planning of multisite refining networks, incorporating uncertainty into parameters. Roy et al. [29] create an EPQ model considering demand as linear, whereas Sana [30] creates an EPQ model considering stochastic demand, with several distributions, including exponential distribution. Pal et al. [31] study an EPQ model for items with stock-dependent stochastic demand. Pal et al. [32] and Maddah and Noueihed [33] add demand as a random variable to the EOQ model.

Regarding the environmental aspects, the EOQ/EPQ models addressing these issues remain poorly discussed in the literature. However, it has been gaining attention between many researchers. Bonney and Jaber [34] propose an EOQ model for sustainable development based on environmental costs. Csutora et al. [35] suggest that the prices of carbon may change the policy of applications of the EOQ. Battini et al. [36] develop a sustainable economic order quantity model (SEOQ). Kazemi et al. [37] extend the basic EOQ model for a retailer by analyzing the imperfect quality of products and environmental issues. Recently, Taleizadeh et al. [19] propose a sustainable EPQ model with the shortage.

To the best of the authors' knowledge, there is no research jointly considering the EPQ model, with the possibility of a backorder, stochastic demand, and environmental assumptions simultaneously. The present study aims to propose a more realistic extension of the EPQ model of sustainable development (SEPQ) presented in [19]. For this, we use the demand as stochastic instead of deterministic.

Furthermore, we include PBO, once it is not always possible to meet all the customer demand. The importance of this work is justified by an EPQ which input more realistic parameters to match the real-world situations considering environmental aspects, once these issues remain scarce in the literature.

In addition to this introductory section, Sect. 2 presents the Model. Section 3 describes the formulation of study. The results of applying the model are present in Sect. 4. Conclusions and future research are discuss in Sect. 5.

2 Model

For the formulation of the new model, we use the following notation:

Parameters (based on [19]):

C_p: Unit production cost (\$/Unit)
C_s: Set up Cost (\$/installation)
C_i: Cost of holding a unit of inventory in a time unit (\$/unit)
C_g: Goodwill loss of an unsatisfied demand (\$/unit)
C_b: Backordering cost of a product unit in a time unit (\$/unit)
C_l: Lost sale cost per unit (\$/unit)
P: Maximum annual rate of production (unit/year)
s: Price of a product unit (\$/unit)
s': Scrap price per unit (\$/unit)
β: Backordered portion of stock-outs (%)
α: Obsolescence rate of inventory (%)
b: Required space for each unit of product (cubic meters per unit)
a: The weight of an obsolete inventory (ton per unit)
C_{ei}: Average emission cost of carbon for inventory holding (\$/m)
C_{eo}: Average disposal, waste collection, and emission cost of carbon for inventory obsolescence (\$/ton.)
C_{ep}: Emission cost of carbon for manufacturing each unit (\$/unit)
S: The highest quantity of shortage (unit/year)
I: The highest quantity of inventory (unit/year)
$\overline{I}$: The annual average level of inventory (unit/year)
B: The highest quantity of backordered (%)
$\overline{B}$: The annual average quantity of backordered (B = βS) (unit/year)
T: The inventory cycle or time between two consecutive orders (time)
F: The fraction of period length with positive inventory level (%)

Parameters added in the base model:

x: Random demand
f(x): Probability of demand function
t: Time observed the demand

The assumptions (1)–(4) follow [19]:

(1) Single product: the company produces only one type of product.
(2) Single period: all periods are similar and, therefore, we only need to model the problem in one period to find the optimal values.
(3) Single transport mode: only one type of logistic modal transported all products.
(4) Finite production rate: the production rate is limited, and the total production capacity is provided.
(5) The demand follows an exponential probability function f(x) in the same way that in [31], that is used in the case of a supplier with a short life cycle, as technological items and clothes. The probability function f(x) is given by:

$$f(x) = \begin{cases} \lambda e^{-\lambda x} \; where \quad 0 \le x \le \infty \\ 0 \qquad\qquad otherwise \end{cases} \tag{1}$$

3 Formulation

The following environmental costs express the total profit function of the production system: cost of emission of inventory holding (C_{ei}), cost of emission of inventory obsolescence (C_{eo}), cost of emission of production (C_{ep}). The other expenses are the cost of production (C_p), set up cost (C_s), inventory holding cost (C_i), obsolescence cost of inventory (C_{obs}), backordering cost (C_b) e goodwill loss cost (C_g) in the same way as presented by the authors. We introduce the demand as stochastic through the Eq. (2) concerning F, T, and t.

$$\begin{aligned} L(F.T.t) = {} & \overbrace{s\left[\left(\int_0^t x\lambda e^{-\lambda x} dt(1-F)\right)\beta + F\right]}^{\text{Sales Revenue}} - \overbrace{\left(\int_0^t x\lambda e^{-\lambda x} dt\right) C_p[(1-F)\beta + F]}^{C_p} - \overbrace{C_{ep}\left(\int_0^t x\lambda e^{-\lambda x} dt\right)[(1-F)\beta + F]}^{C_{ep}} \\ & - \underbrace{\frac{C_s}{T}}_{CF_s} - \underbrace{C_i\bar{I}}_{C_i} - \underbrace{C_{ei}b\bar{I}}_{C_{ei}} - \underbrace{\alpha(s-s')\bar{I}}_{C_{obs}} - \underbrace{\alpha\alpha\bar{I}C_{eo}}_{C_{eo}} - \underbrace{C_b\bar{B}}_{C_g} - \underbrace{C_g\left(\int_0^t x\lambda e^{-\lambda x} dt\right)(1-\beta)(1-F)}_{C_b} \end{aligned} \tag{2}$$

We use the same equations as in [7], presented in Eqs. (3) and (4):

$$\overline{I} = \frac{DTF^2}{2}\left(1 - \frac{D}{P}\right) \tag{3}$$

$$\overline{B} = \frac{\beta DT(1-F)^2}{2}\left(1 - \frac{\beta D}{P}\right) \tag{4}$$

However, considering the demand is stochastic, we have:

$$\overline{I} = \frac{\left(\int_0^t x\lambda e^{-\lambda x} dt\right)TF^2}{2}\left(1 - \frac{\int_0^t x\lambda e^{-\lambda x} dt}{P}\right) \tag{5}$$

$$\overline{B} = \frac{\left(\int_0^t x\lambda e^{-\lambda x} dt\right)\beta T(1-F)^2}{2}\left(1 - \frac{\beta\left(\int_0^t x\lambda e^{-\lambda x} dt\right)}{P}\right) \tag{6}$$

Substituting Eqs. (5) and (6), into Eq. (2):

$$\begin{aligned}
\boldsymbol{L}(\boldsymbol{F}, \boldsymbol{T}, \boldsymbol{t}) = &\left(s - C_p - C_{ep}\right)\left(\lambda txe^{-\lambda x}\right)(F - \beta(F-1)) \\
&+ \frac{C_i F^2 T\left(\frac{\lambda txe^{-\lambda x}}{P} - 1\right)}{2} - C_g\left(\lambda txe^{-\lambda x}\right)(F-1)(\beta-1) - \frac{C_s}{T} \\
&+ \frac{F^2 T\alpha\left(\frac{\lambda txe^{-\lambda x}}{P} - 1\right)\left(\lambda txe^{-\lambda x}\right)\left(s - s'\right)}{2} \\
&+ \frac{C_b T\beta\left(\frac{\beta\left(\lambda txe^{-\lambda x}\right)}{P} - 1\right)\left(\lambda txe^{-\lambda x}\right)(F-1)^2}{2} \\
&+ \frac{bC_{ei} F^2 T\left(\frac{\lambda txe^{-\lambda x}}{P} - 1\right)\left(\lambda txe^{-\lambda x}\right)}{2} \\
&+ \frac{aC_{eo} F^2 T\alpha\left(\frac{\lambda txe^{-\lambda x}}{P} - 1\right)\left(\lambda txe^{-\lambda x}\right)}{2}
\end{aligned} \tag{7}$$

To simplify the notation, we define:

$$w = \left(\frac{\lambda txe^{-\lambda x}}{P} - 1\right) \tag{8}$$

$$z = \left(\lambda txe^{-\lambda x}\right) \tag{9}$$

$$v = \left(\frac{\beta\left(\lambda txe^{-\lambda x}\right)}{P} - 1\right) \tag{10}$$

$$y = s - C_P - C_{ep} \tag{11}$$

$$C' = C_i + \alpha\left(s - s'\right) + bC_{ei} + a\alpha C_{eo} \tag{12}$$

Substituting Eqs. (8)–(12) into Eq. (7):

$$\begin{aligned} \boldsymbol{L(F, T, t)} = (F - \beta(F-1)zy) + \frac{C_b T\beta vz(F-1)^2}{2} \\ + \frac{wzTF^2C'}{2} - C_g z(F-1)(\beta-1) - \frac{C_s}{T} \end{aligned} \tag{13}$$

The next step is to find the optimal values of T and F, maximizing the function $L\ (F, T, t)$. For this, it is necessary to prove the concavity of the profit function. As function (11) is the same as proposed by [19], the function is concave. Thus, through partial derivatives, it is possible to find the optimal values for F and T. To solve the model, we use the software Matlab, version R2016b, run on a machine with 3 GHz Intel i5-3330 processor and Windows 10 Pro operating system. In Eq. (14) we have the partial derivative about:

$$\tfrac{\partial L}{\partial F} = FC'Twz - yz(\beta-1) - C_g z(\beta-1) + C_b T vz\beta(F-1) \tag{14}$$

Setting this derivative to zero, we have the value of F in Eq. (15):

$$F = \tfrac{C_g z(\beta-1) + yz(\beta-1) + C_b T vz\beta}{(C'Twz + C_b T vz\beta)} \tag{15}$$

For T we have the following partial derivative, presented in Eq. (16):

$$\tfrac{\partial L}{\partial T} = \tfrac{C_s}{T^2} + \tfrac{F^2C'wz}{2} + \tfrac{C_b vz\beta(F-1)^2}{2} \tag{16}$$

Setting this derivative to zero, we have the value of T in Eq. (17):

$$T = \sqrt{\tfrac{2C_s}{z\left(C_b v\beta + F^2C'w - 2C_b F v\beta + C_b F^2 v\beta\right)}} \tag{17}$$

Replacing Eq. (15) into Eq. (17), we obtain the optimal T value:

$$T^* = \frac{\sqrt{\left[-C_b C' vwz\beta\left(\begin{array}{c} zC_g^2 - 2zC_g^2\beta + zC_g^2 - 2zC_g y\beta^2 + 4zC_g y\beta - 2zC_g y + zy^2\beta^2 - 2zy^2\beta + zy^2 \\ +2C_s C_b v\beta + 2C' wC_s \end{array}\right)\right]}}{\left(C_b C_s vwz\beta\right)} \tag{18}$$

Replacing T^* into Eq. (15), we have the optimal F value:

$$F^* = \tfrac{C_b C' vw\beta\left[\frac{m}{C'w} + C_g z(\beta-1) + yz(\beta-1)\right]}{(C'w + C_b v\beta)m} \tag{19}$$

$$m = \sqrt{-C_b C' vwz\beta \begin{pmatrix} zC_g^2\beta^2 - 2zC_g^2\beta + zC_g^2 \\ -2zC_g y\beta^2 + 4zC_g y\beta - 2zC_g y \\ +zy^2\beta^2 - 2zy^2\beta + zy^2 \\ +2C_s C_b v\beta + 2C_s C' w \end{pmatrix}} \tag{20}$$

4 Results

For the model validation, we use the numerical example presented in [19] for an Iranian company (Table 1). The demand is equal to 40 units/year. Table 2 shows the comparison between the results found using the model proposed by [19] and the ones obtained by the model proposed in this paper.

To illustrate the proposed model, we present a numerical example using the parameters presented in Table 1, but considering β = 0.5. We use the exponential distribution as in [30], with λ = 0.05. Moreover, to find the annual demand, we set t = 365 *e*

Table 1 Parameters used

Parameters	Value used
P	100 unit/year
s	100 $/unit
s’	5 $/unit
α	10%
C_p	7 $/unit
C_s	20 $/order
C_i	2.5 $/unit
C_b	3 $/unit
C_g	1 $/unit
b	1.7 m/unit
a	2 t/unit
C_{ei}	0.55 $/m
C_{eo}	13 $/t
C_{ep}	0.3 $/unit
β	0.45

Table 2 Model validation

Variables	Results base article [19]	Results of the model presented
T^*	0.452	0.452
F^*	1.1	1.1
L^*	16.9 $/year	16.9 $/year

randomly $x = 3$. Fist, we calculate the values of w, z, v, y e C using Eqs. (8)–(12):

$$w = \left(\frac{0.05(365)3e^{0.05(-3)}}{100} - 1\right) = -0.53$$

$$z = \left(0.05(365)3e^{-3(0.05)}\right) \cong 47$$

$$v = \left(\frac{0.5(47)}{100} - 1\right) = -0.765$$

$$y = 10 - 7 - 0.3 = 2.7$$

$$C' = 2.5 + 0.1(10 - 5) + 1.7(0.55) + 2(0.1)13 = 6.535$$

Therefore, we can calculate the values of T^*, F^* and the total profit, through Eq. (13), Eq. (18), and Eq.(19), respectively:

$$T^* = \frac{\sqrt{\left[(-3(6.535)(-0.765)(-0.53)47(0.5))\begin{pmatrix} 47(0.5)^2 - 47(0.5)2 + 47 - 47(2.7)(0.5)^2 2 + 47(27)(0.5)4 \\ -47(2.7)2 + 47\left(2.7^2\right)0.5^2 - 47\left(2.7^2\right)(0.5)2 + 47(2.7)^2 \\ +2(20)3(-0.765)0.5 + 2(20)(6.535)(-0.53) \end{pmatrix}\right]}}{[(3(6.535)(-0.765))(-0.53(47)(0.5))]}$$

$$T^* = 0.9 \text{ year}$$

$$F^* = \frac{1(47)(0.5 - 1) + 2.7(47)(0.5 - 1) + 3(0.9)(-0.765)(47)0.5}{(6.535(0.9)(-0.53)(47) + 3(0.9)(-0.765)(47)0.5)} = 0.7$$

$$\begin{aligned} L = {} & \frac{3(0.9)(0.5)(-0.765)(47)(0.7 - 1)^2}{2} + \frac{(-0.53)(47)0.9\left(0.7^2\right)6.535}{2} - \frac{20}{0.9} \\ & + (0.7 - 0.5(0.7 - 1))47(2.7) - 47(0.7 - 1)(0.5 - 1) \\ & = 40.83\$/\text{year} \end{aligned}$$

Then, we conduct a sensitivity analysis to check how the changes of parameters affect the optimal L^* (Fig. 1). We set t = 365, we desire once the annual demand. Figure 2 shows only parameters that positively affect the total profit.

The total profit (L^*) is positively affected by demand (x, λ), backordering cost (C_b), and back ordered portion of stock-out (β). Set up cost (C_s), inventory holding cost (C_i), goodwill loss cost (C_g), as well as cost of emission of inventory holding (C_{ei}) and the inventory carbon emission (C_{eo}) affect L^* negatively. Carbon emission of manufacturing (C_{ep}), production rate (P), obsolescence rate of inventory (α), space required for the product (b) and the weight of obsolete stock (a) also affect L^* in a

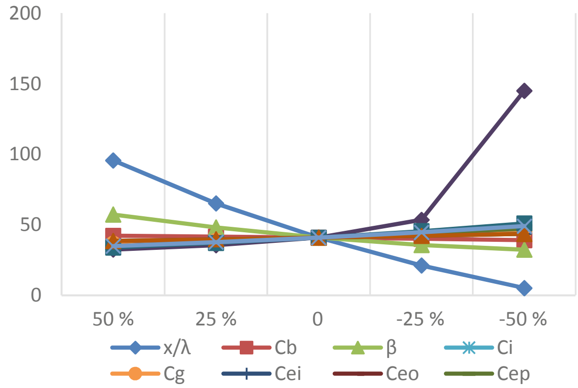


Fig. 1 Graph with all parameters that affect total profit

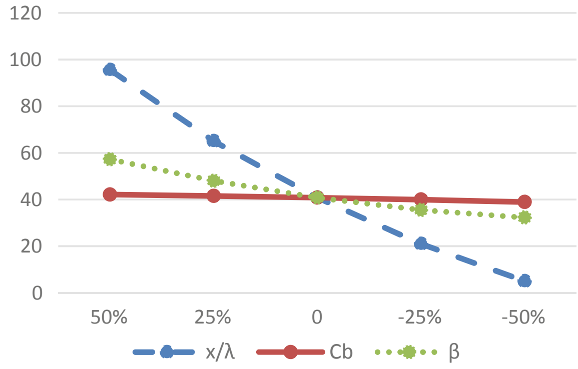


Fig. 2 Graph with parameters that positively affect total profit

negative way. Finally, all the environmental costs affect the total profit, showing the importance of addressing environmental issues in the EPQ models.

Based on the sensitivity analysis graph, we conclude that the demand, represented by x and λ, is the variable with the highest inclination. Thus, the demand considered as stochastic, that is, closer to reality, allows a more realistic analysis.

5 Conclusion

This paper proposes a new EPQ model with environmental aspects, partial backorder, and stochastic demand, as an extension of [19]. We analyzed the changes in the parameters, through a numerical example, and performing a sensitivity analysis. This analysis aims to demonstrate how decision-making can be defined to improve the profit, according to the difference in variables. This new model may be useful for companies that have a concern about environmental issues. Also, the stochastic demand does match the real-life situations, having greater applicability, especially in products with a short life cycle. As previously discussed, the demand is the parameter that most affects the total profit. Hence, at the managerial level, it is essential to observe to what extent the product should be produced or should be interrupted because it does not generate profit anymore.

On the other hand, the cost of backordering (*Cb*) is the parameter that least affects the total profit; however, it should be monitored. Managers can design strategies and policies to retain customers—such as priority in future purchases - since the more customers accept to wait for their order until the next period, the higher is the gain. A limitation presented by [19] and also found in this model is the effort in obtaining some values, such as the average cost of carbon emissions to inventory (which measured is in value per cubic meter); the mean disposal of waste, and the cost of emitting carbon for the manufacture per unit.

Future studies may improve this model in several directions. One way would be the use of other demand probability function, as well as using different sustainability approaches, for instance, the limitation and negotiation of the emission of polluting gases. Still considering the perspective of sustainability, future works can also include social aspects, such as ergonomic issues, considering all the three pillars of the Triple Bottom Line (economic, environmental, and social).

Acknowledgments This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001.

References

1. Harris, F. W.: How Many Parts to Make at Once. Factory, The Magazine of Management, v. 10, n. 2, p. 135–136, 152 [Reprinted in Operations Research], 1990, 38(6), 947–950 (1913).
2. Andriolo, A., Daria, B., Grubbström, R. W., Persona, A. and Sgarbossa, F.: A century of evolution from Harris's basic lot size model: survey and research agenda. Int. J. Prod. Econ., 155, 16–38 (2014).
3. Harris, F. W.: What Quantity to Make at once? Operation and Costs, in the Library of Factory Management. A. W. Shaw Company, Chicago, 47–52 (1915).
4. Taft, E. W.: The most economical production lot. The Iron Age, 101, 1410–1412 (1918).
5. Camp, W. E.: Determining the production order quantity. Management Engineering, [S. l.], 2, 17–18, 1922 (1922).
6. Wilson, R. H. A Scientific Routine For Stock Control. Harvard Business Review, [S. l.], 13(1), 116–128 (1934).
7. Pentico, D. W., Drake, M. J.: The deterministic EOQ with partial backordering: a new approach. European Journal of Operational Research, 194(1), 102–113 (2009).
8. Fabrycky, W. J., Banks, J.: Procurement and Inventory Systems, Theory and Analysis. Reinhold Publishing Corporation, New York, pp. 92–95 (1967).
9. Ali, A.M.: Inventory problems. In: F.C. Jelen (Ed.), Cost and Optimization Engineering. Section 10.5 in Chapter 10, McGraw-Hill, New York, pp. 191–193 (1970).
10. Montgomery, D. C., Bazaraa, M. S., Keswani A. K.: Inventory models with a mixture of backorders and lost sales. Naval Research Logistics Quarterly, 20(2), 255–263 (1973).
11. Rosenberg, D. A new analysis of a lot-size model with partial backlogging. Naval Research Logistics Quarterly, 26(2), 349–353 (1979).

12. Park, K. S.: Inventory model with partial backorders. International Journal of Systems Science, 13(12), 1313–1317 (1982).
13. Mak, K. L.: Optimal inventory policies when the quantity backordered is uncertain. Computers Operations Research, 10(1), 21–28 (1987).
14. Zeng, A. Z.: A partial backordering approach to inventory control. Production Planning & Control, 12, 660–668 (2001).
15. Bera, U. K., Bhunia. A. K., Maiti, M.: Optimal partial backordering two-storage inventory model for deteriorating items with variable demand. International Journal of Operational Research, 16(1), 96–112 (2013).
16. Taleizadeh, A. A. and Pentico, D. W.: An economic order quantity model with partial backordering and all-units discount. International Journal of Production Economics, 155, 172–184 (2014).
17. Salehi, H., Taleizadeh A. A., Tavakkoli-Moghaddam, R.: An EOQ model with random disruption and partial backordering. International Journal of Production Research, 54, 2600–2609 (2015).
18. Cunha, L., Delfino, A., Reis, K., Leiras, A.: Economic production quantity (EPQ) model with partial backordering and a discount for imperfect quality batches, International Journal of Production Research, 56(18), p. 6279–6293 (2018).
19. Taleizadeh, A. A., Soleymanfar, V. R. and Govindan, K.: Sustainable economic production quantity models for inventory systems with shortage. Journal of Cleaner Production, 174, p. 1011–1020 (2018).
20. Wagner, H. M.: Statistical Management of inventory systems, J. Wiley, USA (1962).
21. Faddy, M. J.: The stationary distribution and first exit probabilities of a storage process with general release rule, Math. Oper. Res., 1, 347–358 (1974).
22. Meyer, R. R., Rothkopf, M. H., Smith, S.A.: Reliability and inventory in a production-storage system, Manage. Sci., 25, 799–807 (1979).
23. Zhou, Y. W.: Optimal production policy for an item with shortages and increasing time-varying demand. J. Oper. Res. Soc., 47, 1175–1183 (1996).
24. Sarkar, B., Moon, I.: An EPQ model with inflation in an imperfect production system, Applied Mathematics and Computation, 217(13), pp. 6159–6167 (2011).
25. Kumar, M., Chauhan, A. and Kumar, P.: Economic production lot size model with stochastic demand and shortage partial backlogging rate under imperfect quality items. Int. J. Adv. Sci. Technol. 31, 1–22 (2011).
26. Digiesi, S., Mossa, G., Mummolo, G.: A sustainable order quantity model under uncertain product demand. 7th IFAC Conference on Manufacturing Modelling, Management and Control, International Federation of Automatic Control, St. Petersburg, pp. 664–669 (2013).
27. Ribas, G. P., Leiras, A., Hamacher, S.: Operational planning of oil refineries under uncertainty Special issue: Applied Stochastic Optimization. IMA Journal of Management Mathematics, 23(4), 397–412 (2012).
28. Leiras, A., Ribas, G., Hamacher, S., Eikamel, A.: Tactical and operational planning of multirefinery networks under uncertainty: an iterative integration approach. Industrial Engineering Chemistry Research, 52(25), 8507–8517 (2013).
29. Roy, M. D., Sana, S. S. and Chaudhuri, K. S.: An Economic Production Lot Size Model for Defective Items with Stochastic Demand, Backlogging and Rework. IMA Journal of Management Mathematics, 25(2), 159–183 (2014).
30. Sana, S. S.: An EOQ model for stochastic demand for limited capacity of own warehouse. Annals of Operations Research, v. 233, 383–399 (2015).
31. Pal, S., Mahapatra, G. S., Samanta, G. P.: A three-layer supply chain EPQ model for price-and stock-dependent stochastic demand with imperfect item under rework. Journal of Uncertainty Analysis and Applications, 4(1), 10 (2016).
32. Pal, B., Sana, S. S., Chaudhuri, K.: A mathematical model on EPQ for stochastic demand in an imperfect production system. Journal of Manufacturing Systems, 32(1), 260–270 (2013).
33. Maddah, B., Noueihed, N.: EOQ holds under stochastic demand, a technical note. Applied Mathematical Modelling, v. 45, 205–208 (2017).

34. Bonney, M., Jaber, M. Environmentally responsible inventory models: nonclassical. Int. J. Prod. Econ., 133(1), 43–53 (2011).
35. Csutora, M., Dobos, I., Vörösmarty, G.: A sustainable economic order quantity model with carbon footprint. 17th International Symposium on Inventories, International Society for Inventory Research (ISIR), Budapest (2012).
36. Battini, D., Persona, A., Sgarbossa F.: A Sustainable EOQ model: theoretical formulation and applications. Int. J. Prod. Econ., 149(1), pp. 145–153 (2014).
37. Kazemi, N., Abdul-Rashid, S. H., Ghazilla, R. A. R., Shekarian, E., Zanoni, S.: Economic order quantity models for items with imperfect quality and emission considerations. Int. J. Syst. Sci. Oper. Logist. (2016).

Sustainability in Logistics Systems and Its Impact on the Level of Services Definition: An Exploratory Analysis Using Structural Equation Modeling

Vitor William Batista Martins, Rosley Anhlon, Izabela Simon Rampasso, Dirceu da Silva, and André Cristiano Silva Melo

Abstract This article aims to systematize conceptual foundations about the relationship between green logistics, sustainable logistics, logistics systems and levels of services offered to customers; and to verify if the use of sustainable practices in logistics systems is positively related to the insertion of sustainable guidelines in definition of level of services offered to customers. The methodological procedures consisted of 5 stages: literature review; definition of activities belonging to the logistical systems to be analyzed; elaboration of a theoretical model to be validated; data collection through a survey with professionals specialized in management of logistical systems and sustainability, and; validation of the proposed model via Structural Equation Modeling. The results show that, in general, when companies contemplate sustainable practices in their logistics activities, they tend to consider sustainable characteristics to define level of services offered to their customers. It can be concluded that the findings of this study have several managerial implications: attention is drawn to the synergistic behavior between use of sustainable practices in logistics systems and level of services offered to customers definition; thus, managers interested in improving the sustainable performance of services offered by their companies must implement sustainable practices in each logistical activity

V. W. B. Martins (✉) · R. Anhlon · I. S. Rampasso
University of Campinas, Mendeleyev Street, Campinas, Brazil
e-mail: vitor.martins@uepa.br

R. Anhlon
e-mail: rosley@fem.unicamp.br

I. S. Rampasso
e-mail: izarampasso@gmail.com

V. W. B. Martins · A. C. S. Melo
State University of Pará, Eneas Pinheiro Street, Belém, Brazil
e-mail: acsmelo@uepa.br

D. da Silva
University of Campinas, Bertrand Russell Avenue, Campinas, Brazil
e-mail: dirceuds@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_11

developed by the organization; in addition, they also need to implement these practices synergistically throughout logistics activities, to generate a sustainable logistics system.

Keywords Logistics systems · Sustainability · Sustainable practices · Logistics services · Green logistics

1 Introduction

Current market is increasingly competitive, and aspects such as insertion of innovations must occur in a constant and accelerated manner [1, 2]. In this sense, it is worth noting that consumers are increasingly demanding, and different requirements are presented. This makes companies to seek for new ways to manage their businesses, focusing on customer satisfaction [3, 4]. Therefore, for maintenance and consolidation in current market, it is necessary the development of strategies to guide companies for meeting these requirements, ensuring them a solid base into develop its activities.

In this sense, the insertion of sustainability aspects in business processes is a strategic differential for the development of products and service offerings [3, 4]. However, there is a scarcity of research that directly focuses on the inclusion of sustainability in definition of levels of services offered to customers [3]. More specifically, activities of logistical systems are in evidence at business level. In this sense, it is important to understand what this concept exactly mean. According to [5], logistical systems are formed by a set of activities that aim at the efficient management of the planning, implantation and control processes flow of goods and provision of services.

According to this context, the motivating question of this research is: "When companies develop sustainable practices in their logistical activities, do they tend to consider sustainable characteristics to define levels of services offered to their customers?". To answer this question, this research objectives were: (a) to systematize conceptual foundations about the relationship between Green logistics, Sustainable logistics, Logistics systems and service levels offered to customers; (b) to verify if the use of sustainable practices in logistics systems is positively related to the insertion of sustainable guidelines in the definition of level of services offered to customers.

2 Theoretical Background

This section presents the concepts that served as a basis to understand the research context and to elaborate the hypothesis to be tested.

According to [6], the development of sustainable logistics is crucial for organization competitiveness. In this sense, the execution of sustainable logistical activities must interconnect economic, environmental and social aspects. However, most of companies have difficulties in relating logistics to sustainable requirements due to the complexity of logistics systems.

Sustainable logistics is characterized as an important component of current production systems, as it strives to quantify and control the negative sustainability impacts of production activities in companies. Specifically, sustainable logistics consists of company's ability to provide products and services meeting sustainability guidelines, that is, harmonizing environmental and social aspects with the organization's economic objectives [7]. According to [8], sustainable logistics plays an important role in reaching the global sustainability agenda, improving organizational performance not only considering economic factors but also considering social and environmental aspects. This ability is considered indispensable for companies that aim to improve their performance meeting the needs of their customers.

For the establishment of sustainable guidelines in logistics systems, it is important to know and detail the activities that compose these systems. Regarding transport strategies, there is a growing concern related to the need to consider sustainability as a core issue in logistics activities. In general, most companies around the world concentrate their activities on road transport. However, the choice of transport modal is important to minimize negative sustainability impacts [9]. According to [10], transport modal choice is fundamental for the achievement of sustainable goals. Despite its importance, the modal choice still receives little attention of professionals, a fact that hampers the transport activity from meeting the sustainable guidelines [11].

Another activity to be addressed in the transportation field is the logistic activity of freight definition and pricing. This activity consists of analyzing variables related to the transport modal and identifying total costs for the development of activities in order to establish freight prices according to organization's economic objectives. Currently, with the constant search for providing more sustainable services, aiming to meet new demands of customers, it is highlighted that the establishment of logistical freights must also take into account environmental and social aspects in addition to economic issues [12, 13].

Vehicle programming and routing is also directly linked with transportation field. The activity consists of defining routes to be used by vehicle fleet aiming to provide a transportation service at the lowest possible cost. However, it is necessary to consider environmental and social aspects in the development of this activity. Adopting technologies such as GPS, drones and remote monitoring of routes may provide a better sustainable performance to the vehicle routing activity. Additionally, this kind of technology adoption is increasingly necessary for companies that develop transport activities [14–16].

Analyzing the strategies related to the management of warehouses and stocks, the activity of defining the type of packaging to be used stands out. According to [17], packaging is characterized as a component that supports improvements to achieve sustainable strategies in logistics operations. The management of packaging definition consists of integrating packaging project with variables and needs of logistics management, with an emphasis on strategy and sustainable aspects [17]. The challenge in defining packaging is highlighted due to the complexity for developers to simultaneously balance different environmental requirements [18].

Another logistics activity in warehouse and stock management field is the operational configuration of warehouses. According to [19], many companies have currently adopted sustainable practices to define operational configuration of their warehouses, mainly in the development of operations with reduced energy consumption as the main factor in the search for sustainable excellence. Taking into account the global sustainable trend, an increasing attention to the development of storage processes has resulted in new management concepts, technologies and equipment aiming to reduce the negative sustainable impact of the activities developed in warehouses [20, 21]. In this context, it is worth highlighting the importance of warehouse location in the strategic definition [22, 23].

The logistical activity for order separation procedures consists of receiving, executing and fulfilling orders and purchase order demanded by customers. With the increase in the volume of orders and purchase orders, the basic functionalities of warehouse separation procedures are unable to effectively manage these operations. In addition, it is still necessary to consider sustainability aspects in the development of activities. In this sense, intelligent systems that use operations research and advanced data analysis techniques are necessary to guarantee the efficiency and effectiveness of these logistical operations [24, 25].

Continuing, the logistics area related to relationship and selection of suppliers, as well as the period and quantity of purchases, must be considered in the organizational strategies to achieve sustainable goals. According to [26], the selection of suppliers is considered crucial for the success of any organization due to the amount of financial resources that this activity involves. Haeri and Rezaei [27] highlight that the selection of sustainable suppliers is essential in the current supply chain management environment, having an important role in the achievement by companies of maintaining their strategic competitiveness. Another point to be considered in this context is the management of purchases that changed from tactical to strategic function in most companies, since great part of this activity's contribution to the management of the logistics and supply chain was identified [28].

Aiming to meet new perspectives of customer demands regarding more sustainable services, the logistics activity of defining the level of logistical services becomes central for companies to supply this demand. In the next paragraphs, studies that addressed the insertion of sustainability in the definition of the level of services offered to customers are presented to better contextualize this reality.

Sureeyatanapas et al. [29] developed a study to generate insights on the beginning of sustainable policies insertion in companies providing logistics services, analyzing and identifying factors that influence the adoption of sustainable practices. The results indicate that the eco-driving and vehicle routing activities are the most contemplated and developed factors in the industries. Additionally, the use of alternative energy and the choice of modal were also recognized by professionals as being of great relevance to achieve sustainable goals. However, there are several concerns that still hinder the implementation of these approaches, e.g. company's size, financial aspects, areas of service provision, pressure from customers and lack of organizational support.

Evangelista et al. [30], through an analysis of multiple cases, explored environmental strategies of organizations, considering aspects of sustainable organizational culture, initiatives and factors that influence the adoption of sustainable practices in provision of services. The results show that sustainability is generally recognized as a strategic priority, however, there is still a certain degree of diversity and uncertainty in the implementation of strategies for adopting environmental practices in the definition and provision of services to customers.

Jaaron and Backhouse [31] conducted a study aimed at investigating the impact of the service operations project using the systemic thinking approach on the sustainable performance of service providers. The results highlight the importance of following the guidelines of systemic thinking in the execution of the activities of service providers, especially when there is a strategy for providing more sustainable services. The authors point out that systemic thinking has a significant impact on environmental and social performance, but has no direct effect on economic performance. The results also indicate a statistically positive relationship between environmental and economic performance and between social and economic performance, but not between environmental and social performance, suggesting that the dimensions of sustainable performance should not be seen as equally considered in the definition of strategies for provision of sustainable services.

Based on the context presented, considering the concepts of sustainable logistics, the areas and activities that make up the logistics systems, as well as the discussion of some studies that consider the inclusion of sustainability in the definition and provision of services offered to customers, the following research hypothesis: H1—In general, when companies contemplate sustainable practices in their logistical activities, they tend to consider sustainable characteristics when defining the level of services offered to their customers.

3 Methodology

The following steps were carried out for the development of the research: (a) literature review; (b) definition of the activities belonging to the logistical systems to be analyzed; (c) elaboration of the framework to be validated; (d) data collection through a survey with professionals specialized in the management of logistical systems and sustainability, and; (e) validation of the proposed model through the modeling of structural equations and related discussions.

The literature review was performed using searches on the following scientific bases: Science Direct, Taylor & Francis, Springer, Emerald Insight, Wiley, Scopus and Sage. Initially, aiming at a greater understanding of the concepts associated with sustainable logistics and activities that make up the logistics systems, as well as the characterization of the state of the art on the definition of the level of services offered to customers, considering aspects of sustainability and how these customers are demanding the insertion of sustainability in logistics activities, the following search terms were used: “green logistics”, “sustainable logistics”, “logistics systems”, “logistics operations”, “logistics services”, “sustainable logistic services” and also in a combined way, for example: “logistics services AND green logistics” and “systems logistics AND sustainable logistics”. Several articles were identified and their content was analyzed in detail. A representative summary of these articles is presented in Sect. 2.

Then, 10 logistical activities were defined to be analyzed in this study, namely: selection and definition of transport modal; definition and pricing of freight; vehicle scheduling and routing strategy; definition of the type of packaging considering the handling, storage, losses and damage of the materials; operational configuration of the warehouse (machines, labor and product mix); location of warehouses, total area for storage, layout and design of the docks; execution of order picking procedures; definition of suppliers (source of supplies); definition of the period and quantity of purchases, and; definition of the levels of logistical services offered to customers. It is noteworthy that all the activities considered were selected based on the analysis of their importance, according to the recent literature and the concepts of [5].

Step three consisted in the development of a framework to be validated, which was composed of two constructs, in order to test the research hypothesis. The constructs were named “logistics systems” (LogS) and “service level” (SerL) respectively. The LogS consists of a set of nine activities that together are part of a logistical system and the SerL is composed of an activity that represents the level of service offered to the customer. The activities considered in each construct can be seen in detail in Chart 1 and the structured framework is shown in Fig. 1.

Then, a survey was conducted with professionals specialized in management of logistics systems and sustainability, active in the Brazilian scenario. This step consisted of sending the research questionnaire via email. The questionnaire was composed of 10 questions. Respondents were asked to rate how much Brazilian companies are taking into account aspects of sustainability in each logistical activity presented in the questionnaire. Respondents assigned a score from 0 to 10 for each

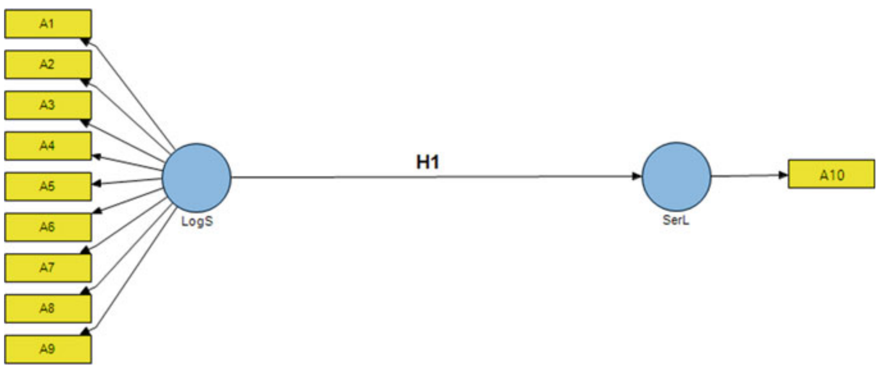


Fig. 1 Initial theoretical model (*Source* Authors)

activity, with score 0 indicating that sustainability is not included in the mentioned activity and note 10 indicated that sustainable practices are very well considered in the mentioned activity. Intermediate grades were awarded freely. The survey evaluated the opinion of professionals about Brazilian companies as a whole and not about the reality of the company in which the professional works. It is noteworthy that for the definition of the minimum size of the valid sample, the G*Power software was used with the parameters recommended by [32], namely: F test for the test family; linear multiple regression, fixed model and R2 deviation from zero for the statistical test; the test power of 80%; 5% for the probability of error; and effect size of 15%. The details and results of the sample size calculation are presented in Sect. 4 of this paper.

Finally, the collected data were processed in order to validate the proposed model. For this, the Structural Equation Modeling (SEM) technique was used via the Partial Least Squares (PLS) method through the use of the SmartPLS 2.0 software. According to [32]: “PLS regression is a regression-based approach that explores the linear relationships between multiple independent variables and a single or multiple dependent variables”. In SEM, the correct allocation of parameters in thematic constructs is analyzed and, subsequently, the causal relationships between these constructs are analyzed [33]. To facilitate results presentation, in Sect. 4 the steps that were followed for the validation of the model are detailed. They were performed based on [32, 34].

4 Findings

Respondents are professionals working in the area of logistics in Brazil, namely: research professors in the area (20%), consultants (6%) and market professionals such as directors, managers and coordinators of logistics for Brazilian companies (75%). The questionnaires were sent to 493 professionals, obtaining a return rate of 17.65%, totaling 87 respondents. There are respondents from the five regions of Brazil, being: 25% from the northern region, 17% from the northeast region, 6% from the central west region, 43% from the southeast region and 9% from the south region. Regarding the respondents’ sector, 28% are from industry, 25% from commerce and 47% from the services sector. Considering time of experience in the area, 28% have been working in the market for more than 20 years, 45% work in the area between 10 and 20 years and 28% have up to 10 years of experience in the area.

To test the research hypothesis, a model (Fig. 1) was constructed, composed of two constructs. The first named “Logistics Systems” (LogS) is formed by nine logistical activities that, according to [5] and the analysis of recent literature, correspond to the activities that are present and form the logistic systems, and; the second construct named “Service Level” (SerL) corresponds to the definition of the level of logistical service offered to customers. Such activities are shown in Table 1.

After preparing the model to be tested, the minimum sample size required was calculated using the G*Power software, using the parameters recommended by [32], Test Family: Ftests; Statistical test: Multiple Regression Omnibus (R^2 deviation from

Table 1 Logistical activities considered

Construct		Logistics activities	Authors
Logistics systems	A1	Selection and definition of modal to be used in transport	[9–11]
	A2	Freight definition and pricing	[12, 13]
	A3	Vehicle scheduling and routing strategy	[14–16]
	A4	Definition of the type of packaging considering the handling, storage, loss and damage of materials	[17, 18]
	A5	Operational warehouse configuration (machines, labor and product mix)	[19–21]
	A6	Location of warehouses, total area for storage, layout and design of the docks	[22, 23]
	A7	Execution of order picking procedures	[24, 25]
	A8	Definition of suppliers (source of supplies)	[26, 27]
	A9	Definition of the period and quantity of purchases	[28, 35]
Service level	A10	Definition of the levels of logistical services offered to customers	[29–31, 36]

Source Adapted from [5] and analysis of recent literature according to authors presented in the table

zero); Effect size f^2 (0.15); α err prob (0.05); Power 1-β err prob (0.80); Number of predictors (1). The minimum sample required totaled 55 respondents. Consequently, the database used in this study, with 87 respondents, was considered adequate (test power of 94.64%).

Then, using the SmartPLS 2.0 software, the PLS Algorithm was applied to the model. The values obtained are shown in Fig. 2 and Table 2. The values presented in Fig. 2 mean: (a) the value of 0.646 corresponds to the path coefficient and it indicates a high causality between the constructs (confirming the research hypothesis); (b) the

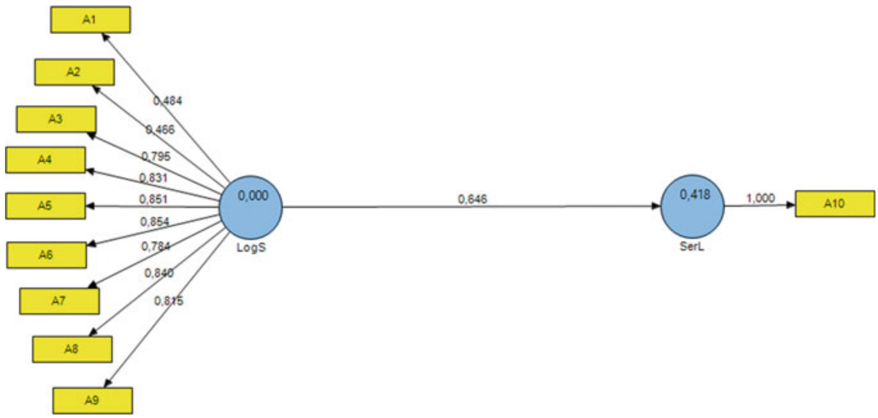


Fig. 2 Values obtained with the application of the PLS-SEM method (*Source* Authors)

Table 2 Quality criteria of the analyzed model

Constructos	AVE	Composite reliability	Cronbach's alpha
LogS	0.579095	0.922606	0.904919
SerL	1.000000	1.000000	1.000000

Source Authors

Table 3 Analysis of cross loads

	LogS	SerL
A1	0.484162	0.285856
A2	0.466058	0.163949
A3	0.794523	0.571314
A4	0.831209	0.56966
A5	0.850855	0.512521
A6	0.854253	0.480749
A7	0.783641	0.512396
A8	0.840291	0.537548
A9	0.814965	0.581626
A10	0.646244	1

Source: Authors

values between the constructs and their parameters represent the factor loads and demonstrate how well each activity is associated with its construct.

Analyzing the Average Extracted Variance (AVE), according to the values presented in Table 2, it is possible to notice that all values are greater than 0.50, which indicates that the model converges to a satisfactory result. Analyzing composite reliability, all values are greater than 0.70 and the values for Cronbach's alpha are greater than 0.60, denoting the absence of bias as recommended by [34].

Then, the cross-load analysis was performed in order to verify the best allocation of each variable [37]. As shown in Table 3, it is possible to notice that the greatest loads for the activities occur in their own constructs and, therefore, it is concluded that the activities are allocated correctly.

Considering the Pearson's coefficients (R2 values) for the proposed model, it is necessary to calculate only for the endogenous construct, in this case, construct 2, on the service level. The calculated value of R2 was 0.418, which characterizes it as a large and satisfactory effect, according to the concept of [38]. For [34], this value denotes the quality of adjusted model.

To verify the hypothesis that linear correlations and regressions are valid for at least 95% of cases, the resampling technique was used. The t-student values observed between the parameters and their constructs were much higher than 1.96, with the lowest value identified for activity A2 (3.587). The t-student value between the two constructs was also shown to be adequate (7.023), as shown in Fig. 3.

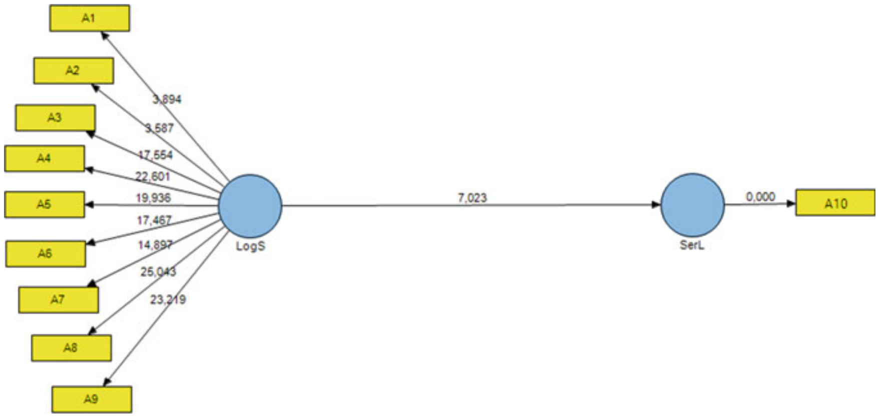


Fig. 3 Bootstrapping values for 1000 subsamples (*Source* Authors)

Table 4 Quality criteria of the adjusted model

	Q2	f2
LogS	0.482927	0.482927
SerL	0.386517	–

Source Authors

Finally, it was analyzed the redundancy (Q2) and communality (f2) indicators. They are associated with the quality of the adjusted model. In Table 4, it is possible to verify that all values are adequate (Q2 > 0; f2 > 0.35), as recommended by [34].

After the aforementioned steps and considering the results obtained, it is possible to verify the model validation and conclude that, according to the perception of professionals in the field of logistics in Brazil, when Brazilian companies contemplate sustainable practices in their logistics activities, they tend to also consider sustainable characteristics when defining the level of logistical services offered to its customers.

5 Conclusions and Associated Debates

Based on the results presented, it is concluded that the objectives proposed for this research were achieved, since it was possible to understand the context of the insertion of sustainable practices in logistics systems and how this insertion impacts the definition of level of service offered to the customer. In general, according to the results indicated by the study sample, it can be concluded that sustainable practices are being developed in logistics activities. By validating the model using PLS-SEM, it was possible to identify that the use of sustainable practices in logistics systems impacts the activity of defining the level of logistics services offered to customers, and the nine activities considered in the "Logistics Systems" construct are representative and impact on the definition of the activity of logistic service levels, tending to provide a more sustainable service.

With the model validation, it was possible to verify that the construct "Logistics Systems" (LogS) had all its variables validated. Analyzing the activities that make up the construct, the "Definition of the type of packaging considering the handling, storage, losses and damage of materials" was the one that, in experts opinion, obtained the highest average use of sustainable practices being developed (6.75), however, considering the modeling, the activity is only the fourth most important in testing the model for the LogS construct, with the activity "Warehouse location, total area for storage, layout and design of the docks" being the most important and representative for the construct (Fig. 2), confirming arguments and the importance presented in the specialized literature [22, 23].

The hypothesis H1 was validated, that is, research findings showed that when companies contemplate sustainable practices in their logistical activities, they tend to consider sustainable characteristics in defining the level of services offered to their customers, according to the sample of this study. This validation is corroborated by classic arguments presented in the literature on the inclusion of sustainability in definition of the level of services offered to customers. Thus, in general, a positive synergistic effect is expected between the use of sustainable practices in logistics systems and the definition of the level of services offered to customers.

The findings of this study have managerial implications. Attention is drawn to the synergistic behavior between the use of sustainable practices in logistics systems and definition of the level of services offered to customers. Thus, managers interested in improving the sustainable performance of the services offered by their companies, must invest in the insertion of sustainable practices in each logistical activity developed by organizations, in addition, they also need to pay attention and dedicate efforts in the insertion of these practices in logistics activities, making their logistics system more sustainable.

Regarding the limitation of this study, it is highlighted that it has an exploratory character, since the theme is little explored in the literature and needs more research to consolidate this thematic area. The findings are valid for the sample of this study. However, although exploratory, the results presented here can contribute significantly to new discussions that analyze the insertion of sustainability in the context of logistics systems.

The contribution of the findings of this research stands out, both for market professionals who work with the management of logistics systems and for researchers interested in the theme. Professionals working in the area can focus on the insertion of sustainable practices in the logistical activities that were analyzed in this study, aiming to enhance the compliance with sustainable guidelines of the logistical activities and operations developed by companies. Considering the importance of logistical systems to achieve sustainable goals, it is pointed out as research opportunities, the development of tools and models for inserting and assessing sustainability in logistical systems that consider environmental, economic and social aspects.

Funding This research was funded by Universidade do Estado do Pará—UEPA—Brazil, grant number 626/18; Conselho Nacional de Desenvolvimento Científico e Tecnológico—CNPq—Brazil, grant number 307536/2018-1; and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001, under process 88887.464433/2019-00.

References

1. Mennens K, Van Gils A, Odekerken-Schröder G, Letterie W (2018) Exploring antecedents of service innovation performance in manufacturing SMEs. Int Small Bus J Res Entrep 36:500–520. https://doi.org/10.1177/0266242617749687
2. Pacheco DA de J, ten Caten CS, Jung CF, et al (2019) Overcoming barriers towards Sustainable Product-Service Systems in Small and Medium-sized enterprises: State of the art and a novel Decision Matrix. J Clean Prod 222:903–921. https://doi.org/10.1016/j.jclepro.2019.01.152
3. Calabrese A, Castaldi C, Forte G, Levialdi NG (2018) Sustainability-oriented service innovation: An emerging research field. J Clean Prod 193:533–548. https://doi.org/10.1016/j.jclepro.2018.05.073
4. Tseng ML, Lim MK, Wong WP, et al (2018) A framework for evaluating the performance of sustainable service supply chain management under uncertainty. Int J Prod Econ 195:359–372. https://doi.org/10.1016/j.ijpe.2016.09.002
5. Ballou RH (2004) Business Logistics/Supply Chain Management: Planning, Organizing and Controlling the Supply chain, 5th Editio. Pearson/Prentice Hall Inc., New Jersey
6. El-Berishy N, Rügge I, Scholz-Reiter B (2013) The interrelation between sustainability and green logistics. IFAC
7. Chhabra D, Garg SK, Singh RK (2018) Analyzing alternatives for green logistics in an Indian automotive organization: A case study. J Clean Prod 167:962–969. https://doi.org/10.1016/j.jclepro.2017.02.158
8. Aldakhil AM, Nassani AA, Awan U, et al (2018) Determinants of green logistics in BRICS countries: An integrated supply chain model for green business. J Clean Prod 195:861–868. https://doi.org/10.1016/j.jclepro.2018.05.248
9. Chang Y-T, Lee PT-W, Kim H-J, Shin S-H (2010) Optimization Model for Transportation of Container Cargoes considering Short Sea Shipping and External Cost. Transp Res Rec J Transp Res Board 2166:99–108. https://doi.org/10.3141/2166-12
10. Leal IC, de Almada Garcia PA, de Almeida D'Agosto M (2012) A data envelopment analysis approach to choose transport modes based on eco-efficiency. Environ Dev Sustain 14:767–781. https://doi.org/10.1007/s10668-012-9352-x
11. Buldeo Rai H, Verlinde S, Merckx J, Macharis C (2017) Crowd logistics: an opportunity for more sustainable urban freight transport? Eur Transp Res Rev 9:39. https://doi.org/10.1007/s12544-017-0256-6
12. Bektaş T, Ehmke JF, Psaraftis HN, Puchinger J (2019) The role of operational research in green freight transportation. Eur J Oper Res 274:807–823. https://doi.org/10.1016/j.ejor.2018.06.001
13. Nagurney A, Salarpour M, Daniele P (2019) An integrated financial and logistical game theory model for humanitarian organizations with purchasing costs, multiple freight service providers, and budget, capacity, and demand constraints. Int J Prod Econ 212:212–226. https://doi.org/10.1016/j.ijpe.2019.02.006
14. Chiang WC, Li Y, Shang J, Urban TL (2019) Impact of drone delivery on sustainability and cost: Realizing the UAV potential through vehicle routing optimization. Appl Energy 242:1164–1175. https://doi.org/10.1016/j.apenergy.2019.03.117
15. Gansterer M, Hartl RF (2018) Collaborative vehicle routing: A survey. Eur J Oper Res 268:1–12. https://doi.org/10.1016/j.ejor.2017.10.023
16. Ibarra-Rojas OJ, Hernandez L, Ozuna L (2018) The Accessibility Vehicle Routing Problem. J Clean Prod 172:1514–1528. https://doi.org/10.1016/j.jclepro.2017.10.249

17. García-Arca J, Carlos Prado-Prado J, Trinidad Gonzalez-Portela Garrido A (2014) "Packaging logistics": Promoting sustainable efficiency in supply chains. Int J Phys Distrib Logist Manag 44:325–346. https://doi.org/10.1108/IJPDLM-05-2013-0112
18. Molina-Besch K (2016) Prioritization guidelines for green food packaging development. Br Food J 118:2512–2533. https://doi.org/10.1108/BFJ-12-2015-0462
19. Boenzi F, Digiesi S, Facchini F, et al (2016) Greening Activities in Warehouses: A Model for Identifying Sustainable Strategies in Material Handling. pp. 0980–0988
20. Bartolini M, Bottani E, Grosse EH (2019) Green warehousing: Systematic literature review and bibliometric analysis. J Clean Prod 226:242–258. https://doi.org/10.1016/j.jclepro.2019.04.055
21. Mahroof K (2019) A human-centric perspective exploring the readiness towards smart warehousing: The case of a large retail distribution warehouse. Int J Inf Manage 45:176–190. https://doi.org/10.1016/j.ijinfomgt.2018.11.008
22. Roh SY, Shin YR, Seo YJ (2018) The Pre-positioned Warehouse Location Selection for International Humanitarian Relief Logistics. Asian J Shipp Logist 34:297–307. https://doi.org/10.1016/j.ajsl.2018.12.003
23. Singh RK, Chaudhary N, Saxena N (2018) Selection of warehouse location for a global supply chain: A case study. IIMB Manag Rev. https://doi.org/10.1016/j.iimb.2018.08.009
24. Ardjmand E, Shakeri H, Singh M, Sanei Bajgiran O (2018) Minimizing order picking makespan with multiple pickers in a wave picking warehouse. Int J Prod Econ 206:169–183. https://doi.org/10.1016/j.ijpe.2018.10.001
25. Öztürkoğlu Ö, Hoser D (2019) A discrete cross aisle design model for order-picking warehouses. Eur J Oper Res 275:411–430. https://doi.org/10.1016/j.ejor.2018.11.037
26. Taherdoost H, Brard A (2019) Analyzing the Process of Supplier Selection Criteria and Methods. Procedia Manuf 32:1024–1034. https://doi.org/10.1016/j.promfg.2019.02.317
27. Haeri SAS, Rezaei J (2019) A grey-based green supplier selection model for uncertain environments. J Clean Prod 221:768–784. https://doi.org/10.1016/j.jclepro.2019.02.193
28. Johnsen TE (2018) Purchasing and supply management in an industrial marketing perspective. Ind Mark Manag 69:91–97. https://doi.org/10.1016/j.indmarman.2018.01.017
29. Sureeyatanapas P, Poophiukhok P, Pathumnakul S (2018) Green initiatives for logistics service providers: An investigation of antecedent factors and the contributions to corporate goals. J Clean Prod 191:1–14. https://doi.org/10.1016/j.jclepro.2018.04.206
30. Evangelista P, Colicchia C, Creazza A (2017) Is environmental sustainability a strategic priority for logistics service providers? J Environ Manage 198:353–362. https://doi.org/10.1016/j.jenvman.2017.04.096
31. Jaaron AAM, Backhouse CJ (2018) Fostering sustainable performance in services through systems thinking. Serv Ind J 0:1–27. https://doi.org/10.1080/02642069.2018.1551371
32. Hair JF, Hult G, Ringle C, Sarstedt M (2014) A primer on partial least squares structural equation modeling (PLS-SEM). Sage Publications
33. Xue X, Zhang X, Wang L, et al (2018) Analyzing collaborative relationships among industrialized construction technology innovation organizations: A combined SNA and SEM approach. J Clean Prod 173:265–277. https://doi.org/10.1016/j.jclepro.2017.01.009
34. Ringle CM, Silva D, Bido D (2014) Modelagem de Equações Estruturais com Utilização do Smartpls. Rev Bras Mark 13:54–71. https://doi.org/10.5585/remark.v13i2.2717
35. Srai JS, Lorentz H (2019) Developing design principles for the digitalisation of purchasing and supply management. J Purch Supply Manag 25:78–98. https://doi.org/10.1016/j.pursup.2018.07.001
36. Cocca S, Ganz W (2015) Requirements for developing green services. Serv Ind J 35:179–196. https://doi.org/10.1080/02642069.2014.990002
37. Chin WW (1998) The partial least squares approach for structural equation modeling. In: Marcoulides, G.A. (Ed.). Modern methods for business research. Lawrence Erlbaum Associates, London, pp 295–336
38. Cohen J (1988) Statistical Power Analysis for the Behavioral Sciences, Second edi. Lawrence Erlbaum Associates

Supply Chain Management Practices in Small Enterprises: A Practical Implementation Guidance

Daniela Biccas Ferraz Matos, Luiz Felipe Scavarda, Rodrigo Goyannes Gusmão Caiado, and Antônio Márcio Tavares Thomé

Abstract Supply chain management (SCM) focused on large companies has received much attention from academics and industry practitioners. However, there is a dearth of studies covering SCM in small enterprises due to the differences between the realities of large and small enterprises, making it challenging to harness the existing accumulated knowledge of SCM for smaller ventures. Small enterprises are of great importance to the economy of many countries, especially in emerging markets such as Brazil. In this context, this article aims to expand the knowledge of SCM in small enterprises by analyzing SCM practices in companies in the State of Rio de Janeiro (Brazil). The practices analyzed in this research are customer relationship management, operations management practices, planning and business processes, and supplier relationship management. It provides a practical guide to implement and manage SCM practices in small enterprises successfully.

Keywords Operations management · Business process · Empirical study

1 Introduction

Supply chain management (SCM) plays a vital role in today's competitive market. Through SCM, small and medium-sized enterprises (SMEs) can obtain several benefits [1], in addition to generating a competitive advantage for these enterprises that need to differentiate themselves from large enterprises [2]. Some benefits are a better relationship with suppliers and customers, reduces costs [3, 4], reduces cycle and inventory time [5, 6], and increases company profit [1]. SCM research focuses on large enterprises, and this statement is still made today [7]. SCM research in small companies has not kept pace with the increase in management research associated with small companies, in addition to a greater focus on large companies [8]. Due to

D. B. F. Matos (✉) · L. F. Scavarda · R. G. G. Caiado · A. M. T. Thomé
Pontifical Catholic University of Rio de Janeiro (PUC-Rio), Marquês de São Vicente Street, Rio de Janeiro, RJ 22451-900, Brazil
e-mail: danielabiccas@uol.com.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_12

the scarcity in the literature of SCM studies in SMEs [9], it is necessary to go deeper into this subject. SMEs have different processes and systems from large enterprises [7], in addition to having more significant restrictions such as limited financial and technological resources [10, 11], thus impacting the approach of these enterprises concerning SCM [8]. Because of this, the implementation of SCM by SMEs is done differently from large enterprises, affecting their performance [12, 13].

Additionally, small enterprises are vital to the community, because SMEs are of great importance for the gross domestic product (GDP) [14] and for generating a large share of jobs in several countries [15]. SMEs contribute up to 60% of jobs and 40% of GDP in emerging countries [16], and they are a significant source of innovation in these countries [17], in addition to having an even more significant impact in developing countries than in developed countries [8]. The SCM effectively has a significant share in the survival of SMEs [18] and this effectiveness can be guaranteed through SCM practices. These practices are composed of a set of activities that aim to generate an effective SCM [19]. There is a shortage of the application of these SCM practices in SMEs [20, 21], however, in addition to having a positive impact on the performance of these enterprises [22], they are also essential to ensure proper implementation of the SMEs' SCM which will consequently improve the competitiveness of these companies in-relation to large enterprises [19, 23].

Taking into account the relevance of this theme and the scarcity of it in the literature applied in small enterprises mainly of SCM practices, and the importance these practices have in the performance of these enterprises, the following research question was elaborated to guide the work: How have SCM practices in small enterprises in a developing country been managed, implemented and structured? This article aims to increase the knowledge of SCM in small enterprises through the analysis of SCM practices in enterprises in the state of Rio de Janeiro. The specific objectives outlined in this work are: identify in the literature the difficulties and barriers faced by small enterprises in the management of their supply chains and propose practical guidance to implement and manage SCM practices in small enterprises successfully. The scope of the research is restricted to a set of companies located in the State of Rio de Janeiro and a set of four SCM practices considered relevant for the analysis.

This article is organized as follows. It presents next the theoretical foundation and then the methodology adopted. Section 4 discusses the main findings, and the final section offers the conclusion and suggestions for future research.

2 Theoretical Foundation

The main barriers and difficulties faced by SMEs in SCM are: SMEs are considered substitutable in the supply chain, and enterprises are afraid of forming partnerships with supplier SMEs [20]; SMEs do not use SCM to complement the company's strategic focus and they have difficulty in implementing SCM practices [12]; SMEs have a shortage of qualified people, lack of resources, lack of knowledge about SCM [3]; SMEs lack financial resources and they have difficulty in implementing technologies [24]; SMEs have scarcity of human resources and lack of capacity for innovation [25]; SMEs face the problem of lack of funding [26]; SMEs have little flexibility in varying the price of their products, there is a lack of managerial skills for decision makers, they have a high level of demand and one of the biggest problems faced by them is the inefficiency of the supply chain [27]; SMEs have difficulty in integrating the supply chain and in adopting communication and information technologies [28]; SMEs face the problem of customer order/demand uncertainty, fluctuation in the price of their raw materials and the lack of knowledge about SCM [29]; SMEs do not have uniformity in the company's goals and resources [8]; SMEs have difficulty in meeting customer requests and keeping quality and prices low [30].

SCM practices are expected to improve the long-term performance of participating enterprises and the supply chain as a whole, as these practices aim to integrate suppliers to the consumers effectively, also including producers and distributors [21, 31–33]. Some authors [34–36] approach SCM practices as business processes because with this approach companies can manage and structure supply chain relationships, making supply chain transactions more efficient and effective [36]. The eight main business processes in the SCM considered by [35] are customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, procurement, product development, and commercialization and returns process. The authors [34, 36, 37] also consider these same eight processes. However, they call the procurement, supplier relationship management, and the returns process, of returns management. The six group classifications of SCM practices by [38] are strategic supplier partnership, customer relationship, information sharing, information quality, internal lean practices e postponement. The author [22] uses five SCM practices, which are supplier integration, internal integration, customer integration, information sharing, and postponement.

Despite the different classifications, the concept behind the practices is the same. In this article, four SCM practices will be considered, as suggested in [39], which are, customer relationship management, operations management practices, planning and business processes, and supplier relationship management. There are many ways to deal with each practice; the equivalences of each will be described next.

Customer Relationship Management (CRM). This practice is understood as the sum of the customer relationship management and customer service management of the authors [34–37]. In customer relationship management, it shall be identified the customer profitability, which customers are critical for the company, and the level of service provided by the company [35]. This practice aims to structure how to develop and maintain the relationship with the customer, checking which activities add value and, if not, eliminate them, in addition, to develop products and services to increase customer loyalty [34, 36, 37]. Customer service management identifies all customer information, providing real-time information such as delivery dates to the customer [34, 36]; they are also responsible for detecting and solving problems before the customer realizes it [37]. As for [38], they consider the practice as customer relationship, whose objective is to deal with complaints and customer satisfaction, as a long-term relationship. The practice of [22], called customer integration, aims to identify and manage customer complaints, identifying their needs to improve their loyalty and create long-term relationships with customers. For [39], this practice aims to maintain and improve the level of service and quality provided to customers.

Operations Management Practices. This practice is understood by the authors [34–37], as the sum of demand management, order fulfillment, and manufacturing flow management. Demand management aims to decrease demand variability, increase supply chain flexibility and use demand forecasting to balance customer orders and company capacity [34–37]. Order fulfillment aims to obtain a continuous process from the supplier to the customer and to reduce the total cost of delivery when fulfilling customer orders [34–37]. Manufacturing flow management aims, through activities such as the analysis of manufacturing capacity and the identification of the level of inventory, necessary to serve the entire chain and make the product flow process more flexible and managing this flow through the facilities [34]. For [35], manufacturing flow management aims to avoid overstocking and unnecessary costs with it. It is understood by the author [38] as the sum of internal lean practices and postponement, the former having the objective of eliminating losses and producing at a speed of mass production, to increase the quality provided and reduce costs. Postponement allows the company to be more flexible when it comes to meeting changes in customer orders and consequently, rescheduling an operation or activity [38]. The authors [22] considers this practice of postponement, and they have the same objective as [38]. For [39], operations management practices aim to produce products and services efficiently.

Planning and Business Processes. This practice is understood to be the product development and commercialization of the authors [34–37]. The practice of product development and commercialization aims to identify the necessary resources and the bottlenecks of the process to produce new products quickly and efficiently [34]. For [36], this practice aims to develop and insert new products or derivatives of other products already on the market [40]. The authors [22], on the other hand, called this practice internal integration, whose objective is to structure his processes and his practices and strategies in a synchronized way [41] and to integrate information along the production chain and processes [38]. According to [37] to reduce the time for placing products on the market, suppliers and customers must be integrated into the process. For [39], the practice of planning and business processes is related to inventory policies and also aims to establish production standards.

Supplier Relationship Management (SRM). This practice is the procurement that aims, through strategic plans developed together with suppliers, to develop a relationship that benefits both sides with the ultimate goal of improving the manufacturing flow [35]. The authors [34, 36, 37] used the same nomenclature defined in this article. For [36], this practice aims to structure how companies should maintain and establish relationships with suppliers. For [34, 37], companies must determine their leading suppliers, identifying the profitability and capacity of each one. For [38], this practice, called the strategic supplier partnership, aims to establish long-term relationships between suppliers and companies, so that the company works with critical suppliers more effectively. The authors [22] referred to this practice as supplier integration, whose objective is to manage collaborative and long-term relationships with suppliers [42]. For [39], it aims to improve interactions with suppliers through practices and processes.

3 Research Methodology

Brazil was chosen as the study sample as it is an important emerging economy [43–45]. The study embraced six companies and the criterion to classify the followed the European Commission classification: microenterprises with 1 to 9 employees, small from 10 to 49 employees, medium from 50 to 249 employees, and large over 250 employees. The methodology adopted in this article comprises three stages. The first consists in applying the MIT GeneSys questionnaire to the six companies in the sample. The second consists of a more in-depth analysis of the shadowing of the company with the best level of adoption of the practices. The third stage consists of a final validation.

For the data collection, it was used the MIT GeneSys methodology proposed by [39], composed of four approaches: questioning, company tour, immersion, and shadowing. Data collection assesses the following criteria: company profile, business practices, SCM practices and behavioral operations. Through these approaches, composed of personal interviews and observations in the workplace, the data was collected on business processes and small enterprise decision-makers. As suggested by the MIT GeneSys methodology, the data collection process was carried out by two people, to understand what the company's day-to-day life is like, as the empirical research needs to involve more than one researcher in field data collection [46]. The questioning is composed of questions about the manager's profile and company profile, both answered by the general manager, to have an overview of the company and the profile of the company. Business practices are also part of the questioning, and they are made to the decision-maker, generally the general manager. The questions about business practices are always followed by questioning, to validate what has been answered, and they are classified into the following practices: cost control and bookkeeping, financial resources management, marketing & sales, replenishment and inventory policies. The company's tour aims to map the company's main assets. The third approach, immersion, aims through the day-to-day experience by the company duo to verify which SCM practices are used, being defined by the duo whether the company uses each practice or not. Practices are classified into customer relationship management, operations management practices, planning and business processes, and supplier relationship management. The MIT GeneSys methodology suggests this step be carried out on two consecutive days, depending on the size of the company. Finally, shadowing is done in pairs by monitoring and observing the activities of the decision-maker, to determine the amount of time spent in each activity, what they are and in which one the decision-maker spends more time [47]. The MIT GeneSys methodology recommends that the entire data collection process should take place in five days: the questioning is carried out in the first two days, the immersion, during the second and third days, and the shadowing takes place in the last two days. At the end of each day, the pair shall meet the decision-maker and validate the information collected on the day. The last step focused on the validation of results and the practical guidance for successfully implementing and managing SCM practices in small enterprises. On this step, it was necessary to return to the company chosen, to analyze a more in-depth way to validate the results obtained by it and the practical guidance; besides, the practical guidance also had a validation with a specialist on the subject [48].

4 Practical Guidance for Successfully Implementing and Managing SCM Practices in Small Enterprises

This section provides practical guidance developed for small enterprises to implement and manage SCM practices successfully. The guidance is organized according to the four SCM practices offered in the theoretical background, as discussed next.

Customer Relationship Management (CRM). An essential activity of this practice is to review the company's corporate and marketing strategies [34], as the company chosen for further analysis stated that marketing is its biggest weakness and it can affect the company's ability to acquire new customers. The company needs to identify and categorize its customers into critics and non-critics, and the criteria to be used for this categorization may be, for example, which customers generate higher profitability for the company, that may vary from company to company, to make critical customers the focus of the company's mission [34, 35]. The categorization of customers will help the company to offer personalized products and services to its critical customers, to increase their loyalty [37]. The company needs to keep track of which products are being purchased, which have had sales growth, in addition to meeting regularly with its customers [34]. The company should create criteria for accepting or rejecting customer order, analyzing the cost, impact on the company's sales, and the investment that will be necessary for the company [34], as the company should only accept an order considered costly or complex if it generates some future benefit or competitive advantage for the company [37]. Also, it is the manager's role to identify opportunities for improvement involving technology and infrastructure, to assess, about the logistics capacity, the weaknesses and strengths of his competitors, and what improvements can be promoted to his clients [37]. Whenever necessary, the company must interfere in favor of the customer, in addition to solving problems before they are perceived by them, verifying customer satisfaction with the product and the entire process until its delivery [37]. The company must also identify, and when necessary develop, which information systems and coordination mechanisms will be used, as these systems and mechanisms will be responsible for providing information to customers such as order status, shipping dates, among others [34]. It is essential for the company to deal with customer complaints and needs and to plan how each product/service will be delivered to it [38]. The manager has a fundamental role in this process, as it will help to identify the causes of customer complaints more quickly, such as delayed delivery [37]. When carrying out all these activities, the company will have a good relationship with its customers, because with that the company will provide a better level of service and quality to them.

Operations Management Practices. The company must know how to balance its customers' orders with the company's supply capacity (production, sales, and distribution) [34, 35]. It is an essential activity of this practice, and this balance can be achieved through demand forecasting, which can be carried out through, for example, sales projections and historical data; and the company must determine which is the best for it [34], taking into account seasonality and promotions in the forecast, as they may result in increased demand [39]. The company must identify problems related to the company's capacity and make suggestions for solving them [34]. Many companies in the sample do not know their capacity. An essential step for companies in this practice is the elaboration of contingency plans for internal or external problems that may interrupt supply or may cause unexpected changes in demand [37]. A way for the company to guarantee, through improvements, a smaller variation in demand, an increase in flexibility, and better use of the company's capacity are through the measurement of the demand forecast error and the use of the company's capacity [34].

The plans of the company's manufacturing, logistics, and distribution areas must be integrated, to effectively meet customer orders [35]. For this to happen, the company must know how many facilities produce which products, in addition to their capacities and locations, and it is also necessary to know where their suppliers are located and which transport modes the company will use [34]. The company must know the capacity and restrictions of its supply chain [37]. To ensure that the process of fulfilling customer orders can be carried out within the company's capabilities, it is necessary, for the manager, to participate in the design of the company's network [37], to meet customer requests and reduce costs related to delivery [35]. The company must record how the product will be picked up, stored and delivered to the customer; that is, all the information necessary to fulfill customer orders [34]. An essential step in this practice is to produce and deliver the product/service in the correct quantity and time [31], which should be one of the company's objectives. The company must also pay attention and carry out post-delivery activities, such as receiving and making payments; it is also essential to list the customers that are in debt [34].

The company needs to determine and know its manufacturing infrastructure necessary to fulfill its customers' orders and to identify when it is necessary to change its manufacturing technology [34]. To identify all the steps necessary to produce and have a process without interruptions, an essential step for the company [38], the company must have all of its processes described and mapped. To determine the minimum lot, establish deadlines and stock requirements, the company must analyze its manufacturing capacity. It is also essential to identify the level of inventory the company needs to meet the supply chain [34]. The following activities/steps were added to the guidance at the recommendation of the external expert: the company must use multi-functional systems to promote a culture of collaboration. Besides, the company needs to maintain excellent communication between the teams, and coordinate their processes in the industry in an integrated manner; it must also perform stock maintenance at safe levels, so that availability is available without the high cost. When carrying out all the steps/activities above, the company will have better control of its demand, thus reducing its costs and its level of inventory [22].

Planning and Business Processes. The company must involve its critical customers and suppliers in the development of new products, as it will efficiently coordinate the flow of new products along the supply chain [37]. The company needs to determine for each new product which resources it will use, and to identify possible problems that may hinder the development and commercialization of that product [34]. The manager has the role of helping to identify which is the best distribution channel for each new product and estimate the costs associated with the manufacture and distribution of these products [37], as each day the products have a shorter useful life, and should be launched with successful and with the shortest possible time to market [35]. It is also essential to determine for each new product which marketing and distribution channel will be used, the expected profitability, and the human resources needed for its development [34]. It is essential that the company's strategy, processes, and practices, are structured and that the information along the supply chain and production processes are integrated [22], obtaining information related to the inventory, such as which products sell more or which ones have a higher profit margin.

The following activities/steps were added to the guidance at the recommendation of the external expert: the company must plan and execute action plans together, thus obtaining a coherent and synchronized planning so that it responds promptly to market variations. It is also essential for the company to define the most appropriate form of organization in terms of systematic integration and coordination and the best strategy for the company at the horizontal and vertical levels. The company needs to optimize its bidirectional flow of goods, services, technology, information, human resources and knowledge among the components of the chain. To improve long-term performance throughout the chain, overcoming time constraints, the company must achieve common and specific objectives. It is also essential for the company to integrate its internal and inter-organizational processes, as well as the performance measurement methods/indicators and the practical requirements necessary for the integration of the supply chain.

Supplier Relationship Management (SRM). It is essential for the company to review its corporate, manufacturing, and supply strategies, in addition to identifying which products and services are essential for the company [34]. The company needs to categorize its suppliers as critical and non-critical, similar to CRM practice [37], using criteria such as the available capacity, profitability and stability of the supplier, the level of service required for the products purchased by the company. These criteria may vary from company to company [34]. The company needs to develop strong relationships with critical suppliers and personalized contracts with them, defining the terms of the relationship [37], and this relationship should be beneficial for both [35]. It is essential for the company to analyze the effect of each supplier on the company's profitability [34], as well as to meet regularly with its critical suppliers. However, several companies in the sample do not do it. Besides, the company needs to have its purchasing process structured and mapped, as well as to develop strategic plans with suppliers to improve the flow of manufacturing [35].

The following activities/steps were added to the guidelines as recommended by an external specialist: the company should use the information and communication technologies (ICTs), for example, e-commerce and Electronic Data Interchange (EDI) to manage the relationship with the supplier. However, due to the difficulty of small enterprises in adopting information and communication technologies, they may have difficulty in accomplishing this step. The company also needs to collaborate strategically with its critical suppliers to increase the value flow between partners using lean practices. The last activity to be recommended was to outsource activities to multiple suppliers.

Figure 1 offers a synthesis of the guidance developed in this research.

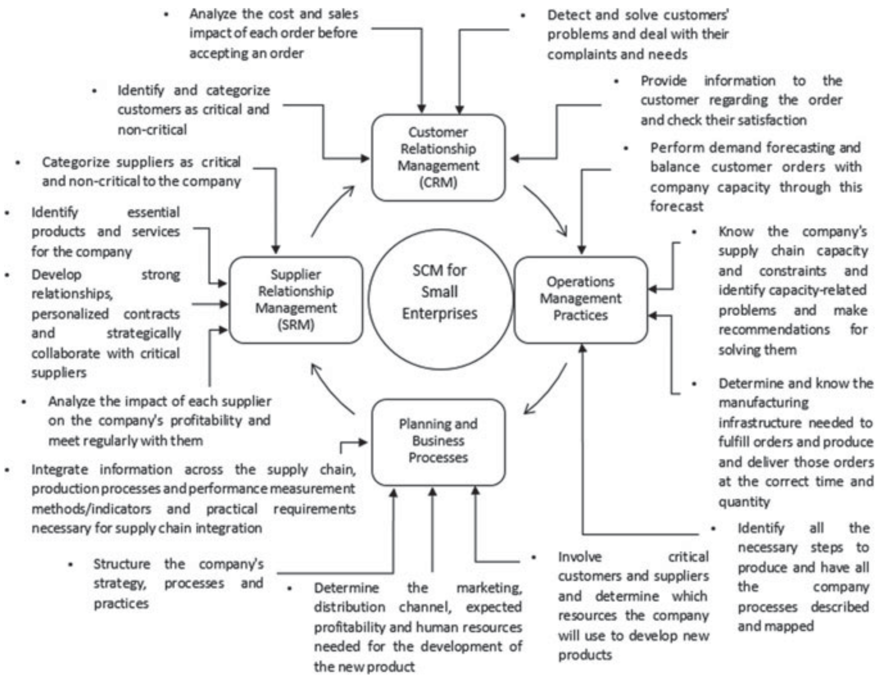


Fig. 1 Overview of the guidance

5 Conclusion

This article addressed, through an empirical study in six enterprises in the State of Rio de Janeiro, the topic of SCM practices in small enterprises, which resulted in practical guidance to successfully implement and manage SCM practices in small enterprises. This work is essential, as small enterprises are responsible for generating a large part of jobs and a large share of GDP in emerging countries, and because of the differences between the realities of small and large enterprises, and a shortage of studies focused on small SCM enterprises.

The research identified main problems and barriers faced by small enterprises in the SCM in the literature, being subsequently confronted with the sample of study to identify which of these problems small enterprises face. The main problems faced by the small enterprises in the sample at SCM are the lack of financial resources, scarcity of human resources and qualified people, and the difficulty in adopting information and communication technologies. After these analyses, practical guidance was developed on how small enterprises can successfully implement and manage SCM practices.

Regarding research limitations, the research was restricted to a set of six small enterprises located in the state of Rio de Janeiro and a set of four SCM practices. It is suggested for future work to expand the sample of enterprises involved in the study, conduct in other emerging countries to assess similarities and differences, and address more SCM practices.

Acknowledgements The following research agencies supported this work: Coordination for the Improvement of Higher Education Personnel—Brazil (CAPES) (Finance Code 001), Brazilian National Council for Scientific and Technological Development (CNPq) (Grant Numbers 404682/2016-2, 304931/2016-0 and 311757/2018-9) and Research Support Foundation of the State of Rio de Janeiro (FAPERJ).

References

1. Thoo, A.C., Sulaiman, Z., Choi, S.L., Kohar, U.H.A. Understanding Supply Chain Management Practices for Small and Medium-Sized Enterprises. IOP Conference Series: Materials Science and Engineering 215(1), article 012014 (2017).
2. Naipinit, T., Kojchavivong, S., Kowittayakorn, V., Na Sakolnakorn, T.P. McKinsey 7S model for supply chain management of local SMEs construction business in upper northeast region of Thailand. Asian Social Science 10 (8), 35–41 (2014).
3. Meehan, J., Muir, L. SCM in Merseyside SMEs: Benefits and barriers. TQM Journal 20(3), 223–232 (2008).
4. Thakkar, J., Kanda, A., Deshmukh, S.G. Mapping of supply chain learning: A framework for SMEs. Learning Organization 18 (4), 313–332 (2011).
5. Susanty, A., Sirait, N.M., Bakhtiar, A. The relationship between information sharing, informal contracts and trust on performance of supply chain management in the SMEs of batik. Measuring Business Excellence 22(3), 292–314 (2018).

6. Tan, K.C., Lyman, S.B., Wisner, J.D. Supply chain management: A strategic perspective. International Journal of Operations and Production Management 22(5–6), 614–631 (2002).
7. Thakkar, J., Kanda, A., Deshmukh, S.G. Supply chain management in SMEs: Development of constructs and propositions. Asia Pacific Journal of Marketing and Logistics 20(1), 97–131 (2008).
8. Kull, T.J., Kotlar, J., Spring, M. Small and Medium Enterprise Research in Supply Chain Management: The Case for Single-Respondent Research Designs. Journal of Supply Chain Management 54(1), 23–34 (2018).
9. Kot, S., Goldbach, I.R., Ślusarczyk, B. Supply chain management in SMES – Polish and Romanian approach. Economics and Sociology 11(4), 142–156 (2018).
10. Liao, Y., Barnes, J. Knowledge acquisition and product innovation flexibility in SMEs. Business Process Management Journal 21(6), 1257–1278 (2015).
11. Aguilar-Fernández, M.E., Otegi-Olaso, J.R. Firm size and the business model for sustainable innovation. Sustainability (Switzerland) 10 (12), article 4785, (2018).
12. Arend, R.J., Wisner, J.D. Small business and supply chain management: Is there a fit? Journal of Business Venturing 20(3), 403–436 (2005).
13. Côté, R.P., Lopez, J., Marche, S., Perron, G.M., Wright, R. Influences, practices and opportunities for environmental supply chain management in Nova Scotia SMEs. Journal of Cleaner Production 16(15), 1561–1570 (2008).
14. Yadav, V., Sharma, M.K., Singh, S. Intelligent evaluation of suppliers using extent fuzzy TOPSIS method: A case study of an Indian manufacturing SME. Benchmarking 25(1), 259–279 (2018).
15. Yacob, P., Wong, L.S., Khor, S.C. An empirical investigation of green initiatives and environmental sustainability for manufacturing SMEs. Journal of Manufacturing Technology Management 30(1), 2–25 (2019).
16. World Bank. Small and Medium Enterprises (SMEs) Finance, https://www.worldbank.org/en/topic/smefinance, last accessed 2019/09/29.
17. Kayvanfar, V., Husseini, S.M.M., Karimi, B., Sajadieh, M.S. Bi-objective intelligent water drops algorithm to a practical multi-echelon supply chain optimization problem. Journal of Manufacturing Systems 44, 93–114 (2017).
18. Hong, P., Jeong, J. Supply chain management practices of SMEs: From a business growth perspective. Journal of Enterprise Information Management 19(3), 292–302 (2006).
19. Wijetunge, W.A.D.S. The role of supply chain managment practices in achieving organizational performance through competitive advantage in Sri Lankan SMES. ISERD International Conference Singapore, 54, 6–13 (2016).
20. Quayle, M. A study of supply chain management practice in UK industrial SMEs. Supply Chain Management 8(1), 79–86 (2003).
21. Koh, S.C.L., Demirbag, M., Bayraktar, E., Tatoglu, E., Zaim, S. The impact of supply chain management practices on performance of SMEs. Industrial Management and Data Systems 107(1), 103–124 (2007).
22. Abdallah, A., Obeidat, B., Aqqad, N. The Impact of Supply Chain Management Practices on Supply Chain Performance in Jordan: The Moderating Effect of Competitive Intensity. International Business Research 7(3), 13–27 (2014).
23. Kumar, R., Singh, R.K., Shankar, R. Critical success factors for implementation of supply chain management in Indian small and medium enterprises and their impact on performance. IIMB Management Review 27(2), 92–104 (2015).
24. Bos-Brouwers, H.E.J. Corporate sustainability and innovation in SMEs: Evidence of themes and activities in practice. Business Strategy and the Environment 19(7), 417–435 (2010).
25. Lee, S.M., Kim, S.T., Choi, D. Green supply chain management and organizational performance. Industrial Management & Data Systems 112(8), 1148–1180 (2012).
26. Sener, S., Savrul, M., Aydin, O. Structure of small and medium-sized enterprises in turkey and global competitiveness strategies. Procedia – Social and Behavioral Sciences 150, 212–221 (2014).

27. Baymout, M. Supply Chain Management for Small and Medium Size Enterprises. International Journal of Advancements in Research & Technology 4(5), 20–34 (2015).
28. Mirkovski, K., Lowry, P.B., Feng, B. Factors that influence interorganizational use of information and communications technology in relationship-based supply chains: evidence from the Macedonian and American wine industries. Supply Chain Management 21(3), 334–351 (2016).
29. Kumar, R., Kumar Singh, R. Coordination and responsiveness issues in SME supply chains: a review. Benchmarking 24(3), 635–650 (2017).
30. Kayvanfar, V., S. Sajadieh, M., Moattar Husseini, S.M., Karimi, B. Analysis of a multi-echelon supply chain problem using revised multi-choice goal programming approach. Kybernetes 47(1), 118–141 (2018).
31. Tatoglu, E., Bayraktar, E., Golgeci, I., Koh, S.C.L., Demirbag, M., Zaim, S. How do supply chain management and information systems practices influence operational performance? Evidence from emerging country SMEs. International Journal of Logistics Research and Applications 19(3), 181–199 (2016).
32. Bayraktar, E., Gunasekaran, A., Koh, S.C.L., Tatoglu, E., Demirbag, M., Zaim, S. An efficiency comparison of supply chain management and information systems practices: A study of Turkish and Bulgarian small- and medium-sized enterprises in food products and beverages. International Journal of Production Research 48(2), 425–451 (2010).
33. Lee, V.-H., Ooi, K.-B., Chong, A.Y.-L., Sohal, A. The effects of supply chain management on technological innovation: The mediating role of guanxi. International Journal of Production Economics 205, 15–29 (2018).
34. Croxton, K.L., García-Dastugue, S.J., Lambert, D.M., Rogers, D.S. The Supply Chain Management Processes. The International Journal of Logistics Management 12(2), 13–36 (2001).
35. Lambert, D.M., Cooper, M.C. Issues in supply chain management. Industrial Marketing Management 29(1), 65–83 (2000).
36. Lambert, D.M., Garcia-Dastugue, S.J., Croxton, K.L. An Evaluation of Process-Oriented Supply Chain Management Frameworks. Journal of Business Logistics 26(1), 25–51 (2005).
37. Lambert, D.M., Garcia-Dastugue, S.J., Croxton, K.L. The Role of Logistics Managers in the Cross-Functional Implementation of Supply Chain Management. Journal of Business Logistics 29(1), 113–132 (2008).
38. Li, S., Rao, S.S., Ragu-Nathan, T.S., Ragu-Nathan, B. Development and validation of a measurement instrument for studying supply chain management practices. Journal of Operations Management 23(6), 618–641 (2005).
39. Velasquez, J., Quinones, C., MIT Genesys: Versão 2.0.7. Boston, MA: Massachusetts Institute of Technology, https://apps.apple.com/br/app/mit-genesys/id1361498872, last accessed 2019/10/05.
40. Rogers, D.S., Lambert, D.M., Knemeyer, A.M. The Product Development and Commercialization Process. The International Journal of Logistics Management 15(1), 43–56 (2004).
41. Flynn, B.B., Huo, B., Zhao, X. The impact of supply chain integration on performance: A contingency and configuration approach. Journal of Operations Management 28(1), 58–71 (2010).
42. Li, S., Ragu-Nathan, B., Ragu-Nathan, T.S., Subba Rao, S. The impact of supply chain management practices on competitive advantage and organizational performance. Omega 34(2), 107–124 (2006).
43. Ceryno, P., Scavarda, L.F., Klingebiel, K. Supply chain risk: empirical research in the automotive industry. Journal of Risk Research (Print) 18, 1145–1164 (2015).
44. Scavarda, A., Daú, G., Scavarda, L.F., Caiado, R.G.G. An Analysis of the Corporate Social Responsibility and the Industry 4.0 with Focus on the Youth Generation: A Sustainable Human Resource Management Framework. Sustainability 11, 5130 (2019).
45. Azevedo, B.D., Scavarda, L.F., Caiado, R.G.G. Urban solid waste management in developing countries from the sustainable supply chain management perspective: A case study of Brazil's largest slum. Journal of Cleaner Production 233, 1377–1386 (2019).

46. Voss, C., Tsikriktsis, N., Frohlich, M. Case research in operations management. International Journal of Operations and Production Management 22(2), 195–219 (2002).
47. McDonald, S., Simpson, B. Shadowing research in organizations: the methodological debates. Qualitative Research in Organizations and Management: An International Journal 9(1), 3–20 (2014).
48. Nascimento, D.L.D.M., Sotelino, E.D., Lara, T.P.S., Caiado, R.G.G., Ivson, P. Constructability in industrial plants construction: a BIM-Lean approach using the Digital Obeya Room framework. Journal of civil engineering and management, 23(8), 1100–1108 (2017).

Information and Data Quality States Model to Support Process-Aware Information Systems

Luiz Camolesi Jr.

Abstract The business productivity depends on the effective and efficient use of technological resources. Current business practices demonstrate the relevance of the effort to align three important organizational intangible assets: Information; Information Systems and Processes, seeking the optimization of related risks. Specifically, Information Systems must perform operations consistent with the business processes and models standardized in an organization or required in compliance with current legislation. The growing relevance of these requirements is realized in organizations that are defining their processes with quality and security parameters. The organizations are carrying out new information systems projects whose data transactions are aligned to non-functional requirements related to process management and corporate governance. In this sense, the researches in Process-aware Information Systems show the demand for adequate and flexible information quality model to fulfill the requirements of process quality. Process Mining, Six Sigma program and other quality analyzes procedures need increase with the improvement of the treatment of information. Considering that an insufficient data quality can cause a harmful effect in a process, this work presents a model of states and transitions for the quality dimensions with an individual focus on each identifiable datum in an information. This quality states model allows refined information control and monitoring in a bottom-up approach which can be used in Information Systems to prevent data with inadequate levels of quality being used in processes.

Keywords Process management · Process-aware information systems · Information quality

L. Camolesi Jr. (✉)
University of Campinas - UNICAMP, 13484-332 Limeira - SP, Brazil
e-mail: camolesi@ft.unicamp.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_13

1 Introduction

The sustainability of business processes depends on the effective and efficient use of technological resources [1]. Strategic Plan and Organizational Policies supported by Corporate Governance must be a guideline for the management areas to establish performance indicators and quality-oriented models. Current business practices demonstrate the relevance of the effort to align three important organizational intangible assets: Information; Systems and Processes, seeking the optimization of resources and related risks [2]. In this effort to integrate technological assets, complexity and costs are limiting to full implementation and consequent maximization of benefits [3]. Aiming at viability, organizations have been involved in quality standards and sustainable goals.

The motivation for this research has some factors: (1) the few studies and documented practices about the Information Asset that show procedures and implementations that would provide return on investments [4]. These studies do not propose an information quality model that is close to the human perception based on composition of quality characteristics of each parts (datum); (2) the common scenario of organizational resistance to implement data quality management processes. This resistance is caused by current approaches in the information technology sectors that do not promote an alignment between software engineering and process management activities, in addition to improve the development of Process-aware Information Systems [5].

Considering the motivation presented, the use of metadata dedicated to certain information quality characteristics is one of the viable research alternatives [6]. In this guideline, the objective of this article is to present the information quality represented by States. The State Model was developed with the proposal to use a bottom-up procedure in which individual attributions of the dimensional quality degree are carry out for each datum, as long as this datum is considered significant for the general quality of the information. The states and transitions represented have the flexibility to attend the diversity of processes and information systems in an organization.

2 Background

2.1 Process-Aware Information Systems

Organizational Practices on models and business process management allowed to recognize operational patterns related to information [7, 8]. Understanding these patterns is essential for the development of Process-aware Information Systems (PAIS), as they are technological processing and communication software that must comply with standards, legislation and business rules. These standards can be classified in [9]:

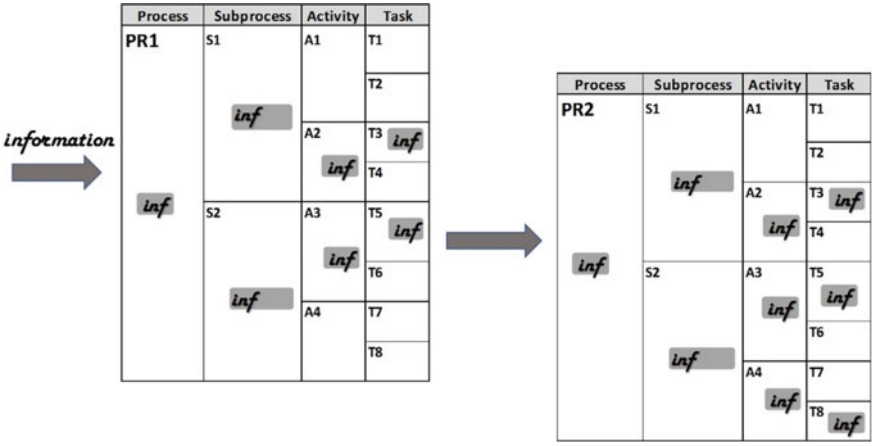


Fig. 1 Example of data-based routing

- Data Visibility: the manner in which data elements are viewed by components in a process;
- Data Interaction: the manner in which data elements are communicated between components in a process;
- Data Transfer: the means (interfaces) by which the data transfer occurs between components in a process;
- Data-based Routing: the manner in which data elements can influence the components in a process (see Fig. 1).

The insufficient quality of information can compromise the effectiveness and efficiency of critical processes. The information must be used in certain tasks or to transit along processes as long as the requirements that establish information quality levels are respected. Thus, information quality degrees are necessary parameters for intrinsic condition on Data-based Routing and the Process-aware Information Systems must monitor and limit the use of data respecting the conditions of information quality.

2.2 *Information Quality*

In the last decades, researches and organizational practices revealed that Quality is a complex property of information that requires details in several characteristics and dimensions [10, 11]. Organizations and stakeholders adopt different sets of dimensions to suit their processes and are limited by the costs of managing information quality. Table 1 presents some of these dimensions combined in categories, based on practices presented in COBIT and in several surveys [12–14].

Table 1 Categories and dimensions of quality information

Categories	Quality dimensions	Description
Intrinsic	QD 1—Accuracy	The degree to which the information is correct and reliable
	QD 2—Objectivity	The independence degree of information related to interference of any stakeholder
	QD 3—Believability	The credibility degree of the stakeholder who create or alter the information
Contextual	QD 4—Timeless	The Information update degree compared to the current scenario
	QD 5—Completeness	The missing degree or insufficient meaning
	QD 6—Relevancy	The importance degree of information for stakeholders and processes
Representational	QD 7—Consistent	The use compliance degree of information
	QD 8—Concise	The content density degree
Accessibility	QD 9—Usability	The easily degree by which information is used on processes
	QD 10—Availability	The degree to which information is available when required

3 Research Methodology

This research is supported in the hypothesis of a state model applied to each quality dimension of each datum that composes an information is a viable and adequate resource for monitoring, control and Process-aware Information Systems. In order to carry out this research involved a qualitative study with more than two hundred professionals on areas of information technology or process management from organizations of different areas and size.

Those professionals participated in a information technology management improvement course promoted by the University of Campinas, and were invited to experiment and improve data quality management practices based on metadata of the quality status. The main steps of these unstructured studies were: (1) the current processes in organizations were questioned and analyzed in relation to the existence and maturity levels of data quality management. The overall result showed consistent interest and concern with these processes, but low levels of implementation; (2) among organizations with implemented processes, at any level of maturity, it was asked whether quality is treated in different dimensions (characteristics) or in a generic and abstract way. The general results showed a low level of detail in the information quality involved in critical processes; (3) In the end, for all groups of professionals, a case study was presented in which a fictitious organization has demand for greater quality control over its information. After being presented with proposals for a state-based quality model, the case study required the groups to make their considerations and solutions for implementing data quality management. The solutions have been refined over the years and by the participating groups, resulting in the Quality States Model presented.

4 The Quality States Model (QSM)

In order to represent the different levels of information quality in an organization, the Quality States Model (QSM) can have a high complexity and unviable cost of implementation. To avoid these negative aspects in the context to support Process-aware Information Systems, a States Model applied to information quality should preferably be simple, with few states and flexible transitions.

The Quality States Model defined in this research is based on the evaluation of four typical scenarios: evolution; regression; passing and neutrality. For the sake of simplicity, the proposed model establishes four basic states in the definition of datum quality degree:

- Required: ideal or acceptable quality to the dimension;
- Transient: transitional or intermediate quality to the dimension;
- Unwanted: invalid or unacceptable quality to the dimension;
- Indifferent: neutral quality to the dimension.

The Quality States Model represented in Fig. 2 shows that any basic state can be the initial State as well as the final State of quality. All transitions (1 until 9) represent changes or validation carried out in a process. Processes with tasks that perform transitions 6 and 9 are increasing the data quality, while the processes that perform transitions 5 and 8 are regressing in quality and, therefore, require more control and management. In certain organizational contexts, the decomposition of any basic state into sub-states may be a requirement for complex and rigorous processes, for example, the *Transient* state having several intermediate transitional sub-states used on validation.

The QSM provides a mapping of the quality of each datum in an information over time. In this quality trajectory, data can transit through several states, but it is not always possible to keep it in the *Required* or Transient state. For example, a trajectory of a datum *Address* or information *Client* can start in state B (*Transient*), passing through state A (*Required*), but also through the *Unwanted* state C (Fig. 3).

The mapping of processes that participate in the trajectory becomes a valuable resource to identify tasks that change information to the *Unwanted* state, causing loss of quality or high cost in the processes that need qualified information. In the case of Fig. 3, the process 2 not perform the necessary update of the information and causes transition 8 to the *Unwanted* state. Following the tasks, process 3 restores the desired quality.

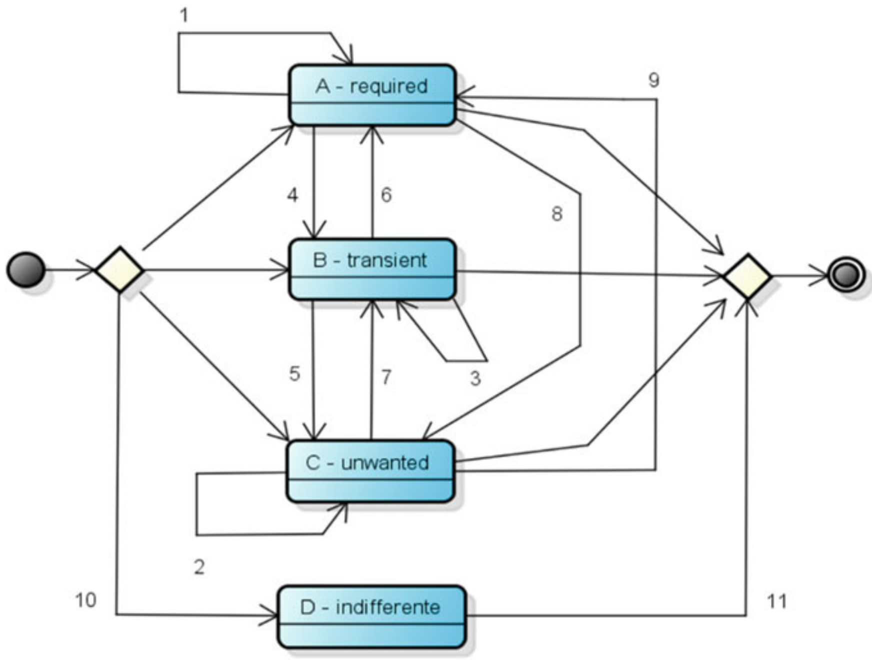


Fig. 2 Model of basic states

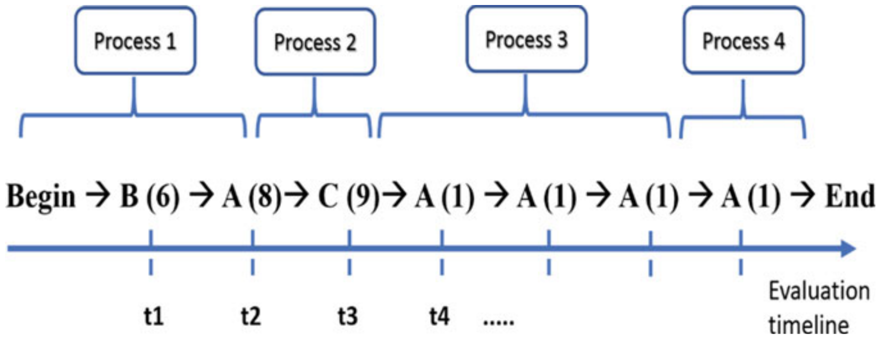


Fig. 3 Information quality trajectory (with processes)

5 Quality Decomposition

Processes may require the information quality to be identified by the quality of its parts. This need is supported by the Feigenbaum's work which describes that a Total Product Quality (QTP) is a combination of several quality characteristics (Ci) of a product and related quality indicators (Qi) or weights [15]. On theses bases, the information is a product whose quality can be perceived by the individual analysis of each datum [16].

For example, consider a Maintenance Management System—MMS for which machine maintenance services are requested. In this system, the *Information Maintenance Request* is composed of several data with different quality levels required by the managers. Based on analysis carried out by the management, it is necessary to establish to each datum which quality dimensions states are acceptable for the processes involved. Ideally, processes should only accept dimensions in the *Required* state, and therefore, only dimensions in these states are used in the general assessment of the information quality (see Fig. 4). In certain organizational contexts, some processes may not be hindered if the datum quality state is *Transient* or *Undesirable*.

In the case of Fig. 4, two simplified processes for a Maintenance Management System—MMS are represented: P1—Maintenance Request Analysis; P2—Completion of Maintenance Request, and use the information *Service Request*. The states not shown in Fig. 4 are quality dimensions not required in the processes. For these cases, a management can choose to use the *Indifferent* state to explain the quality or not indicate anything.

The mapping must support the quality of processes and information systems, such as the Maintenance Management System, and be used to restrict the access to

Process
P1 : Maintenance Request Analysis

Information: Service Request	Quality Dimensions									
Datum	QD 1	QD 2	QD 3	QD 4	QD 5	QD 6	QD 7	QD 8	QD 9	QD 10
Da1 - Requester Identification	State A				State A					
Da2 - Machine Identification	State A				State A	State A				
Da3 - Occurrence Date	State A						State A			
Da4 - Incident Description	State A	State A	State A		State A	State A			State A	
Da5 - Requested Priority					State A	State A				
Da6 - Responsable Department					State A					
Da7 - Accountable Employee							State A			
Da8 - Maintenance Restrictions	State A							State A		
Da9 - Comments										

Process
P2 : Maintenance Request Completion

Information: Service Request	Quality Dimensions									
Datum	QD 1	QD 2	QD 3	QD 4	QD 5	QD 6	QD 7	QD 8	QD 9	QD 10
Da1 - Requester Identification					State A					
Da2 - Machine Identification	State A				State A	State A				
Da3 - Occurrence Date										
Da4 - Incident Description	State A				State A	State A			State A	
Da5 - Requested Priority					State A	State A				
Da6 - Responsable Department					State A					
Da7 - Accountable Employee							State A			
Da8 - Maintenance Restrictions	State A							State A		
Da9 - Comments										

Fig. 4 Process and data quality requirements (dimensions and states)

Information: Service Request	Quality Dimensions									
Datum	QD 1	QD 2	QD 3	QD 4	QD 5	QD 6	QD 7	QD 8	QD 9	QD 10
Da1 - Requester Identification	5%				5%	5%				
Da2 - Machine Identification	10%				5%	5%				
Da3 - Occurrence Date	5%						2%			
Da4 - Incident Description	5%	5%	2%		5%	5%			2%	
Da5 - Requested Priority					5%	5%				
Da6 - Responsable Department					5%	5%				
Da7 - Accountable Employee							2%			
Da8 - Maintenance Restrictions	10%							2%		
Da9 - Comments										

Fig. 5 Summarization of quality dimensions

information that does not aligned to the defined quality indicators [17]. Commonly, a precise control of the information quality for each process involved have high cost, therefore, the composition (summary) of the general quality of information must be carried out, benefiting all processes with a unique quality degree [18].

In Fig. 5, the quality summary shows the necessary dimensions set to represent the information quality. The states composition of the dimensions for all data summarizes the information quality degree required in the analyzed processes. In the case shown, there are twenty-one characteristics (datum, dimension and status) of *Service Request* that must be analyzed to determine the information quality. Additionally, weights can be select for calculate the quality using a Weighted Arithmetic Mean or other mathematical approach.

For the calculation of quality, the weight of each data must be decided by the stakeholders. The decision to assign equal weights for all characteristics should provide less difficulty in implementation and management, but there may be scenarios in which certain characteristics have a greater impact on quality, as shown in Fig. 5.

6 Implementation

Metadata are fully adequate for quality representation because they are targeted at specific professionals who perform management roles [6]. The representation format of quality metadata will depend on the information systems architecture used by the organization, but it is important to select flexible forms that allow inserting and removing quality dimensions when new business requirements have been established. The organization that uses relational databases can extend its tables with a JSON type column containing all characteristics: attribute; dimension; status (see Fig. 6).

Process Mining [19], Six Sigma Program [20] and other quality analyzes require the states labels to be converted to a numerical scale [21]. The discrete values of easy processing can be: (1) Required; (0) Transient State; (−1) Unwanted. Dimensions in the *Indifferent* state do not need to be registered and processed. This scale for each dimension allows the calculation of the general quality of the information, with values between −1 (no quality) and 1 (maximum quality) and the datatables can

Table: Service Request						
Da1	Da2	Da3	Da4	......	Quality Characteristic Metadata	Quality Resume Metadata
E2351	M578	03/05/2019			[{"Atributte" : Da1; "Dimension": QD 1; "State": 1}, {"Atributte" : Da2; "Dimension": QD 1; "State": 1}, {"Atributte" : Da3; "Dimension": QD 1; "State": 1}, {"Atributte" : Da4; "Dimension": QD 1; "State": -1}, ...]	**0,83**
E1389	M9211		machine just won't turn on		[{"Atributte" : Da1; "Dimension": QD 1; "State": 1}, {"Atributte" : Da2; "Dimension": QD 1; "State": 1}, {"Atributte" : Da3; "Dimension": QD 1; "State": -1}, {"Atributte" : Da4; "Dimension": QD 1; "State": 0}, ...]	**0,61**

Fig. 6 Datatable: service request and quality metadata

record the information quality indicator to avoid unnecessary recalculations every time an Information System needs these metadata. In cases of unnecessary precision in the quality indication, the numeric indicator can be converted to a state of the model, using ranges of values such as: *Required* (1.00 to 0.80); *Transient* (0.79 to 0.50); *Unwanted* (0.49 to 0.00).

7 Conclusion

Traditionally, information quality research considers dimensions as macro-characteristics whose analysis is carried out in an extensive and superficial process supported by assertions (constraints) or based on statistical patterns of value distribution. The demands for quality in critical processes and systems require further refinement of the information quality dimensional model.

The present study contributes to existing researches with a comprehensible decomposition of information quality in several characteristics (quality dimensions) of each component (datum). In addition, this research innovates with use of predefined state metadata based on a flexible model that consider four typical scenarios: evolution; regression; passing and neutrality. The Quality States Model (QSM) enables a more accurate quality analysis procedure to support Process-aware Information Systems.

Among the limitations for using this research in organizations is the requirement for adequate maturity levels of selected business processes, so that the quality mapping using the QSM is not wasted in unstable (or unpredictable) processes. In addition to practical implications, another limiting scenario involves the availability of resources to carry out Process-aware Information Systems (PAIS) engineering or Information System reengineering, both requiring a transactional database enable to store and provide the information quality states.

The implementation of QSM requires that the engineering teams (data, software and processes) recognize the data quality requirements and not only elicit the requirements based on the analysis of the information systems projects and process engineering. The model presented enables several procedures for the attribution of quality status. The dimensions that require a subjective validation demand the collaboration of stakeholders to determine the quality status. The objective dimensions, more recommended due to the lower attribution cost, require the Process-aware Information Systems or other software tools to carry out the evaluation based on parameters established by the organization.

Among the future researches is the development of a technique for defining minimum quality indicators based on the QSM, which would be compared with quality metadata such as the Quality Resume Metadata (Fig. 6). These indicators would establish essential non-functional requirements for the use of information in related processes and information systems.

References

1. The Open Group: The Open Group Architecture Framework (TOGAF), Version 9.2, The Open Group (2018).
2. Lee, Y. W.; Strong, D. M.; Kahn, B. K.; Wang, R. Y.: AIMQ: A methodology for information quality assessment. Elsevier, Information & Management 40, 133–146 (2002).
3. English, L. P.: Improving Data Warehouse and Business Information Quality: Methods for Reducing Costs and Increasing Profits. Wiley Computer Publishing (1999).
4. Fan, W.; Geerts, F.: Foundations of Data Quality Management. Morgan & Claypool Publishing (2012).
5. Madnick, S. E.; Wang, R. Y.; Lee, Y. W.; Zhu, H.: Overview and Framework for Data and Information Quality Research. ACM Journal of Data and Information Quality 1(1), 2–22 (2009).
6. Inmon, W. H., O´Neil, B., Fryman, L.: Business Metadata. Elsevier (2018).
7. Aalst, W. M. P. van der; Hee, K. van: Workflow Management: Models, methods, and systems. MIT Press (2004).
8. Russell, N.; Aalst, W. V. D.; Hofstede, A. H. M.: Workflow Pattern: The Definitive Guide. MIT Press (2016).
9. Dumas, M; Aalst, W. M. P. V.; Hofstede, A. H. M.: Process-aware Information System: Bridging People and Software Through Process Technology. Wiley-Interscience (2015).
10. Batini, C.; Scannapieco, M.: Data Quality: Concepts, Methodologies and Techniques. Springer (2006).
11. DAMA: DMBoK - Data Management Book of Knowledge. 2nd edn. Technics Publications (2017).
12. ISACA: COBIT 5: Enabling Information. Information Systems Audit and Control Association (2013).
13. ISACA: COBIT 2019 Framework: Governance and Management Objectives. Information Systems Audit and Control Association (2018).
14. Ladley, J.: Making Enterprise Information Management (EIM) Work for Business A Guide to Understanding Information as an Asset. Elsevier (2010).
15. Feigenbaum, A.: Total Quality Control. McGraw-Hill (2015).
16. Wang, R. Y.; Lee, Y.; Pipino, L.; Strong, D.: 1998. Managing your information as a product. MIT Sloan Management Review. Summer, 95–106 (1998).
17. McGilvray, D.: Executing Data Quality Projects. Morgan Kaufmann Publishing (2008).
18. Loshin, D.: The Practitioner's Guide to Data Quality Improvement. Elsevier (2011).
19. Aalst, W. M. P. van der.: Process Mining: Data Science in Action. 2nd edn. Springer (2016).
20. Pyzdek, T.: The Six Sigma Handbook: Revised and Expanded: Complete Guide for Green Belts, Black Belts, and Managers at All Levels. McGraw-Hill (2003).
21. Sebastian-Coleman, L.: Measuring Data Quality for Ongoing Improvement: A Data Quality Assessment Framework. Morgan Kaufmann Publishers (2013).

Identifying Patient Demand New Patterns in Emergency Departments a Multiple Case Study: A Forecasting Approach

Daniel Bouzon Nagem Assad, Javier Cara, and Miguel Ortega-Mier

Abstract Patient demand arrival prediction is a critical problem to emergencies departments (EDs) that must delivery timely and adequate treatment to meet patient needs. High accuracy on patient demand forecasting allows ED managers to better size and allocate health care professionals. Besides patients can arrive any time expecting for quickly medical assistance, ED managers must provide efficient resource planning in order to fulfill that expectance limited by balance financial budgets. In this paper, the problem of ED patient arrival forecast is proposed as a planning tool allowing ED managers to better prepare short- and long-term staffing policies for the coming demand variations. We apply statistical time series techniques on four EDs historical data to catch patient demand pattern arrival behavior hourly, weekly and yearly all over the time and, thereafter, we forecast them one year ahead. The hourly forecasted patient demand pointed out the grown of pediatrician service while physician service decreases over the time. In addition, forecasted results shows that health care professionals which work on night shifts will find more variation in patient demand than professionals which work on morning shifts.

Keywords Health care operation management · Emergency department · Forecast

D. B. N. Assad (✉) · J. Cara · M. Ortega-Mier
Universidad Politécnica de Madrid, Madrid, Spain
e-mail: daniel.nagem.bouzon@alumnos.upm.es; danielbouzon@gmail.com

J. Cara
e-mail: javier.cara@upm.es

M. Ortega-Mier
e-mail: miguel.ortega.mier@upm.es

D. B. N. Assad
Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_14

1 Introduction

Brazilians' Unified Health System (SUS) was established as a strategy to overcome traditional Health Regions fragmentated health services and management. SUS's objective is guaranteeing that the set of needed services and resources with effectiveness and efficiency. In this context, Emergency departments (EDs) plays a key role in the whole healthcare system connecting local health systems on different levels of attention to deliver a proper and resolutive service [1].

All over the world patients go to EDs in order to be quickly treated by EDs services at any time (every day and 24 h/day). Thus, planning an efficient medical operation became a great challenge as long as patients' needs no appointments to access an ED. It requires from managers perspective a set of allocative decisions that must be made eventually on real time in order to fill and balance all ED processes (e.g., registration, triage, and consultation) that meets timely patient treatments within limited financial budgets [2].

In order to better estimate "timely" or/and "required resources" to patient's treatment, at the global level, the most used protocols are Australian Triage Scale, Canadian Emergency Department Triage and Acuity Scale, Emergency Severity Index e Manchester Triage Scale [3]. Recent researches like Afilal et al. [4] and Kadri et al. [5] improved the "traditional" protocols by proposing alternatives triage criteria by introducing categories to help the ED's staff planning their activities in the long and the short-term and integrating a specific patient group (classification/triage) to specific resources like radiology and biology services respectively.

Even adopting rigorous medical protocols or improving them considering another variable, occasionally ED demands exceed capacity (overcrowding) [6] due to patients demand characteristics, which are described above. The ED overcrowding problem and its consequences are unfortunately common on several countries and are, in general, caused by inadequate resources allocation, increase in demand for ED services and epidemic seasons [7]. Besides overcrowding, a recent systematic literature review (SLR) [8] pointed out extended length of stay (LOS), prolonged wait time and excessive patient time flow time as decisive factors that impact the number of patients who leave without being seen (LWBS). Additionally, LWBS can be potentially be readmitted within the next few hours with more severe and complex needs.

Thus, the same authors conduced their SLR in order to answer how current researchers and practitioners deals with resource allocation problems or process design for some "unknown" patient demand (uncovered on their review).

But how can we discuss resource allocation to meet patient "timely" treatment without previous evaluation patient arrival behavior? The current research aims to discuss properly the theoretical background about the ED patient forecasting while in [9] we focus on answer this "balance" question applying time series techniques on four EDs manage by a public company on Rio de Janeiro city.

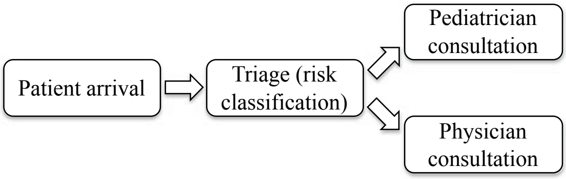


Fig. 1 ED process. *Source* The authors

The current research is, therefore, an enhanced version of Assad et al. [9] where we improved the theoretical background section. In [9] we used time series techniques in order to:

1. Evaluate historical patient arrival by each classification risk degree dividing them in pediatrician and physician attendance in four different ED's on Rio de Janeiro state. These processes are presented in Fig. 1;
2. Predict all these patient arrivals one year ahead;
3. Point out differences between historical and predicted patient arrivals in each shift (morning and night).

2 Theoretical Background

The ED's efficiency expressed by waiting time and length of stay (LOS) are related to how better is balance between ED resources (doctors, nurses, beds, medical equipment, etc.) and demand (patient arrivals). Linking them, accurate forecasting of ED patient demand can support long and short-term staffing policies in order to better prepare ED for the coming demand variations [10].

Although time-series forecasting drew the attention of the scientific community when Yule introduced a general approach for time-series analysis in 1927 [11] only in 1988 appeared the first based model to forecast total attendance of an ED using autoregressive and moving average models [12] and, recently, statistical forecasting concept has gained popularity in ED problems by allowing ED stakeholders to plan their processes efficiently and, as consequence, improving service quality [10].

In 2009, Wargon et al. [13], evaluated models for forecasting ED visits in a systematic review and discussed the limitations and pointing advantages of nine identified studies. 9 year later Gul and Celik [10] provided an exhaustive review and analysis on applications of statistical forecasting in hospital emergency departments where 106 were classified by: method(s) used, specific objective, data range, aggregation of available data (by hour, day, week or month) and performance measures.

Looking at ED admission Gul and Celik's review [10] found 41 papers that deals with univariate or multivariate time series using basically the following models: autoregressive and moving average models (ARMA, ARIMA, SARIMA, MSARIMA), regression models (Linear, support vector, Poisson, Logistic), exponential smooth (Holt-Winters, Seasonal multiplicative Holt-Winters), Support vector machine, Artificial neural network and Exponentially weighted moving average.

Although the mentioned authors had found many forecast techniques their review presented only five researches where the available data were aggregated/analyzed hourly. In this short sample only Morzuch et al. [13] and Kim et al. [15] researches had the aim to forecast properly ED patient demand while Chase et al. [16] proposed forecasts an indicator ("care utilization ratio") that takes into account 3 variables: patient demand (new arrivals), patients waiting to see a doctor (patients triaged) and total physician capacity. The other researches tried to predict the patient admission on next hours or days of visits based on previous web site information [17], predict patient demand volume based on a function of temporal, climatic, and patient factors [18].

Although Chase et al. [16] proposal allows manage on real time the ED "physician response", care utilization ratio indicator can potentially hide a high patient waiting time when the physician capacity estimator has high level. It becomes possible because physician capacity takes into account not only physician historical average attendance rate, but also depends on the level of experience of professionals' workforce. In other words, an "acceptable" care utilization ratio could be seen in a scenario with higher patients waiting times and being served by professionals with higher level of experience.

Uncovered by Gul and Celik [10], Jiang et al. [19] states that frequently traditional statistical models are used to predict patient arrival like General Linear Method (GLM), ARIMA models, and classical shallow artificial neural network (ANN) has poor accuracy in long-term and proposes a deep learning approach to forecast patient demand per hour 28 days ahead.

The data used in our proposal and in similar researches [14–16, 19] is summarized below:

1. date and time of check-in (registration);
2. date and time of triage consultation (begin and end);
3. patient risk degree level (given in triage process);
4. date and time of doctor consultation (begin and end).

Other researches have been conducted discussing daily patient demand but proposes different triage criteria in other meet patient needs (severity and resources required) like Afilal et al. [4] and Kadri et al. [5].

We focus on researches which had worked with hourly forecasts by a unique reason: the challenged of health care professional allocation is widely divided into two time windows of 12 h that will be called as shift. In Brazil, these two shifts start at 7 a.m. (also known as morning shift) and at 7 p.m. (also known as night shift). So, although daily and monthly time windows forecasting can provide great insights for general resource allocation problems, in workforce planning problem it does not work well. Moreover, hourly forecast can provide us analyze demand peaks all over the hours and better estimate the patient waiting time problem.

3 Problem Statement

RioSaúde is a public company located in Rio de Janeiro, Brazil and is responsible for the management of 4 emergency departments in the city. These 4 emergency departments are open 24 h a day, and each ED receives an average of 121,195.5 patients per year (an average of 334.22 patients daily). The data used were provided by the company tracks the beginning and ending data and time of each ED activity by patient for all units for the period from 01/01/2015 to 30/06/2017.

In Brazil, this capacity is clearly defined only to doctors by Ordinance no. 10 of January 3, 2017 [20] as presented in the Table 1. Although the same ordinance state that triage process must be done before patient consultation, minimal number of nurses has no mention.

The Manchester Triage Scale (MTS) has been adopted in most emergency department as a guiding instrument for risk classification, prioritizing the most serious cases based on the degree of risk [1]. Each risk classification degree and their maximum waiting time expected are presented in Table 2. The triage is conducted by nurses.

Patient demand by unit and by classification risk degree as well as unit classification according to ordinance parameters are presented in Table 3. In Table 4 presents

Table 1 Minimal number of doctors by ED size per shift. *Source* Brazilian ordinance [20]

ED sizes	Monthly average of medical consultations	Minimal number of doctors from 7 a.m. to 7 p.m.	Minimal number of doctors from 7 p.m. to 7 a.m.
I	2250	1 doctor	1 doctor
II	3375	2 doctors	1 doctor
III	4500	2 doctors	2 doctors
IV	5625	3 doctors	2 doctors
V	6750	3 doctors	3 doctors
VI	7875	4 doctors	3 doctors
VII	9000	4 doctors	4 doctors
VIII	10125	5 doctors	4 doctors

Table 2 Risk classification degree and patient maximum waiting time expected to see a doctor. *Source* Current company's medical protocol

Risk classification degree (color)	Maximum waiting time expected	Patient clinical condition
Red	Immediately	Resuscitation
Orange	Less than 15 min	High emergency
Yellow	Less than 30 min	Intermediate emergency
Green	Less than 60 min	Low emergency
Blue	When there are no emergency patient waiting	No emergency

Table 3 Patient Classification risk degree proportion and ED size classification. *Source* The authors retrieved from company dataset and Brazilian ordinance [20]

Patient classification risk degree	CER ED	CDD ED	RM ED	RM ED	SC ED
Red (%)	1.17	0.32	0.45	0.20	1.17
Orange (%)	5.55	3.27	2.32	1.39	5.55
Yellow (%)	26.54	17.07	16.19	14.19	26.54
Green (%)	66.48	78.70	79.88	83.65	66.48
Blue (%)	0.26	0.63	1.16	0.57	0.26
Monthly medical consultation average	10718	8714	10764	10468	10718
ED size (see Table 2 parameters)	VIII	VII	VIII	VIII	VIII

Table 4 Total patient demand by ED and by type of service offered. *Source* The authors retrieved from company dataset

ED versus services	Physician	Dentistry	Pediatrician	Psychiatry
CER ED	173958	0	67743	1230
CDD ED	115079	5017	38626	0
RM ED	167460	0	71696	0
SC ED	180753	4449	64477	0

the total patient demand by ED and by type of service offered. As dentistry and psychiatry are not offered by all units and together only represents 1.2% from total patient's records, in this research, we only are taking into account physician and pediatrician services.

3.1 Research Questions

In Sect. 2 we pointed out that ED patient demand forecasting can support long- and short-term staffing policies and in this research, we will use it in order to answer the following questions:

1. Is possible to state that 1 year ahead all ED's mentioned in Table 3 will remain on their actual ED size comparing forecasted demand with monthly average of medical consultations presented in Table 2?
2. The proportion between physician and pediatrician consultations will change comparing in each ED actual versus forecasted demand?
3. The proportion between patient arrival in morning shift and night shift will change comparing in each ED actual versus forecasted demand?

4 Forecasting

In this section we will present the approach used to determine and build the forecasting models for our case study. In order to answer research questions above our horizon in this problem will be 1 year using hourly steps, in other words, we will forecast 8760 h ahead.

The software used for data processing was Software R Version 3.5.2 and to deals with hourly forecasting we had to consider 3 frequencies: the day, the week and the year.

4.1 Forecasting Model Selection

We analyzed all 40 time-series (one time-series by each unit, patient classification risk and medical service) using 80% of original time-series as data training (patient demand on first 7008 h) and the other 20% as data test (the last 1752 h). The data training was used as input data by the following forecast techniques:

1. Naive (NAIVE);
2. Seasonal naive (SNAIVE);
3. Random walk with drift (RWF);
4. Exponential Smoothing State Space Model (ETS);
5. Autoregressive Integrated Moving Average (ARIMA);
6. Trigonometric Exponential Smoothing State Space model with Box-Cox transformation, ARMA errors, Trend and Seasonal Components (TBATS);
7. Linear regression (LR).

Thereafter, for each forecasting model presented we predict 1752 h ahead and compare that expected value with our data test (last 20% of our original data). For each time-series we choose the model that presented the lower Root Mean Square Error (RMSE).

Finally, after choosing all 40 better models considering RMSE criteria we were able to conduce the 1 year forecast ahead that allow us to answer the research questions proposed on Sect. 3.

4.2 Forecasting Results and Discussion

In Table 5 we answer the first research question giving the monthly average expected by patient demand forecasted in each ED. Research's' question 2 and 3 are summarized in Table 6 where we present patient's admission average by hour at historical morning shift (HMS), historical night shift (HNS), Forecasted morning shift (FMS), Forecasted night shift (FNS) and their performance measure chosen to evaluate error: root mean squared error (RMSE).

Table 5 ED patient admission monthly average forecasted, and ED size based on Brazilian ordinance [6] criteria. *Source* The authors

EDs	Monthly average forecasted	ED sizes based on forecasted values	ED sizes based on historical data
CER ED	10420	VIII	VIII
CDD ED	5739	V	VII
RM ED	9329	VII	VIII
SC ED	9116	VII	VIII

Table 6 Patient Classification risk degree proportion and ED size classification. *Source* The authors

Patient classification risk degree	HMS	HNS	FMS	FNS	RMSE
CER ED yellow physician	2.93	1.68	3.72	2.33	1.80
CER ED green physician	6.52	3.37	7.84	4.61	0.14
CER ED yellow pediatrician	0.84	0.55	1.11	0.74	0.81
CER ED green pediatrician	2.91	1.58	4.41	2.98	3.05
CDD ED yellow physician	1.99	1.09	1.21	0.53	0.16
CDD ED green physician	7.92	4.28	5.03	2.09	1.09
CDD ED yellow pediatrician	0.72	0.46	0.86	0.52	0.05
CDD ED green pediatrician	2.68	1.31	3.77	2.33	0.31
RM ED yellow physician	2.22	1.13	1.53	0.58	2.19
RM ED green physician	8.86	3.86	8.64	3.59	0.06
RM ED yellow pediatrician	0.79	0.50	0.61	0.34	1.25
RM ED green pediatrician	4.04	1.74	5.90	3.54	0.21
SC ED yellow physician	1.80	1.20	1.61	0.99	0.58
SC ED green physician	9.83	4.52	9.04	3.59	4.37
SC ED yellow pediatrician	0.59	0.48	0.75	0.55	0.15
SC ED green pediatrician	3.46	1.68	4.96	3.01	0.83

Although we are not taking into account dentistry and psychiatry on our forecast models, in other words, the forecasted demand should be increased on ED's where these services are provided, it makes no difference because CER ED got the maximum ED size and historical data presented on Table 4 show us that dentistry service account for only 3.16% and 1.8% of CDDs' ED and SC's ED total records, respectively.

From the ordinances' definition this result could suggest us that is expected that we will not need the same number of doctors than we currently have. But, as we had already explained in Sect. 1, we cannot ensure that all patients' waiting times will be lower than maximum waiting times presented in Table 1 by each classification risk degree. Thus, we should not suggest any workforce planning reduction before better understanding patient arrival behavior (aim of this research), process duration and their both variabilities (uncertainties).

We applied the forecasting models to all patients' classification risk degree to get closer from a better total attendance estimation (Table 5). However, as green and yellow patient's risk degree account for more than 90% in all records we consider only them in Table 6 to highlight the differences between historical data versus expected (forecasted) ones in each shift (morning and night) that are present bellow:

- In CER ED is expected a patient admission growth of, at least, 20% in all patient classification risk degree in pediatrician and physician services. In all cases, patient admission growth in night shift is higher than in morning shift. Patient admission growth for pediatrician service is higher than patient admission growth for physician service;
- In CDD ED is expected a patient admission decrease of, at least, 36% for physician service, but, at the same time, a patient admission growth for pediatrician service of 14% on the morning shift and 78% in night shift;
- In RM ED is expected a patient admission for physician service a little decrease of green risk classification patients of 0.03% in morning shift and 0.07%. However, yellow risk classification patients will decrease by 31% in the morning shift and 49% on the night shift;
- In SC ED is expected a patient admission decrease of, at least, 8% on morning shift and 18% on night shift for physician service while pediatrician service a patient admission will grow at least on 15%.

Even though highlights above give us a way to better estimate patient admission behavior we must enhance two points:

- These changes on patient admission behavior allow us to predict in ED's classification according to Brazilian ordinance, but it does not give us enough information to answer how many doctors and nurses should be available to meet "timely treatment" parameters presented in Table 1.
- The analysis provided in this section is only possible working with hourly forecasts which is still a little explored by recent researches as we showed in Sect. 2.

5 Conclusion

This research proposed a forecast approach to provide a tool for better understanding ED patient arrival behavior. From practice, this tool allows ED managers elsewhere to better prepare (balance) their staff for the coming demand variations and measure their results by waiting time and LOS.

In addition, this approach should be seen as a first step to build a better ED workforce planning. On the next step, to ensure that all patients must have their "timely treatment" we must combine it with ED processes durations and their natural variability. Propose an optimization approach to deals with these two problems is ongoing.

From the theory, this research fulfills a literature gap as long as it pointed out differences between historical and forecasted data in different shifts which is only possible working with hourly forecast.

Seven forecasting techniques were used to find, for each time series, which technique should be applied. We split each time series in training data (first 80% of observed values in original data series) and test data (last 20% of observed values in original data series). All forecasting techniques were applied over training data and thereafter we made all forecasting to compare results expected in each technique with test data. These comparisons were made using RMSE as a performance measure and the technique with lower RMSE was chosen. Finally, only for the technique with lower RMSE in each case we made the hourly forecasting on a range of one year.

Only in CER ED we can expect a growth in both shifts and services. On the others EDs we expect in one hand a patient admission growth of pediatrician services, but on the other hand a decrease on physician service patient admission.

References

1. De Brito, F. G., Resende, E. S., de Araújo Rodrigues, A. A., Junqueira, M. A. B., Barreto, V. R., Destro Filho, J. B: Demand forecast in the emergency department in Minas Gerais. Bioscience Journal. J., 35(5), 1640–1650 (2019).
2. Guo, H., Gao, S., Tsui, K. L., Niu, T.: Simulation optimization for medical staff configuration at emergency department in Hong Kong. IEEE Transactions on Automation Science and Engineering, 14(4), 1655–1665 (2017).
3. Pinto Júnior, D., Salgado, P. D. O., Chianca, T. C. M.: Predictive validity of the Manchester Triage System: evaluation of outcomes of patients admitted to an emergency department. Revista latino-americana de enfermagem, 20(6), 1041–1047 (2012).
4. Afilal, M., Yalaoui, F., Dugardin, F., Amodeo, L., Laplanche, D., & Blua, P.: Forecasting the emergency department patients flow. Journal of Medical Systems, 40(7), 175, (2016).
5. Kadri, F., Harrou, F., & Sun, Y.: A multivariate time series approach to forecasting daily attendances at hospital emergency department. In 2017 IEEE Symposium Series on Computational Intelligence (SSCI), 1–6, (2017).
6. Hopp, W. J., Lovejoy, W. S.: Hospital operations. Upper Saddle River: FT Press (2013).
7. Afilal, M., Yalaoui, F., Dugardin, F., Amodeo, L., Laplanche, D., Blua, P.: Forecasting the emergency department patients flow. Journal of Medical Systems, 40(7), 175 (2016).
8. Ortíz-Barrios, M. A., & Alfaro-Saíz, J. J. (2020). Methodological approaches to support process improvement in emergency departments: a systematic review. International Journal of Environmental Research and Public Health, 17(8), 2664.
9. Assad, D. B. N., Ortega-Mier, M., & Cañas, F.J.C.: Patient demand forecast in emergency departments a multiple case study. 26th IJCIEOM – International Joint Conference on Industrial Engineering and Operations Management. Springer. (2020).
10. Gul, M., Celik, E.: An exhaustive review and analysis on applications of statistical forecasting in hospital emergency departments. Health Systems, 1–22 (2018).
11. Yule, G. U. VII: On a method of investigating periodicities disturbed series, with special reference to Wolfer's sunspot numbers. Philosophical Transactions of the Royal Society of London. Series A, Containing Papers of a Mathematical or Physical Character, 226(636–646), 267-298, (1927).
12. Milner, P.C.: Forecasting the demand on accident and emergency departments in health districts in the Trent region. Stat. Med. 7(10), 1061–1072 (1988).

13. Wargon, M., Guidet, B., Hoang, T. D., Hejblum, G.: A systematic review of models for forecasting the number of emergency department visits. Emergency Medicine Journal, 26(6), 395–399 (2009).
14. Morzuch, B. J., & Allen, P. G.: Forecasting hospital emergency department arrivals. In: 26th Annual Symposium on Forecasting, Santander, Spain (2006).
15. Kim, S. W., Li, J. Y., Hakendorf, P., Teubner, D. J., Ben- Tovim, D. I., Thompson, C. H.: Predicting admission of patients by their presentation to the emergency department. Emergency Medicine Australasia: EMA, 26(4), 361–367 (2014).
16. Chase, V. J., Cohn, A. E., Peterson, T. A., & Lavieri, M. S.: Predicting emergency department volume using forecasting methods to create a "surge response" for noncrisis events. Academic Emergency Medicine, 19(5), 569–576 (2012).
17. Ekström, A., Kurland, L., Farrokhnia, N., Castrén, M., Nordberg, M.: Forecasting emergency department visits using internet data. Annals of Emergency Medicine, 65(4), 436–442 (2015).
18. McCarthy, M. L., Zeger, S. L., Ding, R., Aronsky, D., Hoot, N. R., Kelen, G. D.: The challenge of predicting demand for emergency department services. Academic Emergency Medicine, 15(4), 337–346 (2008).
19. Jiang, S., Chin, K. S., & Tsui, K. L.: A universal deep learning approach for modeling the flow of patients under different severities. Computer methods and programs in biomedicine, 154, 191–203 (2018).
20. Brasil. Ministério da Saúde. Portaria no 10, de 3 de janeiro de 2017. Redefine as diretrizes de modelo assistencial e financiamento de UPA 24 h de Pronto Atendimento como Componente da Rede de Atenção às Urgências, no âmbito do Sistema Único de Saúde. Gabinete do Ministro, Brasília, DF (2017).

Visual Management in Healthcare: A Systematic Literature Review of Main Practices and Applications

Carolina Melecardi Zani, Paula Kvitko de Moura, Bruno Miranda dos Santos, and Tarcisio Abreu Saurin

Abstract Visual Management illustrates lean measures by non-verbal means. It provides alternatives aiming to reduce complexity and expenses in Complex Sociotechnical Systems, such as hospitals. Consequently, VM also enhances hospital's sustainability and increases processes transparency. This study addresses the main practices and devices supported by Visual Management used in healthcare presented in articles selected from a systematic literature review. Of 330 studies, 45 were examined from the perspective of: (i) approach nature (whether it is a practice or a device); (ii) user adhesion and (iii) performance dimensions. The most cited practice supported by Visual Management aimed at developments in information flow, and for Visual Device was visual reminders and electronic messages. An Importance Score framework is developed for the implementation of Visual Management practices/devices. The highest scores are indicated for implementation: standardized work and collaborative work, supported by posters and computers.

Keywords Visual management · Visual devices · Healthcare · Lean practices

C. M. Zani (✉) · B. M. dos Santos · T. A. Saurin
DEPROT/UFRGS (Industrial Engineering and Transportation Department), Federal University of Rio Grande Do Sul, Osvaldo Aranha Av 99, 90035190 Porto Alegre, Brazil
e-mail: zani.carol@gmail.com

B. M. dos Santos
e-mail: bruno.miranda@ufrgs.br

T. A. Saurin
e-mail: saurin@ufrgs.br

P. K. de Moura
Graduate Program in Civil Engineering, Federal University of Rio Grande Do Sul, Osvaldo Aranha Av 99, 90035190 Porto Alegre, Brazil
e-mail: paula.moura@ufrgs.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_15

1 Introduction

Visual Management (VM) is a set of practices that support decision-making processes and organizational improvements [1]. VM tools are understood as Visual Devices (VD), and it gives precise information when and where needed [2]. VM provides support to lean principles, which is aligned with sustainable behaviors, since it aims to optimize tasks by eliminating losses, enabling high-quality products and services at low cost [3]. Health systems benefit from this philosophy due to the high complexity and high expenses of hospital environments [4, 5]. These environments are called Complex Sociotechnical Systems (CSS) and have characteristics such as: a large number and diversity of elements; frequent unexpected variability in their processes; and dynamics in their interactions [6]. VM provides alternatives to reduce unnecessary complexity while supporting resources visibility and monitoring [1]. Consequently, VM also enhances hospital's sustainability and increases processes transparency. Meanwhile, VD helps to promote innovation and team commitment [2], and can influence behaviors by giving instructive information. Behavioral influencing strategies are also known as 'nudges' or techniques of persuasion, often expressed through visual means [7]. Purposeful changing the order of a medication list, so the first item is preferably chosen, is an example of nudges.

Despite the healthcare discipline having the potential to deal with VM subject, it does not have consolidated literature with this approach. According to Beynon-Davies [8], regardless of some exceptions [9–11], there is a lack of VM coverage in academic literature, both in production and operations management and in health management as well [12, 13]. Bueno et al. [14] carried out a systematic literature review on interventions to improve processes in ICUs. In his study, he aligns management practices with CSS's main characteristics, established in previous studies by Saurin et al. [6]. Of the 91 articles analyzed by the authors, only 17 primarily address interventions related to VM. The need for further investigations related to process transparency is highlighted as this appears as a secondary element in such interventions.

This study aims to answer: (i) what are the most used practices supported by VM and VDs in hospitals; (ii) what is the main user's level of adhesion with practices/devices; and (iii) which are the performance dimensions most attended by practices supported by VM and VDs. At the end of the study, an Importance Score framework for the implementation of practices/devices is provided. For this, a systematic literature review was carried out within the PRISMA model [15].

2 Visual Management and Visual Devices

The concept of VM started in manufacturing through the lean production philosophy, proposed by the principles of Taylorism in 1911. According to Greif [16], VM should assist lean practices by communicating quality information (necessary, relevant, correct, immediate, easy-to-understand and stimulating). The basis of VM is to help people to make sense of the organizational context "at a glance"—merely looking around [16]. It does so through VD (i.e. tools that exposes the information). Yet, Galsworth [2] defines VM as a management approach that utilizes either one or more of information giving, signaling, limiting or guaranteeing (mistake-proofing/poka-yoke) visual devices to communicate with "doers", so that places become self-explanatory, self-ordering, self-regulating and self-improving.

In this paper, the definition of VM is in accordance with Greif [16] and Galsworth [2]: a system to increase information availability and remove blockages in the information flow, through the provision of VD. To analyze the practices and devices was considered whether it is part of lean actions of the organization, aiming at more systemic efficiency and continuous improvements, or whether it is an isolated measure, which has a specific behavioral pretension, such as 'nudges.' Example of a practice supported by VM in hospitals is the use of boards to discuss patient care plans within multidisciplinary teams [10], while for VD is an electronic panel with real-time patient's conditions [8].

3 Methodology

This study aims to investigate how VM is applied in hospitals from a systematic literature review based on the review protocol Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [15]. The recommendations of Moher et al. [15] (Fig. 1) were used to structure the article. Four databases were selected to identify studies (Web of Science, Science Direct, Scopus, and PubMed) following Augusto and Tortorella [17], who reported that these databases are predominantly selected in health review studies. The areas consulted were management, engineering, health, and social sciences for each database. The search was conducted in December 2019, and no data period or filter was applied. The search algorithm used was:

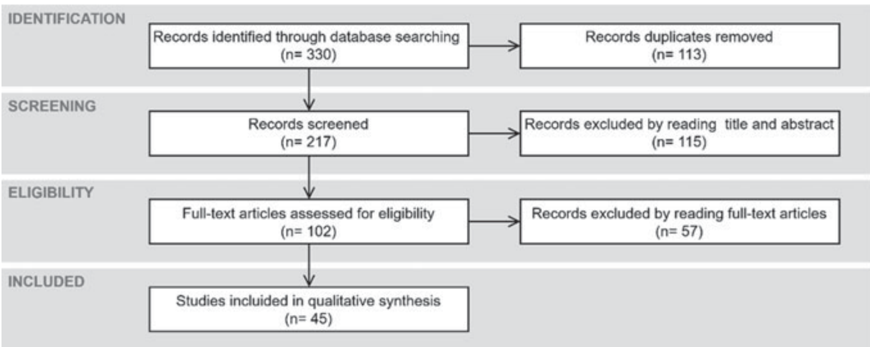


Fig. 1 Guidelines for choosing articles

"healthcare" OR "hospitals" OR "health system" OR "health service" AND "visual management" OR "process transparency" OR "patient information flow" OR "visual devices" OR nudges OR poka-yoke—in title, abstract and/or keywords. The database search resulted in a total of 330 studies. After excluding 113 duplicates, 217 studies were selected for title and/or abstract review.

The reading of titles and abstracts was performed to identify the articles related to the objective. A total of 115 articles were removed according to the exclusion criteria: (i) non-scientific texts (e.g., magazine paper, book chapters, etc.) (6 records); (ii) papers written in non-English languages (4 records); (iii) conference proceedings (28 records); (iv) review papers (2 records); and (v) papers that did not address the issue of VM in the health area (75 records). Based on these criteria, 102 articles were selected for full review. The full-text analysis was carried out, and 57 articles were removed because they did not address and/or only tangent the issue of VM in healthcare, or the full text was not available. A total of 45 articles were selected for data extraction, considering a thematic analysis to characterize practices supported by VM and VDs, according to the following categories:

– Bibliometric information—journal, year of publication and country where the study was carried out;
– Hospital profile—whether it was a teaching hospital or not;
– Hospital sector where the practice/device was applied;
– Approach classification (i.e., systematic for VM and isolated for VD);
– Users of the practice/device, aligned with Brandalise [18];
– Performance dimension's classification—(i) efficiency operations, (ii) patient safety, well-being, and satisfaction, (iii) family member's well-being, and (iv) professionals learning and safety;
– Impacts of using these practices/devices as a support for interpretation of other categories of data analysis.

Regarding performance dimensions, it was inspired by Bueno et al. [14] proposals for efficiency, patient, and family. The "professionals" performance dimension was added due to the attention that this subject receives from studies derived from the CSS literature [19]. Based on these criteria, it was possible to create a ranking of which practices supported by VM and VDs are most important in health systems to attend specific performance criteria.

The practices/devices were also analyzed qualitatively and quantitatively based on the two dimensions evidenced in the results: (i) performance (quantitative) and (ii) user adhesion (qualitative). The performance dimension (i) was analyzed conforming developments for efficiency, patient, family, and employee. The user adhesion dimension (ii) was analyzed according to the number of people included, diversity of areas involved, and possibility of interaction with practices/devices. The "implementation" category was also considered in this dimension to assess whether the practice or device proposed by the study was implemented for at least three months. A score from 0 to 3 was assigned for each practice and device to develop a Importance Score Framework (see Table 2 in Sect. 5). The performance dimensions were assessed based on the number of citations. For user adherence (exception of the "implementation" category), emphasis on the evidence determined the scores. Two authors evaluated and compared their scores to reach a common denominator. Implementation of the practice/device was assessed according to the number of studies that implanted it. The last score for the diffusion for each one was the sum of their respective scores for each performance and user adherence dimension. Then the final values were rescaled on a continuous scale of [0, 1]. The results are shown in the left part of Table 2 (see Sect. 5), for performance and in the right part for user adherence. The performance and user adherence rates for each practice supported by VM and VD were multiplied to obtain a final score of importance. The number of standard deviations that each practice/device score has in relation to the overall average established a differentiation index. Previous studies (e.g. [20, 21]) used a similar differentiation index to remove scale effects and indicate management priorities for implementation.

4 Results

4.1 Studies Characterization

The 45 articles selected were published in 40 different journals, suggesting interest in the topic of VM in hospitals. The most frequent journal, with five articles, was the British Medical Journal, followed by the American Journal of Infection Control (3 articles), and the Journal of the Australian Healthcare & Hospitals Association (2 articles). The interventions were performed mostly in 4 countries: United States (49%); Australia (14.9%); United Kingdom (8.5%); and Canada (6.4%). Most of the studies (93%) were published from 2014 to 2019. The hospitals that implemented practices supported by VM and VDs were characterized by (i) belonging to both teaching and non-teaching hospitals (54%) and only non-teaching hospitals (46%); and (ii) application of the practice or device in more than one sector (20%) or only one sector (80%).

4.2 Approach Classification

The articles were classified according to (i) practices supported by VM (n = 18) or (ii) visual devices (n = 37). It was classified as practices supported by VM studies that refer preferably to systemic measures, continuous improvements and team integration, even if eliciting VD (Table 1). Even so, ten studies emphasize both aspects of VM and therefore it was not possible to separate them [8, 10, 15, 22–28].

Table 1 VM and VD authors citation according to the type of approach

Practices supported by visual management	Multidisciplinary meetings	[8, 37, 38]
	Gemba walk	[37]
	Priorities visualization	[8, 22, 37]
	A3 thinking	[37]
	Value flow mapping	[10, 15, 23–25, 37]
	Information flow	[10, 15, 23–25, 37, 47]
	Culture of continuous improvement	[8, 22, 26, 37, 48, 49]
	Monitoring of goals	[8, 37, 38]
	Collaborative work	[8, 26, 30, 38]
	Organization of the environment	[14, 27, 49, 50]
	Standardized work	[14, 22, 28, 37]
Visual management devices	Whiteboards	[13, 25]
	Electronic boards	[22, 24, 25, 39, 51]
	Posters	[23, 27, 40, 52–54]
	Computer	[8, 36, 43, 55–57]
	Tablet	[54]
	Sensors	[32, 58, 59]
	Visual reminders and electronic messages	[10, 11, 28, 29, 31, 33, 51, 53, 58, 60–62]
	Visual highlighting in records	[32]
	Information display format	[35, 36, 41, 53]
	Traffic color system	[13, 61]
	Stock indicator	[62]

4.3 Systemic Information Approach: Practices Supported by VM

Actions that illustrate and support lean measures are called VM. A total of 11 practices aligned with VM are categorized: multidisciplinary meetings, Gemba walk, priorities visualization, A3 thinking, value flow mapping, information flow, culture of continuous improvement, monitoring of goals, collaborative work, organization of the environment, and standardized work (Table 1). According to studies, these practices provide visibility to processes, which helps hospital performance, especially to optimize patient flow and reduce waste [13, 25, 29]. For CSS, when the information presented is efficient, the team becomes more capable of dealing with system variability, a key issue for creating value in the hospital [24, 30]. Thus, practices supported by VM appear as: (i) a mean to educate the team to behave accordingly to the organization's lean goals; (ii) a guideline of the best ways to perform a task or activity; and (iii) a framework to ensure that changes to improve patient care and hospital efficiency are applied consistently and reliably [23].

4.4 Isolated Information Approach: Visual Devices

Visual device (VD) is an element of non-verbal communication that informs, guides and/or instructs people on day-to-day activities [1, 31]. The articles that focused on solving specific problems of information needs through the development of devices or sensory resources were classified as VD approach. VDs were used to (i) recognize errors and resolve them in an agile way; (ii) promote autonomy in operational teams; (iii) reduce the time searching for information and materials; and (iv) assist in routine activities. VD is usually integrated into the processes and can be openly displayed in easily accessible places in the workplace [16]. Typical examples were present in Table 1, such as posters and electronic boards, to show information to patients and employees. VDs namely nudges influence choices in a subtle way when compared to methods that explicitly expose information. Two examples are: (i) influence medical test selection by highlighting specific ones in red [32] and; (ii) displaying the medication brand name instead of generic options, leading to more expensive prescriptions [33]. VD based on digital technologies automatize and speed up procedures by being able to give specific information, filtered intelligently, and presented at appropriate times [34]. Memory aids, like electronic messages and interactive web-based computerized devices are examples of this VD [8, 15].

4.5 Users of Practices Supported by VM and VD

User adherence is fundamental for practices and devices to integrates with the routines and processes [18]. Three categories of users of practices and VDs are emphasized in the works: (i) number of people included; (ii) diversity of areas involved; (iii) possibility of interaction with VM or VD. For quantifying the items (i) and (ii), the spectrum reached was evaluated according to Brandalise's study [18]. VDs "one to many" (89%) has only one interface, which passes information to different groups (e.g., integrative software used by various professionals) [22, 35]. VDs "one to one" communicates the information between a transmitter and a receiver. This VDs aims to pass specific and personalized information quickly and of easily interpretation (e.g., particular messages attached to examinations showing the level of radiation exposure for physicians) [36]. As for practices supported by VM, the collaborative quality of actions conveys the information from "many to many." These practices distribute the information to groups of different departments or hierarchical levels. Po et al. [37] and Wu et al. [38] are examples of works that

Table 2 Proposed framework for implementation of practices supported by VM and VDs

		Performance[1]						User adhesion[2]						Importance score	
		Efficiency	Patient	Family	Professional	Total	Rescaled [0-1]	Number of people	Areas diversity	Interaction	Implementation[3]	Total	Rescaled [0-1]	Total	Diff. index
Practices supported by VM	Multidiscplinary meetings	2	0	0	0	2	0.034	3	3	3	2	11	0.060	0.0021	−0.0498
	Gemba walk	1	0	0	0	1	0.017	1	1	2	0	4	0.022	0.0004	−1.2827
	Priorities visualization	2	0	0	0	2	0.034	2	3	1	2	8	0.043	0.0015	−0.4608
	A3 Thinking	1	0	0	0	1	0.017	1	2	1	0	4	0.022	0.0004	−1.2827
	Value flow mapping	3	0	0	0	3	0.052	1	1	1	3	6	0.033	0.0017	−0.3238
	Information flow	2	0	0	0	2	0.034	3	3		3	11	0.060	0.0021	−0.0498
	Culture of continuos improvment	2	1	0	0	3	0.052	3	3		2	11	0.060	0.0031	0.7036
	Monitoring of goals	2	0	0	0	2	0.034	1	1	1	2	5	0.027	0.0009	−0.8717
	Collaborative work	2	0	0	1	3	0.052	3	3		3	12	0.065	0.0034	**0.9091**
	Organization of the environment	3	0	0	0	3	0.052	1	1	1	3	6	0.033	0.0017	−0.3238
	Standardized work	3	1	0	1	5	0.086	3	3	1	2	9	0.049	0.0042	**1.5255**

(continued)

Table 2 (continued)

		Performance[1]						User adhesion[2]						Importance score	
		Efficiency	Patient	Family	Professional	Total	Rescaled [0-1]	Number of people	Areas diversity	Interaction	Implementation[3]	Total	Rescaled [0-1]	Total	Diff. index
VM devices	White board	1	0	0	0	1	0.017	3	3		3	12	0.065	0.0011	−0.7347
	Electronic boards	2	1	0	0	3	0.052	3	3	1	3	10	0.054	0.0028	0.4981
	Poster	1	2	1	1	5	0.086	3	3	1	3	10	0.054	0.0047	**1.8680**
	Computer	1	2	0	1	4	0.069	3	3		3	12	0.065	0.0045	**1.7310**
	Tablet	1	0	0	0	1	0.017	1	2		3	8	0.043	0.0007	−1.0087
	Sensors	1	1	0	0	2	0.034	2	3	1	3	9	0.049	0.0017	−0.3238
	Visual reminders and electronic messages	2	3	0	2	7	0.121	1	1	1	3	6	0.033	0.0039	1.3200
	Visual highlight in records	1	0	0	0	1	0.017	1	1	1	3	6	0.033	0.0006	−1.1457
	Information display format	0	1	0	2	3	0.052	2	2	1	2	7	0.038	0.0020	−0.1183
	Traffic color system	1	1	0	1	3	0.052	3	2	2	3	10	0.054	0.0028	0.4981
	Stock indicator	1	0	0	0	1	0.017	1	1	2	3	7	0.038	0.0007	−1.0772
	Total	35	13	1	9			45	48	37	54			0.0014	

Note [1]Citation frequency: $x \leq 2 = 1$ $3 \leq x \geq 5 = 2$; $x \geq 6 = 3$
[2]Evidence Enphasis: 1 = Low; 2 = Moderate; 3 = High
[3]Implementation: 0 = not imp.; 1 = less than half imp.; 2 = half imp.; 3 = all imp

emphasize collaborative work. The category (iii) concerns the possibility of users to participate in the information construction, to respond actively to warnings and to acquire knowledge. Within this category, both for practices supported by VM and VDs, the main users are the front-line team (physicians, nurses and nursing technicians), followed by allied professionals (physiotherapists, clinical pharmacists, psychologists, and nutritionists), only them comes management team and patients, whereas family members have been little mentioned.

4.6 Performance Dimensions

The performance dimensions were classified as (i) efficiency operations; (ii) patient safety, well-being, and satisfaction; (iii) family member's well-being; and (iv) professionals learning and safety. The first three compiled from Bueno et al. [14], and the fourth added by its relevance for CSS. Although performance dimensions are correlated, data coding was based on the dimensions emphasized by the revised articles. O'Brien et al. [13], Ulhassan et al. [25] and Gururajan et al. [29] give examples of VM connected to efficiency dimensions, such as electronic boards that illustrate information from the patient flow. Contrary, VD studies focus on patient well-being and satisfaction, as better methods for medication administration [39, 40]. The (iv) dimension is addressed as means to turn the work safer and more accessible to professionals. For instance, VD used to show laboratory risks for the professional in Lewis et al. [36]. Usually, VDs associated with this dimension has an educational nature, as in Yera et al. [41], Shakespeare et al. [42] and Yadav et al. [43]. Finally, few studies address the family member's well-being, like communication clarity or comfort in the waiting room. Keyworth et al. [28] suggest improvements for waiting rooms with posters, whereas Fanning et al. [44] explores ways of better communication among family members, patients, and health professionals.

5 Importance Score for VM Implementation

Hospitals seeking to achieve better performance results based on the implementation of lean management principles and techniques may need guidance for measures and efforts [45]. This study proposes an implementation strategy through practices supported by VM and VDs framework based on an importance score. A high importance score indicates versatile practices and devices, both in terms of contribution to the performance of the hospital's and the user's adherence. The results shown in Table 2 indicate that the practice "Standardized Work" (differ. index = 1.5255) and "Collaborative Work" (differ. index = 0.9091) have priority for implementation. The literature widely suggests standardized work to indicate system failures and information deficits. Collaborative work, on the other hand, highlights the importance of exchanging experiences and system resilience skills. Posters (difference index =

1.8680) are the most important VD in terms of performance and user adherence. This result may be related to the simplicity and facility of implementation, as well as little effort and cost to the organization. According to Galsworth's [2] classification of control degree, posters are visual indicators, i.e., a passive device that depends on the user for compliance with its content. Also, posters contribute in all categories of the performance dimensions: efficiency [46], patient [43], family [28], and employee [42]. Computer-based devices, second on the importance scale, receive lower scores when compared with poster, probably because it demands more resources from the hospital such as implementation time since it requires a level of training and costs.

6 Conclusion

This study investigates what the practices supported by VM and VDs most used in hospitals are, how it contributes to the hospital's performance, as well as the level of user adherence. A total of 45 articles were identified through a systematic literature review and coded according to the type of approach, user adherence, and performance. Eleven practices and visual devices were identified. Isolated approaches (i.e., application of a VD) were more common. The most cited were visual reminders and electronic messages, posters, and electronic boards. For the practices, the most often aimed at developments in information flow, value flow mapping, and culture of continuous improvement. Concerning user adherence, both practices and devices encouraged different perspectives of work. Regarding the performance dimension, the relation between practices supported by VM and efficiency predominates. VDs, on the other hand, were related to patient safety, well-being, and satisfaction performance dimension. The fact that studies involving the dimension family have received little attention is a topic for further investigations. The main contribution of this work is the Importance Score framework, which identifies implementation importance for both practices supported by VM and VDs. The highest score for practices was standardized work and collaborative work, while for VD was poster and computer. Even though the practices and VDs identified are aligned with the hospital context, this work is limited to it. Future studies can address the concept of VM for different areas and make a toolbox for application in different contexts. Other studies may use the framework for applications in hospitals and validate the practices and devices identified as the most important for implementation.

References

1. Jaca, C., Taylor, P., Viles, E., Jurburg, D.: Do companies with greater deployment of participation systems use Visual Management more extensively? An exploratory study. Int. J. Prod. Res. 52(6), 1755–1770 (2013)
2. Galsworth, G.D.: Visual systems: harnessing the power of the visual workplace. American Management Association New York (1997)
3. Martínez León, H.C., Calvo-Amodio, J.: Towards lean for sustainability: Understanding the interrelationships between lean and sustainability from a systems thinking perspective. J. Clean. Prod. 142(4), 4384–4402 (2017). https://doi.org/10.1016/j.jclepro.2016.11.132
4. Soliman, M., Saurin, T.A., Anzanello, M.J.: The impacts of lean production on the complexity of socio-technical systems. Int. J. Prod. Econ. 197, 342–357 (2018)
5. Rosko, M.D.: Cost efficiency of US hospitals: A stochastic frontier approach. Health Econ. 10(6), 539–551 (2001). https://doi.org/10.1002/hec.607
6. Saurin, T.A., Rooke, J., Koskela, L.: A complex systems theory perspective of lean production. Int. J. Prod. Res. 51(19), 5824–5838 (2013)
7. Keeffe, M.O., Traeger, A.C., Hoffmann, T., Ferreira, G.E., Soon, J., Maher, C.: Can nudge-interventions address health service overuse and underuse? Protocol for a systematic review. BMJ Open. 9(6), e029540 (2019)
8. Beynon-davies, P., Lederman, R.: The Management of Operations Making sense of visual management through affordance theory. Prod. Plan. Control. 28(2), 142–157 (2017)
9. Bateman, N., Lethbridge, S.: Managing operations and teams visually. Routledge, Oxon, UK (2014)
10. Bateman, N., Philp, L., Warrender, H.: Visual management and shop floor teams – development, implementation and use. Int. J. Prod. Res. 54, 7345–7358 (2016)
11. Parry, G.C., Turner, C.E.: Application of lean visual process management tools. Prod. Plan. Control. 17, 77–86 (2006)
12. O'Neill, S., Jones, T., Bennett, D.: Nursing Works The Application of Lean Thinking to Nursing Processes. JONA J. Nurs. Adm. 41, 546–552 (2011)
13. O'Brien, L., Bassham, J., Lewis, M.: Whiteboards and discharge traffic lights: visual management in acute care. Aust. Heal. Rev. 39, 160–164 (2015)
14. Bueno, W.P., Saurin, T.A., Wachsb, P., Kuchenbeckerc, R., Braithwaited, J.: Coping with complexity in intensive care units : A systematic literature review of improvement interventions. Saf. Sci. 118, 814–825 (2019)
15. Moher, D., Liberati, A., Tetzlaff, J.A.D., Altman, D.G.: PRISMA 2009 flow diagram. Prism. statement. 6, 1000097 (2009)
16. Greif, M.: The visual factory: building participation through shared information. Portland: CRC Press (1991)
17. Augusto, B.P., Tortorella, G.L.: Literature review on lean healthcare implementation: assessment methods and practices. Int. J. Serv. Oper. Manag. 32, 285–306 (2019)
18. Brandalise, F.: Método de Avaliação de Sistemas de Gestão Visual na Produção da Construção Civil, (2018)
19. Wachs, P., Abreu, T., Weber, A., Lewis, R.: Resilience skills as emergent phenomena: A study of emergency departments in Brazil and the United States. Appl. Ergon. 56, 227–237 (2016)
20. Tortorella, G.L., Fogliatto, F.S.: Method for assessing human resources management practices and organisational learning factors in a company under lean manufacturing implementation. Int. J. Prod. Res. 52, 4623–4645 (2014)
21. Tortorella, G.L., Garcia, L., Vergara, L., Ferreira, E.P.: Lean manufacturing implementation: an assessment method with regards to socio-technical and ergonomics practices adoption. Int. J. Adv. Manuf. Technol. 89, 3407–3418 (2017)
22. Glegg, S.M.N., Ryce, A., Brownlee, K.: A visual management tool for program planning, project management and evaluation in paediatric health care. Eval. Program Plann. 72, 16–23 (2019)

23. Silver, S.A., Mcquillan, R., Harel, Z., Weizman, A. V, Thomas, A., Nesrallah, G., Bell, C.M., Chan, C.T., Chertow, G.M.: How to Sustain Change and Support Continuous Quality Improvement. Clin. J. Am. Soc. Nephrol. 11, 916–924 (2016)
24. Jackson, M.D., Bartman, T., Mcginniss, J., Widener, P., Dunn, A.L.: Optimizing patient flow in a multidisciplinary haemophilia clinic using quality improvement methodology. Haemophilia. 25, 626–632 (2019)
25. Ulhassan, W., Schwarz, U.V.T., Westerlund, H.: How Visual Management for Continuous Improvement Might Guide and Affect Hospital Staff : A Case Study. Qual. Manag. Health Care. 24, 222–228 (2015)
26. Mannon, M.: Lean Healthcare and Quality Management: The Experience of ThedaCare. Qual. Manag. J. 21, 7–10 (2017)
27. Bourdeaux, C.P., Thomas, M.J.C., Gould, T.H., Malhotra, G., Jarvstad, A., Jones, T., Gilchrist, I.D.: Increasing compliance with low tidal volume ventilation in the ICU with two nudge-based interventions: evaluation through intervention time-series analyses. BMJ Open. 6, e010129 (2016)
28. Keyworth, C., Nelson, P.A., Griffiths, C.E.M., Cordingley, L., Bundy, C.: Do English healthcare settings use 'Choice Architecture' principles in promoting healthy lifestyles for people with psoriasis? An observational study. BMC Health Serv. Res. 15, 215 (2015)
29. Gururajan, R., Hafeez Baig, A., Sturgess, J., Clark, K.: An Exploratory Qualitative Study to Identify Factors that Influence the Use of Electronic Patient Journey Boards in Queensland Health. eJournal Heal. Informatics. 9, (2015)
30. Moore, S., Arthur, R.: A Quality Improvement Initiative: Using Lean Methodology to Improve Efficiency of the Morning Cycle Monitoring at an Ambulatory Academic Fertility Clinic. J. Obstet. Gynaecol. Canada. 41, 755–761 (2019)
31. Tezel, A., Koskela, L.J., Tzortzpoulos, P.: Visual management in production management : A literature synthesis. J. Manuf. Technol. Manag. 27, 766–799 (2016)
32. Horng, S., Joseph, J.W., Calder, S., Stevens, J.P., Donoghue, A.L.O., Safran, C.: Assessment of Unintentional Duplicate Orders by Emergency Department Clinicians Before and After Implementation of a Visual Aid in the Electronic Health Record Ordering System. JAMA Netw. Open. 2, e1916499–e1916499 (2019)
33. Monsen, C.B., Liao, J.M., Gaster, B., Flynn, K.J., Payne, T.H.: The effect of medication cost transparency alerts on prescriber behavior. J. Am. Med. Informatics Assoc. 26, 920–927 (2019)
34. Osheroff, J.A., Teich, J.M., Middleton, B., Steen, E.B., Wright, A., Detmer, D.E.: A roadmap for national action on clinical decision support. J. Am. Med. informatics Assoc. 14, 141–145 (2007)
35. Kumar, S., Aldrich, K.: Overcoming barriers to electronic medical record (EMR) implementation in the US healthcare system: A comparative study. Health Informatics J. 16, 306–318 (2010)
36. Lewis, S., Young, B., Thurley, P., Shaw, D., Cranwell, J., Skelly, R., Langley, T., Norwood, M., Sturrock, N., Fogarty, A.: Evaluation of a nudge intervention providing simple feedback to clinicians of the consequence of radiation exposure on demand for computed tomography: a controlled study. Clin. Med. (Northfield. Il). 19, 290–293 (2019)
37. Po, J., Rundall, T.G., Shortell, S.M., Blodgett, J.C.: Lean Management and US Public Hospital Performance: Results From a National Survey. J. Healthc. Manag. 64, 363–379 (2019)
38. Wu, S., Brown, C., Black, S., Garcia, M., Harrington, D.W.: Using Lean Performance Improvement for Patient-Centered Medical Home Transformation at an Academic Public Hospital. J. Healthc. Qual. 41, 350–361 (2019)
39. Westbrook, J.I., Baysari, M.T.: Nudging hospitals towards evidence- based decision support for medication management. Med J Aust. 210, s22–s24 (2019)
40. Jones, M., Butler, J., Graber, C.J., Glassman, P., Samore, M.H., Pollack, L.A., Weir, C., Bidwell, M.: Think twice: A cognitive perspective of an antibiotic timeout intervention to improve antibiotic use. J. Biomed. Inform. 71, S22–S31 (2017)
41. Yera, A., Muguerza, J., Arbelaitz, O., Perona, I., Keers, R.N., Ashcroft, D.M., Williams, R., Peek, N., Jay, C., Vigo, M.: Modelling the interactive behaviour of users with a medication safety dashboard in a primary care setting. Int. J. Med. Inform. 129, 395–403 (2019)

42. Shakespeare, T., Fehlberg, M., Slejko, T., Taylor, J., Bolsin, S.: Successful use of " Choice Architecture" and " Nudge Theory" in a quality improvement initiative of analgesia administration after Caesarean section. J. Eval. Clin. Pract. 25, 125–129 (2019)
43. Yadav, K., Meeker, D., Mistry, R.D., Doctor, J.N., Fleming-dutra, K.E., Fleischman, R.J., Gaona, S.D., Stahmer, A., May, L.: A Multifaceted Intervention Improves Prescribing for Acute Respiratory Infection for Adults and Children in Emergency Department and Urgent Care Settings. Acad. Emerg. Med. 26, 719–731 (2019)
44. Fanning, J.B., Farkas, C.M., Dewitt, P.M., Webster, T.H.G., Burnam, J., Piras, S.E., Schenck, D., Miller, A.: Obstacles to Shared Expectations in a Burn Intensive Care Unit. Qual. Health Res. 27, 351–362 (2017)
45. Anand, G., Kodali, R.: Development of a framework for implementation of lean manufacturing systems. Int. J. Manag. Pract. 4, 95–116 (2010)
46. O'Reilly-Shah, V.N., Easton, G.S., Jabaley, C.S., Lynde, G.C.: Variable effectiveness of stepwise implementation of nudge-type interventions to improve provider compliance with intraoperative low tidal volume ventilation. BMJ Qual. Saf. 27, 1008–1018 (2018)
47. Williamsson, A., Dellve, L., Karltun, A.: "Nurses' use of visual management in hospitals—A longitudinal, quantitative study on its implications on systems performance and working conditions.". J. Adv. Nurs. 75, 760–771 (2019)
48. Jacob, J.T., Herwaldt, L.A., Durso, F.T.: Preventing healthcare-associated infections through human factors engineering. Curr. Opin. Infect. Dis. 31, 353–358 (2018)
49. Caris, M.G., Labuschagne, H.A., Dekker, M., Kramer, M.H.H., Agtmael, M.A. Van: Nudging to Improve Hand Hygiene Corresponding author. J. Hosp. Infect. (2017)
50. Clark, K.W., Moller, S., O'Brien, L.: Electronic patient journey boards a vital piece of the puzzle in patient flow. Aust. Heal. Rev. 38, 259–264 (2014)
51. Crupi, V., Calzavarini, F., Elia, F., Aprà, F.: Understanding and improving decisions in clinical medicine (IV): prospects and challenges of nudging in healthcare. Intern. Emerg. Med. 13, 791–793 (2018)
52. Shaban-nejad, A., Mamiya, H., Riazanov, A., Forster, A.J., Baker, C.J.O., Tamblyn, R., Buckeridge, D.L.: From Cues to Nudge: A Knowledge-Based Framework for Surveillance of Healthcare-Associated Infections. J. Med. Syst. 40, 23 (2016)
53. Bourdeaux, C.P., Davies, K.J., Thomas, M.J.C., Bewley, J.S., Gould, T.H.: Using 'nudge' principles for order set design: a before and after evaluation of an electronic prescribing template in critical care. BMJ Qual Saf. 23, 382–388 (2014)
54. Uddin, M., Allen, R., Huynh, N., Vidal, J.M., Taaffe, K.M., Lawrence, D., Greenstein, J.S.: Assessing operating room turnover time via the use of mobile application. Mhealth. 4, (2018)
55. Kwok, Y.L.A., Juergens, C.P., Mclaws, M.: Automated hand hygiene auditing with and without an intervention. Am. J. Infect. Control. 44, 1475–1480 (2016)
56. Franklin, B.B.J.: Development of a Best Practice Model for the Implementation of a Radiofrequency Identification System in a Healthcare Environment. In: IEEE 33rd Annual Northeast Bioengineering Conference. pp. 289–290 (2007)
57. Arora, V.M., Machado, N., Anderson, S.L., Desai, N., Marsack, W., Blossomgame, S., Tuvilleja, A., Ramos, J., Francisco, M., Lafond, C., Leung, E., Valencia, A., Martin, S., Meltzer, D., Farnan, J., Balachandran, J., Knutson, K., Mokhlesi, B.: Effectiveness of SIESTA on Objective and Subjective Metrics of Nighttime Hospital Sleep Disruptors. J. Hosp. Med. 14, 38–41 (2019)
58. Schwartz, P.H., Perkins, S.M., Schmidt, K.K., Muriello, P.F., Althouse, S., Rawl, S.M.: Providing Quantitative Information and a Nudge to Undergo Stool Testing in a Colorectal Cancer Screening Decision Aid: A Randomized Clinical Trial. Med. Decis. Mak. 37, 688–702 (2017)
59. Tannenbaum, D., Doctor, J.N., Persell, S.D., Friedberg, M.W., Meeker, D., Friesema, E.M., Goldstein, N.J., Linder, J.A., Fox, C.R.: Nudging Physician Prescription Decisions by Partitioning the Order Set : Results of a Vignette-Based Study. J. Gen. Intern. Med. 30, 298–304 (2015)
60. Vaughn, V.M., Linder, J.A.: Thoughtless design of the electronic health record drives overuse, but purposeful design can nudge improved patient care. (2018)

61. Mazza, M., Dynan, L., Siegel, R., Tucker, A.: Nudging Healthier Choices in a Hospital Cafeteria: Results From a Field Study. Health Promot. Pract. 19, 925–934 (2018)
62. Vaillancourt, L., Truong, M.: Is your turnaround time fast enough? Implementing a lean project in hospital pharmacy to reduce prescription preparation time. J. Pharm. Clin. 36, 89–95 (2017)

Systematic Review on the Use of Eggshell: Reflections About Circular Economy

Samuel Vinícius Bonato, Elaine Cristina do Nascimento, Lourdes Helena Rodrigues Martins, Cynthia Faviero, and Carla Schwengber ten Caten

Abstract Research on the full utilization of the egg is scarce. The circular food economy proposes the full utilization of food avoiding waste and reuse. The article aims to conduct a systematic review on the use of eggshells. Given that it can be consumed as food rich in minerals and proteins proposing the full utilization of food and reducing waste. Thus, articles were researched (2009–2019) in the Web of Science, Scopus (Elsevier) and Scielo databases. Of 591 articles, 179 were included and the full abstracts were read and only 41 were included in this study. The main points worked were the inclusion of eggshell as food, biodiesel, biomaterial and building material. The articles were classified according to the most recurrent themes about the subject, presenting a summary of the articles found and presenting the state of the art on the subject. It is concluded that there is a growing global interest on the utilization of eggshell and that the eggshell has high nutritional value in calcium, and may supply nutritional deficiency in situations of extreme poverty.

1 Introduction

The unfamiliarity with nutritional principles of food leads to its poor use and tons of food waste. The reuse of food offers a nutritional alternative to a low-cost diet, such as some fruit peels, that are actually rich in nutrients [1].

Food waste in Brazil is very high and is an important issue from an environmental point of view, since there is still no social awareness, generating a large amount of waste that could be reused [2]. In spite of that, according to the FAO, between 2002 and 2013, there were about 82% of Brazilians in a situation of malnutrition.

S. V. Bonato (✉) · E. C. do Nascimento · L. H. R. Martins
Universidade Federal do Rio Grande, Rio Grande, RS, Brazil
e-mail: svbonato@gmail.com

C. Faviero · C. S. ten Caten
Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_16

The Ellen MacArthur Foundation's Cities and Circular Food Economy report provides an overview of how cities can transition to a food system that is favorable both to people and environment. There is also an emphasis on an opportunity that companies, retailers, governments and institutions have to work together to create a system that is healthier and that works for future generations [3].

Circular Economy maintains the added value of products for as long as possible and mitigates waste. It is a strategic concept based on the prevention, reduction, reuse, recovery and recycling of materials and energy. The circular model, in addition to the inherent environmental benefits, such as the preservation of natural resources, reductions in waste of materials and the reduction of residues and pollution, also presents economic and social benefits, as it will be necessary to redesign the economy so that products are designed to last and to be used as by-products in production/manufacturing processes, and thus not considered waste streams [4].

It is possible to make full use of food (stalks, seeds, shells and leaves) and such use contributes to the reduction of food discarded daily. In addition to reducing the cost of preparation, increasing yield, reducing spending on food and providing a high rate of absorption of nutrients that are wasted daily (vitamins, minerals, proteins and fibers). For the mentioned authors, developing environmental and nutritional education programs, with the purpose of stimulating food waste is one of the measures to reduce food waste [5].

Thus, we question the alternatives, within a concept of circular economy, for reusing eggshells, especially when taking into account the deficiency of unique studies that present a range of possibilities on the subject. This study aims to verify the scientific production on the use of eggshell in the last ten years. What motivated the study was the opportunity to explore the concept of circular economy in the use of food, especially egg shell. Its important to have in mind that there are times of increasing hunger in Brazil, it was identified as an opportunity to investigate the field of study to verify possible measures that involve the maximization of the use of available resources.

2 Methodological Procedures

This study presents a qualitative and quantitative approach, as qualitative criteria were used for the selection and classification of the articles identified for their analysis. To fulfill the objective, the research was classified as exploratory, as it directly involves the bibliographic survey and, in relation to the procedures, it is classified as bibliographic, since it was elaborated fundamentally from material already published (scientific papers).

The research protocol was adopted and the steps are detailed, beginning with the definition of the issue; the conceptual framework is as follows: the purpose of this study is to explore the concept of circular economy in the use of food, especially egg shell. The research question is as follows: what are the main alternatives to reuse eggshell? The work team conducting the search process in scientific databases was formed by authors of this study as follow: each author have performed the search individually following the inclusion and exclusion criteria defined below. Afterwards, the results were compared and the differences found were discussed and resolved by consensus [6].

The search strategy included the following: keywords, period, databases, inclusion/exclusion criteria and eligibility/coding. To determine keywords, definitions, and Boolean operators, a preliminary search was performed in Scopus and Web of Science in the fields "abstract" and "title." This scientific databases was selected because it has been mentioned in prior studies as a reference regarding the quality and number of publications on circular economy.

A systematic search was carried out from July to September 2019, using the following keywords, in English, in the bases Web of Science, Scielo and Scopus: eggshell; powdered eggshell, eggshell flour and eggshell in the diet (eggshell; powder of eggshell; eggshell flour; eggshell as food). The period considered for this study was between 2009 and 2019, covering one decade of this research topic.

The inclusion and exclusion criteria are an important aspect in systematic review studies [6]. In the investigated databases, 591 articles were found, that had in their corpus of study the correlation of egg shell and use of. Among these, only 179 abstracts were read according to the inclusion criteria of reuse of eggshell, emerging only results that could be classified in the following categories: human and animal feed, reuse in the production of construction materials, use of eggshell as biodiesel, use of eggshell as biomaterial.

The exclusion criteria defined were: the specifics of the egg (improvements in egg quality, pigmentation; color, thickness, weight); poultry feeding and its influence on egg quality; specific egg characteristics; poultry diet and egg quality; intestinal structure of birds; influences on eggshell structure; use of hormones and egg structures; calcium levels in the animal diet; influences of the induction of chemical substances in the eggshell. However, only 41 were chosen, which were considered adequate to meet the objectives of this investigation. The exclusion criteria were applied based on reading the titles and abstracts of publications. When the reading of the title and abstract was not enough to determine the relevance of the publication for the review, the methods were analyzed and, although the adherence to the research was still not clear, the reading occurred in full.

The Scielo database used the same keywords previously reported and, for the terms searched separately, the total return was 199 results. Obeying the inclusion and exclusion criteria of studies, only abstracts of 43 articles were read. In the Web of Science database, the same terms mentioned above were sought. 219 open access articles were found. Of these, with inclusion criteria and criteria, only 71 met what was expected and their abstracts were read. In the Scopus database, the search for terms resulted in 173 articles. And following the inclusion and exclusion criteria, 65 abstracts were read. Thus, a total of 47 articles were used in this study, obtained through searches performed on the three platforms (Table 1). It should also be noted that only articles resulting from the searches were considered, not having been carried

Table 1 Scientific production on the use of eggs

Year	Authors	Country	Subject
2019	Matsuoka et al.	Japan	Foods
2019	Mariosi et al.	Brazil	Construction material
2019	Vilar; Sabaa-Srur; Marques	Brazil	Foods
2019	Waheed et al.	Pakistan	Foods
2019	Yasar, F.	Turkey	Biodiesel
2019	Verma et al.	India	Biomaterials
2019	Senthil et al.	China	Biomaterials
2019	Jhatial et al.	Pakistan	Construction material
2019	Seeharaj, P. et al.	Thailand	Biomaterial
2019	Kavitha; Geetha, Jacqueline	India	Biodiesel
2019	Tangboriboon et al.	Thailand	Biomaterial
2019	Shiferaw et al.	Korea	Construction material
2019	Silva	Portugal	Construction material
2019	Suparmaniam et al.	Malaysia	Biodiesel
2019	Makuchowska-Fryc	Poland	Biodiesel
2019	Petrová; Juhaniaková; Terentjeva	Slovakia	Foods
2019	Aminah; Meikawati; Rosidi	Indonesia	Foods
2018	Alsuhaiban	Saudi Arabia	Foods
2018	El-Shibiny et al.	Egypt	Foods
2018	Izquierdo; Soto Izquierdo; Ramalho	Brazil	Construction material
2018	Gupta et al.	India	Foods
2018	Mateus et al.	Portugal	Construction material
2018	Tizo et al.	Philippines	Biodiesel
2018	Bartter et al.	Australia	Foods
2018	Guisolfi et al.	Brazil	Foods
2018	Rangel; Melo; Carvalho	Brazil	Biodiesel
2018	Alueshima; Eterigho; Friday	Nigeria	Biodiesel
2017	Bradauskiene; Montrimaite; Moscenkova	Lithuania	Foods
2017	Petrasek; Muller	Czech republic	Foods
2017	Caliman et al.	Brazil	Biomaterial
2017	Khan et al.	India	Foods
2017	Krause; Monaco; Haddade	Brazil	Foods
2016	Siqueira et al.	Brazil	Construction material
2015	Milbradt et al.	Brazil	Foods
2015	Wembabaz et al.	Uganda	Biodiesel
2015	Tan et al.	Malaysia	Biodiesel

(continued)

Table 1 (continued)

Year	Authors	Country	Subject
2013	Jia; Saito; Aw	Japan	Foods
2007	Naves et al.	Brazil	Foods
2006	Freire; Holanda	Brazil	Construction material
2001	Câmara; Madruga	Brazil	Foods

out backward and forward searches on its references however, three articles that were not included in the pre-established period of 10 years (2009–2019), but that are strongly related to the approach of the study were used.

3 Literature Review

3.1 Egg Shell as Food

Each year, larger amounts rich sources of minerals, especially calcium, are wasted globally. Thus, the use of eggshell in food industries would eventually reduce the global burden of eggshell waste to some extent [7].

It was found that it is possible to overcome calcium deficiency in fortified wheat, using industrial food residues [8]. Fermented breads and unleavened breads were prepared from whole wheat flour fortified with powdered chicken bone extract and powdered eggshell. Comparing the two situations, breads fortified with powdered bone extract were less acceptable in the sensory analysis carried out by study participants regarding color, flavor, texture and general acceptability than powdered eggshell and fortified breads. However, when making bread enriched with calcium, it is recommended to add an eggshell powder to the rye flour with lactic acid bacteria. The sensory evaluation shows that bread with powdered eggshell has a better appearance of the crust, color of the crumb, flavor and acceptance in comparison to the control bread, however, the flavor remained similar or worsened [9].

To obtain the eggshell powder, the shells were washed, sanitized, dried in an oven and ground in a mill. The results indicate that the eggshell can be used in human nutrition, since it is rich in calcium, does not present toxic metal contamination and, if processed properly, it has good hygienic-sanitary quality [10].

The use of "multimixture" as a food supplement, in nutritional intervention programs for needy Brazilian populations, has been presenting itself as a food alternative of reasonable nutritional value, low cost, quick preparation and regionalized taste. This results from the fact that it consists mainly of unconventional foods and/or agro-industrial by-products rich in different nutrients [11].

For some authors, egg shells are considered by-products, as well as oyster shells, which are new candidates for use as calcium supplements. The effect of bread fortification with natural sources of calcium, such as skimmed-milk powder, powdered eggshell and oyster shell, on rheological, nutritional and sensory properties was determined [12].

In animal feed, eggshell flour to replace calcific limestone in poultry feed has a significant effect on egg weight, egg mass, feed conversion rates by egg mass, white and shell weights, without that there is a reduction in the productive performance of the birds. Chicken eggshell, generally considered to be waste in large quantities, can become an economically advantageous raw material for the removal of carcinogenic properties from the body of water [13].

3.2 Egg Shell as Construction Material

The continued growth in demand for cement has raised concerns in the sector on environmental and sustainability issues. In addition, the worldwide generation of large quantities of solid waste threatens human health and environmental quality. In the study of the authors it was possible to evaluate the feasibility of using a residual powder derived from organic residues of vegetable or animal origin to replace part of the cement during the production of concrete [14].

The use of polluting solid waste produced in different industrial activities (chicken egg residue and welding slag residue) serves as a source of alternative raw materials for the production of bricks, soil-cement for civil construction. Industrial solid waste behaves as a loading material, as well as influencing both the technical properties and microstructure of soil-cement bricks [15].

Egg shells are one of the world's solid wastes and are considered hazardous according to European Commission regulations. The use of solid waste, such as egg shells, will help to create a sustainable environment, minimizing solid waste that is discarded in the environment. The use of eggshell powder in cement also helps to reduce carbon dioxide emissions from cement plants [16].

In Brazil, the food industry generates large quantities of avian eggshell residues annually, and a critical issue is to find an appropriate use for this residue. Eggshell, rich in hydrophilic cabornate, can be used as an alternative raw material in the production of wall covering materials [17].

Concrete is the most preferred building material in the world and its production has increased exponentially with the rapid construction of infrastructure. Waste generation has also increased due to rapid urbanization. Eggshell is one of those solid wastes that is being generated in large quantities, due to the fact that it is an inexpensive source of nutrition. It was observed that the partial replacement of cement was successful in obtaining greater resistance compared to the control sample [18].

The possibility of producing glassy foams (materials used for acoustic and thermal insulation) from recycled materials was verified, making use of raw materials with easy local access and high incidence in the market: non-returnable beer bottles and eggshell as a foaming agent [19].

Specifically, the powder is derived from a living being, such as food scraps (meat, vegetables, fruits and eggshells), paper, wood, bones and seeds. Its scientific contribution is a conscious change due to the development of an alternative material to contribute to more sustainable processes in the construction industry. Therefore, the residual powder can be used as a filling material to replace part of the cement, resulting in denser and more resistant concrete, in addition to less specific absorption and voids [14].

3.3 Egg Shell as Biomaterial

Biological waste in the form of avian eggshells is an unusual type of biomaterial, as it forms quickly, indicating the generation of a huge bio-waste. Avian eggshells have a large amount of calcium carbonate. Its use of biological waste as additives or coating agents for electrode materials opens a significant way to reduce the amount of biological waste generated [20]. Ostrich egg shells are a potentially abundant, high-purity, low-cost source of calcium to produce phosphate and hydroxyapatite, important calcium phosphates used as biomaterials. These two phosphates are the most used in the medical field [21].

In a sustainable manner, it is possible to manufacture a super-hydrophobic coating from organic eggshell residues. The super-hydrophobic eggshell coating showed good properties of environmental stability, self-cleaning and oil/water separation. Those suggests that eggshell bio-waste can be used for super-hydrophobic applications [22].

Raw duck eggshell is a potential candidate as a bio-ceramic material to prepare calcium hydroxyapatite suitable for biological use, such as bone tissue engineering, drug and gene delivery, remineralizing agent in toothpaste and fillers of bone cavities for orthopedics and restoration [23]. Bone repair is facilitated by bone substitutes' use, such as an apatite drug delivery system derived from eggshell, as it is very suitable for curing osteosarcoma, preventing post-cancer inflammation and modulating bone repair and regeneration [24].

Biomaterials are synthetic or natural materials used as replacement parts for a biological system to play a certain role in contact with living tissue. A bioactive material slowly dissolves when in contact with living tissue, forming a layer of biological apatite before reaching the bone and forming a direct connection to the bone. Instead, a resorbable material dissolves and allows new tissue to grow within its irregularities, not necessarily interacting with the bone [21].

3.4 Egg Shell as Biodiesel and Catalysts

Population growth coupled with high consumption has increased the generation of solid waste. There are several negative impacts generated by the incorrect destination of these tailings. Therefore, the use of waste is increasingly attractive, both economically and environmentally. This demonstrates the production of glassy foams, with low environmental impact, using as waste material fluorescent lamp glass and red eggshell as a foaming agent. In addition, it is possible to minimize the environmental impacts caused by the improper disposal of fluorescent lamps and egg shell residues [25].

The yield of a converted biodiesel, from a source of cooking oil, used by means of heterogeneous catalysts, derived from a very rare type of eggshell, the ostrich eggshell. Parametric effects on biodiesel production were investigated. It was found that the calcium oxide catalyst derived from ostrich eggshells shows potential savings and accessible production possibilities for biodiesel [26].

The viability of using a by-product of the food industry, residues that arise in the processing of chicken eggs, that is, egg shells. The authors identified the possibilities of using microparticles, based on chicken egg shells, as a filler in the two-component structural resin [27]. The research was based on the assumption of an optimization of the use of waste from renewable resources, with the objective of obtaining a material that provides good mechanical properties.

A heterogeneous biocatalyst, synthesized from sucrose, sawdust and chicken egg shells, is characterized and demonstrated qualitative analysis of biodiesel and regular diesel [28]. The authors highlighted the potential as a cheap, fast and accurate diagnostic tool for easy identification and characterization of different materials and products. Another found is the feasibility of reusing chicken egg shells and cooking oil and their physicochemical properties as biodiesel [29].

Chicken egg shells are a residual product, which can be used as a substitute for clay limestone in removing heavy metals from the wet flue gas desulfurization plant. These demonstrate comparable characteristics between chicken egg shells and clay limestone, in the context of their application in removing heavy metal cations from solutions [20]. As microalgae biomass is considered the safest source of biodiesel and chicken eggshell is one of the most effective biofloculants, as it reaches above 60% efficiency [30].

Therefore, derivatives obtained from eggshells can be effectively reused and recycled, as a heterogeneous catalyst for the production of biodiesel [31]. The catalysts used in transesterification are one of the important parameters that affect the efficiency of production in the production process by transesterification of biodiesel. The use of cheap and domestic eggshell as a catalyst has significant effects on product yield and fuel properties, in addition to the cost of biodiesel being significantly reduced [32].

4 Results and Discussion

The interest in understanding the reuse of food has increased in the last 10 years, not only as food, but also as the use of egg shells in the production of food for humans, animals, production of constuction materials, biomaterials and biodiesel.

Overall, the study showed that eggshell, which is generally wasted in large quantities, can become an economically advantageous raw material. Of the 41 selected papers, 39% focus on the use of eggshells as food; 17% in the use of construction materials; 19% in biomaterial and; 27% biodiesel.

Among the 41 papers reviewed, 16 addressed food and highlight the importance of calcium concentrated in egg shells and how it can be inserted in the human diet. Only two were presented in this study taking into account the issue of egg hygiene, attention to health criteria and risks of possible diseases such as. Especially in situations of extreme poverty, the importance of including eggshell in the nutritional diet of food is mentioned. The studies showed improvements in the by-product intake.

It got evident that there is a great relevance of the approach in relation to the reuse of solid residues and in this way it can contribute to reduce the depletion of Earth's resources. From the papers reviewed, eleven correspond to the use of eggshell as biodiesel. Not only can the chicken egg shell be used in the process, but also the ostrich's. This developments are alternative sources of fuel, in renewable, viable and easily available ways, with resources that contribute to a cleaner environment.

In the eight papers referring to the use of eggshell as biomaterials, which correspond to 17%, the great importance of eggshell in biological residues as synthetic or natural materials used as spare parts of a biological system was evidenced to perform a certain contact with living tissue. The analyzed papers demonstrate that the eggshell has great importance in the treatment of cancer, production of dressings and presents itself as an abundant resource.

In construction materials, the seven papers reviewed showed that the continuous growth in demand for cement raised concerns in the sector, about environmental and sustainability issues. And solutions such as the use of polluting solid waste produced in different industrial activities (eggshell residue) serve as a source of alternative raw materials for the production of bricks, soil-cement for civil construction. Not only brick and cement, but also in the production of glassy foams (materials used for acoustic and thermal insulation) from eggshells.

The interest in studying the use of eggshell is present in several countries. It should be noted that publications on the subject have been concentrated in recent years and, mainly, on the use of eggshells as food, as shown in Table 1.

5 Conclusions and Research Directions

From this study, it was possible to identify that there are several alternatives for the use of eggshell, avoiding food waste and decreasing the costs of producing biodiesel and producing biomaterial. It was hoped to find studies more focused on the waste of eggshell as food and reuse in composting. However, several other possible uses for eggshell have been discovered.

The search results initially presented more articles with the exclusion criteria than inclusion. There were several readings of abstracts and, in some cases, partial reading of the article to identify those that met the demand of this study.

In this perspective, the use of eggshell meets the circular economy as a proposal to change the form of consumption, since it aims to transform discarded waste into inputs for the manufacture of new items, creating a circular logic and thus opposing the linear production process, in which a product "is born" (is produced), is used by one period and is discarded. It should be noted that in the circular economy there is no idea of waste, as the raw material is continuously transformed for a new cycle. This system is also responsible for rethinking economic practices, three "Rs" (reduce, reuse and recycle), as it aims to unite the sustainable model of development and concomitant with the pace of accelerated development of production.

Thus, it is verified the importance that the eggshell has, because in addition to the nutritional values in calcium, there are other possibilities of use in the medical, engineering, biological sciences, technology and others, offering a vast field of research. It is noticed that there is a growing global interest on it and a concern with sustainability and total use of food. The continued growth in demand for cement and biofuel has raised concerns in the sector on environmental and sustainability issues.

As suggestions for future research, some paths are to investigate the feasibility of using eggshells from university restaurants, in view of the high volume of daily eggshell production; and to identify how this waste is disposed of and whether there are actions developed to take advantage of this by-product.

References

1. Gondim, J. A. M., Moura, M. D. F. V., Dantas, A. S., Medeiros, R. L. S., & Santos, K. M.: Composição centesimal e de minerais em cascas de frutas. Food Science and Technology, 25(4), 825–827 (2005).
2. Teixeira, S. M. F., Oliveira, Z. M. C. D., Rego, J. C. D., & Biscontini, T. M. B.: Administraçäo aplicada às unidades de alimentaçäo e nutriçäo. In *Administraçäo aplicada às unidades de alimentaçäo e nutriçäo* (pp. 219–219) (2006).
3. Ellen MacArthur Foundation Homepage, https://www.ellenmacarthurfoundation.org/assets/downloads/Cidades-e-Economia-Circular-dos-Alimentos_Resumo-Executivo.pdf Last accessed: 2019/06/05.
4. Pimenta, R., Poggi, F., & Firmino, A. M. V.: Economia Circular como contributo para a implementação de medidas de eficiência energética ao nível dos Municípios/Associações de Municípios. In *Proceedings of the 25th APDR Congress* (pp. 527–537). Associacao Portuguesa para o Desenvolvimento Regional (APDR) (2018).
5. Nunes, J. T.: Aproveitamento integral dos alimentos: qualidade nutricional e aceitabilidade das preparações. Brasília (2009).
6. Dresch, A., Lacerda, D.P., Antunes Jr., J.A.V. Design Science Research: A Method for Science and Technology Advancement. Springer, pp. 161 (2015).

7. Waheed, M., Butt, M. S., Shehzad, A., Adzahan, N. M., Shabbir, M. A., Suleria, H. A. R., & Aadil, R. M.: Eggshell calcium: A cheap alternative to expensive supplements. *Trends in Food Science & Technology*, *91*, 219–230 (2019).
8. Khan, M. R., Wahab, S., QAZI, I., Ayub, M., Muhammad, A., Uddin, Z., … & Noor, M.: Effect of Calcium Fortification on Whole Wheat Flour Based Leavened and Unleavened Breads by Utilizing Food Industrial Wastes. *Asian Journal of Chemistry*, *29*(2) (2017).
9. Bradauskiene, V., Montrimaite, K., & Moscenkova, E.: Facilities of bread enrichment with calcium by using eggshell powder. In 11th Baltic Conference on Food Science and Technology" Food science and technology in a changing world" FOODBALT 2017, Jelgava, Latvia, 27–28 April 2017 (pp. 91-95). Latvia University of Agriculture (2017).
10. Milbradt, B. G., Müller, A. L. H., da Silva, J. S., Lunardi, J. R., Milani, L. I. G., de Moraes Flores, É. M., … & Emanuelli, T.: Casca de ovo como fonte de cálcio para humanos: composição mineral e análise microbiológica. *Ciência Rural*, *45*(3), 560–566 (2015).
11. Câmara, F. S., & Madruga, M. S.: Cyanic acid, phytic acid, total tannin and aflatoxin contents of a Brazilian (Natal) multimistura preparation. Revista de Nutrição, 14(1), 33–36 (2001).
12. Alsuhaibani, A.: Rheological and Nutritional Properties and Sensory Evaluation of Bread Fortified with Natural Sources of Calcium. Journal of food quality (2018).
13. Tizo, M. S., Blanco, L. A. V., Cagas, A. C. Q., Cruz, B. R. B. D., Encoy, J. C., Gunting, J. V., … & Mabayo, V. I. F.: Efficiency of calcium carbonate from eggshells as an adsorbent for cadmium removal in aqueous solution. *Sustainable Environment Research*, *28*(6), 326–332 (2018).
14. Izquierdo, I., Soto Izquierdo, O., & Ramalho, M.: Propiedades físicas y mecánicas del hormigón usando polvo residual de desechos orgánicos como reemplazo parcial del cemento. Revista ingeniería de construcción, 33(3), 229–240 (2018).
15. Siqueira, F. B., Amaral, M. C., Bou-Issa, R. A., & Holanda, J. N. F.: Influence of industrial solid waste addition on properties of soil-cement bricks. Cerâmica, 62(363), 237–241 (2016).
16. Shiferaw, N., Habte, L., Thenepalli, T., & Ahn, J. W.: Effect of Eggshell Powder on the Hydration of Cement Paste. *Materials*, *12*(15), 2483 (2019).
17. Freire, M. N., & Holanda, J. N. F.: Characterization of avian eggshell waste aiming its use in a ceramic wall tile paste. Cerâmica, 52(324), 240–244 (2006).
18. Jhatial, A. A., Sohu, S., Memon, M. J., Bhatti, N. U. K., & Memon, D.: Eggshell powder as partial cement replacement and its effect on the workability and compressive strength of concrete. International Journal of Advanced and Applied Sciences, 6(9), 71–75 (2019).
19. Mariosi, F. R., Camaratta, R., Machado, F. M., & Rodrigues Jr, L. F.: Desenvolvimento de espumas vítreas a partir de garrafa e casca de ovo. *Matéria (Rio de Janeiro)*, *24*(1) (2019).
20. Senthil, C., Vediappan, K., Nanthagopal, M., Kang, H. S., Santhoshkumar, P., Gnanamuthu, R., & Lee, C. W.: Thermochemical conversion of eggshell as biological waste and its application as a functional material for lithium-ion batteries. *Chemical Engineering Journal*, *372*, 765–773 (2019).
21. Caliman, L. B., Silva, S. N. D., Junkes, J. A., & Sagrillo, V. P. D.: Ostrich eggshell as an alternative source of calcium ions for biomaterials synthesis. Materials Research, 20(2), 413–417 (2017).
22. Seeharaj, P., Sripako, K., Promta, P., Detsri, E., & Vittayakorn, N.: Facile and eco-friendly fabrication of hierarchical superhydrophobic coating from eggshell biowaste. *International Journal of Applied Ceramic Technology*, *16*(5), 1895–1903 (2019).
23. Tangboriboon, N., Suttiprapar, J., Changkhamchom, S., & Sirivat, A.: Alternative green preparation of mesoporous calcium hydroxyapatite by chemical reaction of eggshell and phosphoric acid. *International Journal of Applied Ceramic Technology*, *16*(5), 1989–1997 (2019).
24. Verma, A. H., Kumar, T. S., Madhumathi, K., Rubaiya, Y., Ramalingan, M., & Doble, M.: Curcumin Releasing Eggshell Derived Carbonated Apatite Nanocarriers for Combined Anti-Cancer, Anti-Inflammatory and Bone Regenerative Therapy. *Journal of nanoscience and nanotechnology*, *19*(11), 6872–6880 (2019).
25. Rangel, E. M., Melo, C. C. N. D., Carvalho, C. D. O., Osorio, A. G., & Machado, F. M.: Synthesis and characterization of foam glass from solid waste. *Matéria (Rio de Janeiro)*, *23*(1) (2018).

26. Tan, Y. H., Abdullah, M. O., Nolasco-Hipolito, C., & Taufiq-Yap, Y. H.: Waste ostrich-and chicken-eggshells as heterogeneous base catalyst for biodiesel production from used cooking oil: Catalyst characterization and biodiesel yield performance. *Applied Energy*, *160*, 58–70 (2015).
27. Petrasek, S., & Muller, M.: Polymeric particle composites based on filler from hen egg-shells. In *proceedings of the international scientific conference*. Latvia University of Agriculture (2017).
28. Wembabazi, E., Mugisha, P. J., Ratibu, A., Wendiro, D., & Kyambadde, J.: Spectroscopic analysis of heterogeneous biocatalysts for biodiesel production from expired sunflower cooking oil. *Journal of Spectroscopy*, (*2015).*
29. Gupta, A. R., & Rathod, V. K.: Waste cooking oil and waste chicken eggshells derived solid base catalyst for the biodiesel production: Optimization and kinetics. Waste management, 79, 169–178 (2018).
30. Suparmaniam, U., Lam, M. K., Uemura, Y., & Shuit, S. H.: Development of Bioflocculant from Chicken's Eggshell Membrane to Harvest Chlorella vulgaris. In *IOP Conference Series: Earth and Environmental Science* (Vol. 268, No. 1, p. 012121). IOP Publishing (2019).
31. Kavitha, V., Geetha, V., & Jacqueline, P. J.: Production of biodiesel from dairy waste scum using eggshell waste. Process Safety and Environmental Protection, 125, 279–287 (2019).
32. Yaşar, F.: Biodiesel production via waste eggshell as a low-cost heterogeneous catalyst: Its effects on some critical fuel properties and comparison with CaO. *Fuel*, *255*, 115828 (2019).

The Importance of Measurement Uncertainty Analysis on Statistical Quality Control

Giselle Elias Couto and Pedro Carlos Oprime

Abstract Statistical Quality Control tools require data about the process quality, which is obtained through measurement systems. These measurement systems have error components involved in their measurements, and even when they are studied and corrected, uncertainty remains on the final measurement value, generating doubt on how well this result represents the quantity measured. Imprecise measurement can seriously affect quality-oriented companies because of the risks involved in making wrong decisions based on process control tools. Consequently, the measurement uncertainty effect on these tools needs to be carefully investigated. The present study aims to provide an overview of the measurement uncertainty consideration in control charts, process capability indices, and conformance testing and to emphasize its importance in these statistical quality assurance strategies. It was found that large values of measurement uncertainty tend to distance the actual process capability values from the observed ones. In control charts analysis, new critical limits must be calculated to consider measurement uncertainties. Moreover, setting suitably the test uncertainty ratio reduces the out-of-control risks related to measurement uncertainty. Since few studies explore this context, some suggestions to motivate future studies are also provided.

Keywords Statistical quality control · Measurement uncertainty · Process control

G. E. Couto (✉) · P. C. Oprime
Department of Production Engineering, Federal University of São Carlos - UFSCar, São Carlos, SP 13565-905, Brazil
e-mail: giselle.couto@outlook.com

P. C. Oprime
e-mail: pedro@dep.ufscar.br

G. E. Couto
Federal Center for Technological Education Celso Suckow da Fonseca - CEFET/RJ, Itaguaí, RJ 20271-110, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_17

1 Introduction

It is well known that Statistical Process Control (SPC) is an essential collection of problem-solving tools to achieve process stability through variability reduction. Implementing these tools requires data about the process quality which is obtained through measurement systems [1, 2].

Many statistical processes monitoring researches assumes these measurement systems are precise and accurate. However, the existence of errors for either the measurement system and/or operators is inevitable. A difference between the real quantities and the measured ones will always exist, even with highly advanced measuring systems [3].

The International Vocabulary of Metrology (VIM) [4] defines measurement error as the measured quantity value minus a reference quantity value and the measurement uncertainty as a non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used.

Although these terms are not always applied correctly, their distinction is important. Even when all error components are studied and their corrections are applied, uncertainty remains on the final measurement value, generating doubt on how well this result represents the quantity measured [5].

A wide range of factors contributes to uncertainty in measurements. Some major contributors are [6]:

- Metrological system characteristics, which can present errors due to electronic components drift, wear, aging, and other unanticipated problems;
- Inspection method, which may not be correctly defined to the actual measurement task;
- Imported uncertainties, since any measurement system has its uncertainty and this affects the subsequent measurement;
- Operator's skills, because certain measurements rely on both the operator's skill and their judgment;
- Sampling concerns, that must represent the process being assessed; and
- Environmental conditions, since the measuring instrument can be significantly influenced by either the component being measured or from any variations in temperature, humidity, air pressure, and vibrational effects as well as many more unexpected conditions.

Several papers show the influence of measurement errors on statistical quality control tools [7–12]. However, the consideration of measurement errors requires the use of the concept of true value, which cannot always be obtained in an operational sense. Hence, since the publication of the Guide to the Expression of Uncertainty in Measurement (GUM), there has been a rising recognition that the evaluation of measurement uncertainty is as critical as the measurement error evaluation itself [12].

Imprecise measurement can seriously decrease quality-oriented company profits because it affects the process variability, leading to possible additional management costs. Consequently, the effect of measurement uncertainty on process control techniques needs to be carefully investigated [3, 13].

As stated above, studies concerned with measurement errors on process monitoring and control tools have been performed in recent years. However, scarce studies have been conducted about the impact of measurement uncertainties in this context based on GUM definition.

The present study aims to provide an overview of the measurement uncertainty consideration in control charts, process capability, and conformance testing and to emphasize its importance in these statistical quality assurance strategies. Moreover, some directions to motivate future studies are provided.

2 Influence of Measurement Uncertainty on Process Capability Indices

Process capability analysis is one of the key tools that can improve product quality. This analysis comprises two essential parts: the process output variability measurement; and the comparison between measured variability and a pre-specified value. Thus, the process capability analysis aims to determine whether the natural variability in process output is within an acceptable range [3].

To simplify this analysis, indices are used as a statistical measure of process capability. The process capability index (PCI) is a value that reflects the real-time process quality. Because of its dimensionless, it allows comparisons between hundreds of processes. PCI most used in industrial applications is the *Cp* and *Cpk* indices [13–15].

Cp is an unlimited symmetric index and can be expressed as presented in Eq. 1, where USL and LSL represent the upper and lower specification limits, respectively, and σ represents the process standard deviation.

$$Cp = \frac{USL - LSL}{6\sigma} \tag{1}$$

In practical applications, the process standard deviation is almost always unknown and should be replaced by its estimative, such as the sample standard deviation [1, 16].

The fragility of this method is that it does not recognize the process mean location. To prevent this problem, the *Cpk* index was developed. It considers the process mean variability relative to the specified values. Its result is the smallest value between the two calculated ratios, as showed in Eq. 2 [17].

$$Cpk = min\left\{\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right\} \tag{2}$$

Measurements are an enormous part of process capability calculations. In this way, an imprecise measurement system can lead to severe decision-making errors.

Aware of this, [18] compared expanded measurement uncertainty, calculated based on GUM, to tolerances calculated from process capability ratio to get reliable critical limits and confidence bounds. The measurement uncertainty was included to compensate for errors due to experimental setup errors, time-varying parameters, tool wear, measuring method, and measuring instrument.

Equation 1 was used considering that process capability and standard deviations are known. So, they calculated the tolerance at the manufacturing level and compared it to the uncertainty-to-tolerance (U/T) ratio. The effectiveness of the proposed method was verified in a case study for sheared billets measurements, proving to be successful in actual process performance evaluation in a quantifiable manner. This study presented some limitations since deviations from measured variable normality assumption and process stable condition have a significant effect on the error associated with using the *Cp* index.

To obtain a more accurate assessment of the process capability, [2] modified the *Cp* and *Cpk* indices to the "observed" process capability indices, Eqs. 3 and 4, respectively.

$$\hat{C}_{p,obs} = \frac{z_{\alpha/2}\hat{C}_{p,real}}{\sqrt{z_{\alpha/2}^2 + \left[6\gamma\hat{C}_{p,real}\right]^2}} \tag{3}$$

$$\hat{C}_{pk,obs} = \begin{cases} \frac{z_{\alpha/2}\hat{C}_{pk,real}}{\sqrt{z_{\alpha/2}^2 + \left[6\gamma\hat{C}_{pk,real}K^{-1}\right]^2}} & if\ \ K \neq 0 \\ 0 & if\ \ K = 0 \end{cases} \tag{4}$$

The "observed" process capability indices are based on the ratio of the measurement uncertainty to the tolerance and the process capability got from the standard deviation of the production process. Where $z_{\alpha/2}$ is the value of the standard normal distribution, $\hat{C}_{p(k),real}$ is the capability index of the manufacturing process, γ is a constant value and K represents the ratio of the amount the center has moved off-target divided by the amount from the center to the nearest specification limit.

They found that the greater the measurement uncertainty, the greater the distance between the "observed" capability and the "real" capability, showing the need to consider the measurement uncertainty effect on the process capability analysis, in particular in those processes of smaller natural variability.

Another analysis of the impact of measurement uncertainty on the *Cp* and *Cpk* indices was made by [19] for both optical and tactile measuring systems used in the quality control of microinjection molded products. With this purpose, they replaced the estimate of the standard deviation in Eqs. 1 and 2 with the square root of the quadratic sum of the process sample standard deviation and the estimate of the measurement uncertainty for the measurand in question. *Cp* and *Cpk* were calculated as a function of the expanded measuring uncertainty (U) in five different situations:

U = 0 (perfect/ideal measurement), U = 10% of the process tolerance, U = 20% of the process tolerance, U = U of the optical measuring system and U = U of the tactile measuring system.

They point out that in the quality control of micro-manufacturing processes it must be ensured that the measurement uncertainty is sufficiently small to verify the specified tolerances and to not introduce a too large spread and bias in the quality control. Depending on the considered measurand, measuring instruments with uncertainty-to-tolerance ratios up to 20% could be used and allow an effective process capability assessment, on the other hand, it was found that the process was not capable of producing some dimensions required within the specifications, showing the relevance of considering the measurement uncertainty in the process capability indices.

3 Influence of Measurement Uncertainty on Control Charts

A control chart is another well-established statistical tool that allows to control and monitor the variability in many industrial processes. This technique use occurs in two distinct phases. Control charts that are used to determine the process stability and to estimate parameters are referred to as Phase I charts, while those used to monitor and detect shifts in the process parameters are defined as Phase II charts [20, 21].

In establishing a control chart, the following three basic elements should be calculated: Central Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL). The first represent the target-value. The last two represent the boundaries that if trespassed will cause an out-of-control event. Both are frequently set by the mean and standard deviation estimation of the random variable that represents the quality characteristic of interest [22, 23].

Since these estimators are calculated with values obtained by using measuring systems, each one of these limits is intrinsically associated with sources of measurement uncertainty, which, if not properly considered, can lead to errors in the control chart's interpretation.

In control charts analysis, two errors can occur: the type I error occurs when the process is in-control and the control chart signals the presence of an assignable cause, and the type II error occurs if the process is out-of-control and the control chart cannot detect this status [24].

Concerning this issue, [5] studied the measuring uncertainties effect on the creation of control charts and their impact on the sensitivity, rate of false alarms, and type I and II errors. Considering the law of propagation of uncertainty and the control chart properties, they formulate an equation that determines the probability of each sample in a control chart representing a special cause, using critical control limits, which corresponds to extremity values of the control limits uncertainty region.

Another study on the influence of measurement uncertainties on control charts was done by [25]. Although for better control chart analysis it is desired the measurement uncertainty is the smallest possible, the authors stated that an appropriate tradeoff needs to be found between the costs associated with the management of this condition and the costs caused by wrong decisions.

Despite in most cases control charts are developed to control production processes, [26] proposed modifications in a control chart considering an analytical system as a process where the products are the analytical results. They present a novel approach for fixing the control limits, named the u-approach mean control chart, combining the uncertainty got from the method validation information.

Through a comparative study on “in-control” simulated, bibliographic, and real laboratory data, their approach proved to have better applicability and robustness than the traditional mean control chart for controlling methods exhibiting moderate bias, even fixing the center line at the reference value.

When the influence of measurement uncertainties is considered in the construction of control charts, there is a need to assess whether a measurement or a sample, will be considered as a special cause according to its position to the uncertainty zone. To provide a decision rule also valid in the uncertainty range, [27] present a Fuzzy Decision Making (FDM) technique.

This method allows calculating the maximum measurement uncertainty that the system can be affected by according to the related effects on the decision-making process, therefore with information on the measurement system performances and on the level of measured data confidence. Their model enables decision making about the conformance or non-conformance of quality characteristics with specifications or control limits and can be applied for a wide variety of measurement systems.

4 Influence of Measurement Uncertainty on Conformance Testing

Another procedure used in process control is the conformance testing, by which a quality characteristic is measured against pre-set specifications. The total cost of a conformance test procedure is a combination of direct or indirect expenses due to making incorrect decisions and the sum of the measurement-related costs, thus being a consequence of the accuracy of the measuring system used [28].

As in control charts, in conformance testing the contribution of measurement uncertainty may lead to an out-of-limit wrongly accepted product, called consumer-risk (CR), or a valid product wrongly rejected, called producer-risk (PR). These risks can be characterized by their corresponding probabilities of occurrence [22].

To consider the influence of measurement uncertainty in conformance testing, [22] proposed new approximate expressions to CR and PR under the hypothesis of normally and uniformly distributed uncertainties. They found that out-of-conformance or out-of-control risks related to measurement uncertainty can be reduced by setting suitably the test uncertainty ratio associated with the equipment used.

Macii and Petri [28] also reformulate the CR and PR equations considering the measurement uncertainty value to improve the efficiency of the conformance testing design in quality-oriented organizations. They found that if a measurable quality characteristic is assumed to be normally distributed and centered within a known specification interval, CR and PR can be kept below the target values by suitably setting both the Test Uncertainty Ratio (TUR) and the Gauging-to-tolerance-interval ratio (GTR) of the testing procedure.

5 Conclusions

To assess a process and ensure that it is stable and reliable, it is necessary to know how the measurement system uncertainty affects the effectiveness of the quality control tools used in its evaluation. The literature review shows that large values of measurement uncertainty tend to distance the actual values of process capability from the observed ones.

In control charts analysis, measurement uncertainties have a direct impact on the estimation of Type I and Type II errors, requiring the consideration of critical control limits calculated from the measurement uncertainty from the collected data. As for the conformance testing, it was found that out-of-control risks related to measurement uncertainty can be reduced by setting suitably the test uncertainty ratio associated with the measurement system used.

Although it proved to be relevant, scarce studies have been conducted about the influence of measurement uncertainties in statistical quality control tools. It is suggested for future work to explore the effect of measurement uncertainty in more complex process data like non-normal, autocorrelated, profile, and multivariate data.

Attention should be considered to the measurement uncertainty impact in other types of control charts besides traditional ones like control charts for the mean and the range. Moreover, following technological developments related to measurement systems and data collection processes, additional studies are suggested on the influence of measurement uncertainty on the statistical control of processes inspected by optical and nanoscale measurement systems and processes monitoring involving big data and neural networks.

References

1. Montgomery, D.: Introduction to Statistical Quality Control. Arizona State University, John Wiley & Sons (2013)
2. Villeta, M., María Rubio, E., Angel Sebastián, M., Sanz, A.: New criterion for evaluating the aptitude of measurement systems in process capability determination. Springer. 50, 689–697 (2010)
3. Maleki, M.R., Amiri, A., Castagliola, P.: Measurement errors in statistical process monitoring: A literature review. Comput. Ind. Eng. 103, 316–329 (2017)

4. BIPM: JCGM 200:2012 International vocabulary of metrology—Basic and general concepts and associated terms (VIM). (2012)
5. Hack, P.S., ten Caten, C.S.: Effect of Measurement Uncertainty in Control Charts. In: XVIII International Conference on Industrial Engineering and Operations Management., Guimarães, Portugal (2012)
6. Smith, G.T.: Machine tool metrology: An industrial handbook. Springer (2016)
7. Mittag, H.-J.: Measurement Error Effects on the Performance of Process Capability Indices. In: Frontiers in Statistical Quality Control 5. pp. 195–206. Springer-Verlag London Ltd (1997)
8. Bordignon, S., Scagliarini, M.: Statistical analysis of process capability indices with measurement errors. Qual. Reliab. Eng. Int. 18, 321–332 (2002)
9. Kanazuka, T.: The Effect of Measurement Error on the Power of $\bar{X}$-R Charts. J. Qual. Technol. 18, 91–95 (1986)
10. Shore, H.: Determining measurement error requirements to satisfy statistical process control performance requirements. IIE Trans. (Institute Ind. Eng. 36, 881–890 (2004)
11. Scagliarini, M.: Multivariate process capability using principal component analysis in the presence of measurement errors. AStA Advances in Statistical Analysis. 95, 113–128 (2011)
12. Hsu, B.M., Shu, M.H., Pearn, W.L.: Measuring process capability based on Cpmk with gauge measurement errors. Qual. Reliab. Eng. Int. 23, 597–614 (2007)
13. Anis, M.Z.: Basic process capability indices: An expository review. Int. Stat. Rev. (2008)
14. Abbasi Ganji, Z., Sadeghpour Gildeh, B.: Assessing process performance with incapability index based on fuzzy critical value. Iran. J. Fuzzy Syst. 13, 21–34 (2016)
15. Bargelis, A., Kuosmanen, P., Stasiskis, A.: Intelligent Interfacing Module of Process Capability among Product and Process Development Systems in Virtual Environment. Stroj. Vestnik/Journal Mech. Eng. (2009)
16. Abdolshah, M.: Fuzzy Process Capability Indices: A Review. World Applied Sciences Journal, v. 16, n. 12, p. 1734–1740, (2012)
17. Chatterjee, M., Chakraborty, A.K.: Univariate Process Capability Indices for unilateral specification region - A review and some modifications. International Journal of Reliability, Quality and Safety Engineering, v. 19, n. 04 (2012)
18. Mahshid, R., Mansourvar, Z., Hansen, H.N.: Tolerance analysis in manufacturing using process capability ratio with measurement uncertainty. Precision Engineering, v. 52, p. 201–210, (2018)
19. Tosello, G., Hansen, H.N., Gasparin, S.: Integrating Measuring Uncertainty of Tactile and Optical Coordinate Measuring Machines in the Process Capability Assessment of Micro Injection Moulding. In: Proceeding of 10th International Euspen Conference. p. 168–171. (2010)
20. Mason, R.L., Champ, C.W., Tracy, N.D., Wierda, S.J., Young, J.C.: Assessment of Multivariate Process Control Techniques. Journal of quality technology, v. 29, n. 2, p. 140–143 (1997)
21. Kazemzadeh, R.B., Noorossana, R., Amiri, A.: Phase I Monitoring of Polynomial Profiles. Commun. Stat. Methods. 37, 1671–1686 (2008)
22. Carbone, P., Macii, D., Petri, D.: Measurement uncertainty and metrological confirmation in quality-oriented organizations. Meas. J. Int. Meas. Confed. 34, 263–271 (2003)
23. Ipek, H., Ankara, H., Ozdag, H.: The application of statistical process control. Miner. Eng. 12, 827–835 (1999)
24. Amiri, A., Moslemi, A., Doroudyan, M.H.: Robust economic and economic-statistical design of EWMA control chart. Springer. 78, 511–523 (2015).
25. Macii, D., Carbone, P.: Management of measurement uncertainty for effective statistical process control. IEEE Transactions on Instrumentation and Measurement, v. 52, n. 5, p. 1611–1617, (2003).
26. Bonet-Domingo, E., Escuder-Gilabert, L., Medina-Hernández, M.J., Sagrado, S.: Uncertainty-based internal quality control. Harmonization considerations. Anal. Chem. 78, 8113–8120 (2006).

27. De Capua, C., De Falco, S., Morello, R., Pasquino, N.: Validation of a fuzzy decision making technique on environmental quality indexes measurement. In: Proceedings of the 10th International Measurement Confederation TC7 Symposium on Advances of Measurement Science, Saint Petersburg, Russia. p. 522–525 (2004).
28. Macii, D.; Petri, D.: Guidelines to manage measurement uncertainty in conformance testing procedures. IEEE Transactions on Instrumentation and Measurement, v. 58, n. 1, p. 33–40, (2008).

Evaluation Model for Sustainable Supply Chain Management in the Food Industry

Mauro Lizot, Flavio Trojan, Shirley Suellen Thesari, and Andreia Santos Goffi

Abstract The objective of this work is to present a structured methodology that allows the evaluation of sustainable supply chain management through a proposed model constructed and applied in a case study performed in a food industry. In methodological terms, the model was elaborated with seven stages, namely: environmental management, supplier selection, supplier collaboration, supplier evaluation, customer selection, customer collaboration and customers' evaluation. The results achieved in the environmental management stage denoted a satisfactory average for this aspect, due to legal issues and internal procedures followed by the company. In the other stages the company studied has presented in average a low level of sustainability. As a conclusion, the application of the model provided an assessment of environmental practices and construction of planning of actions for the company in order to leverage the sustainable aspects and improve the supply chain management.

Keywords Evaluation model · Methods of evaluation of supply chain · Case study of a food industry

1 Introduction

The relationship between the supply chain and the environment protection aspects has increased in recent years, mainly concerning consumers, businesses and governments responsible by environmental issues [1]. Clean processes, reuse of products and components, and recycling techniques are effective initiatives to reduce the environmental impact on logistics networks [2].

This movement of sustainability in business is known as Green Supply Chain Management (GSCM) [1, 2]. The practices adopted directly interfere in the supply chain, providing convergent interactions for the needs of all members [2]. Therefore, the development of methods and models to solve problems in this theme should

M. Lizot (✉) · F. Trojan · S. S. Thesari · A. S. Goffi
Federal University of Technology–Parana (UTFPR), Ponta Grossa, PR 84017-220, Brazil
e-mail: mauro.lizot@unochapeco.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_18

be further developed. On the other hand, the green supplier development programs require substantial resources and investments from the companies [3].

In the literature, the GSCM theme has already been addressed in some research. Azevedo et al. [2] have investigated the relationships between green supply chain management practices and supply chain performance. The study by Lozano and Huisingh [4] analyzed the Social Responsibility reports of three companies in a comparative way, addressing the GSCM's degree of maturity. Chiou et al. [5] sought to develop a method to encourage companies to implement GSCM and green innovation, in order to improve their environmental performance and increase their competitive advantage in the global market. The study by Green et al. [6] addressed the adoption of GSCM practices by manufacturing organizations, in which a better environmental and economic performance was perceived, which positively affected operational performance. The research by Govindan et al. [7] assesses a method of selecting suppliers to increase GSCM performance based on the Triple Bottom line (TBL) approach. Lizot et al. [8] evaluated the GSCM theme in the literature through a bibliometric study and listed the main methods applied in companies.

For Supply Chain Management to take place in a sustainable way, it is necessary to incorporate sustainability into the company's mission and vision [3], as well as the company needs to present an aggregate planning, that is, the process by which a company determines the ideal levels of capacity, production, subcontracting, stock, lack of stock and even prices for a specified time horizon, so the objective of aggregate planning is to satisfy demand while maximizing profit [9].

The sustainable supply chain exploitation dates back to the 1980s [10]. The Triple Bottom Line (TBL) concept is another important concept for the sustainability research, which refers to three groups: the first is the social aspect, related to the treatment of human capital; the second one is the economic, deals with the economic result; and the third one, environmental, related to the natural resources destined for a company or society [11]. According to Lozano, Huisingh [4] in organizations, managers and employees are increasingly getting involved in voluntary actions as a contribution to sustainability.

For supply chain management becomes a sustainable practice, the philosophy of sustainability should be incorporated into the company's mission and vision [6], and the companies must develop an aggregated planning to achieve optimal levels. The goal of the aggregated planning is to provide subsidies for demand satisfaction, thereby maximizing results [9].

2 Objectives

Given the context, the research problem of this work is to evaluate the level of sustainable supply chain development in companies. The general objective was built through a structured methodology to assess the sustainability level of the supply chain in the companies. Thus, to better achieve the general objective, some specifics goals were defined into three directives, which were: (i) perform the selection procedure in order to choose potential models for application, (ii) perform of a case study to apply the model selected according to the company characteristics, and (iii) analyze and present the research results, contributing to the advancement of discussions on this subject.

This study is justified due to the recent spread of scientific works on this subject, and the relevance of the theme on the sustainable management of supply chains [12]. The development of new approaches in this theme might contribute for stakeholders in the companies, as well as a bibliographic reference for future research on sustainable supply chain management.

3 Methods

To construct the model and apply it in a case study, we used the concepts presented on [2, 4, 6, 7, 13, 14], which determine the intervention method divided into three stages: design, data collection and analysis. Thus, the development of research occurs through a procedure to assess sustainable supply chain management applied in the food industry segment. The research is based on the qualitative data analysis method proposed by [15], which provides the development of conceptual models in an anticipated and simultaneous way to collect data and apply tests.

The model consists on seven stages: (a) stage of environmental management, (b) selection (c) collaboration of suppliers, (d) supplier evaluation, (e) customer selection, (f) customer collaboration and (g) customer evaluation, as illustrated in Fig. 1.

(a) Environmental Management addresses questions referring to the internal activities in the company that through the diagnosis it is possible to investigate the utilization levels of tools related to increase environmental management aspects. Several authors have been publishing works in supplier selection regarding to environmental aspects [11].
(b) Supplier Selection can evaluate potential suppliers to attend the company concomitantly addressing the entire life cycle of a product, raw materials, and service providers [7].
(c) Collaboration of Suppliers focuses on supporting organizations to improve environmental protection activities, integrating it in the entire supply chain. The goal of supplier development goes beyond your partners to become more sustainable. It helps the suppliers become greener [3].
(d) In the supplier assessment, it is relevant to identify the critical criteria for developing an efficient system of strategies for sustainable supply chain [11].
(e) The stage related to clients (selection (e), collaboration (f) and evaluation (g)) is a differential in the model developed in this work. They address questions about whether the company has tools, programs, or attitudes toward the sustainable development for its customers.

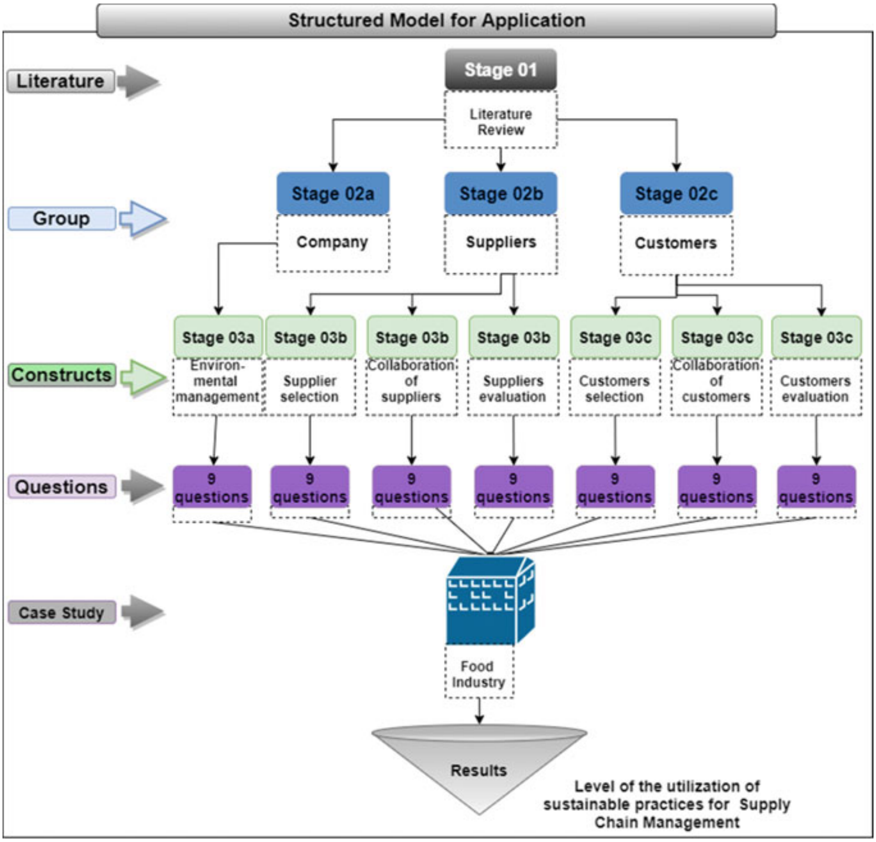


Fig. 1 Proposed structured model. *Source* Adapted from Azevedo et al. [2] and Lozano and Huisingh [4]

Regarding the methodology of evaluation on sustainable supply chain management, it was elaborated with a 5-point Likert scale. Where 1, represents "Never"; 2, "Almost Never"; 3, "Sometimes"; 4, "Almost Always"; 5, "Always".

However, some questions regarding the professional profile were also considered. In the elaboration of the methodology, the researchers considered: (a) the literature review on the subject; (b) previous research on sustainable supply chain management; (c) interview with specialists; (d) interview with managers from the case study. For data triangulation, the following research techniques were defined: interviews (E), verification and collection of documents (D) and observation (O). The presence of these items evidence in Industry studied appears in Tables 1, 2, 3, 4, 5, 6 and 7. The case study was developed in a food industry located in southern Brazil, in the state of Santa Catarina, which has a collaborative staff of approximately 520 employees. Currently the company produces pasta, wheat, corn flour and cookies. Its products are

Table 1 Stage of environmental management

	Stage of Environmental Management	*Scale*							
1	Does your company focus on environmental legislation?	1	2	3	4	5	E	D	O
2	Is your the production sector than to other sectors?	1	2	3	4	5	E	D	O
3	Does your company adopt end-of-line solutions (ie, it treats waste and effluents at the end of the production process, for example, performs water, air or soil treatment)?	1	2	3	4	5	E	D	O
4	Does your company focus on efficient use of resources (eg apply principles such as the 3 Rs - Reduce, Reuse, Recycle)?	1	2	3	4	5	E	D	O
5	Does your company practice activities to improve its eco-efficiency (ie producing more and better with less resources and generating less waste)?	1	2	3	4	5	E	D	O
6	Is senior management committed to the company's environmental management?	1	2	3	4	5	E	D	O
7	Do all sectors of the company discuss about environmental management?	1	2	3	4	5	E	D	O
8	Can the company's environmental performance be considered a competitive advantage?	1	2	3	4	5	E	D	O
9	Is the company's overall strategy influenced by its environmental performance?	1	2	3	4	5	E	D	O

Source: Research data.

distributed in approximately 30,000 points of sale in Brazil, in addition to production for export to several countries.

The data collection was organized through interviews, considering the availability of respondents and adequate time for responses. The questionnaires were applied to 14 employees at the management, supervision and leadership levels of the supply department, who were selected due to their participation in the researched company's GSCM process. The interviews took place between December 15 and 22, 2019 and were applied through a questionnaire compost for 31 questions based in the literature [2, 4, 6, 7, 13, 14] (questions are presented in Tables 1, 2, 3, 4, 5, 6 and 7), according to the proposed model presented in Fig. 1.

4 Results

In the "Environmental Management" stage, this theme complies with the state environmental legislation of Santa Catarina (called FATMA—Foundation of the Environment of the Government of Santa Catarina). This environmental agency aims to define the documentation required for licensing and establish criteria for environmental plans, programs and projects in small, medium and large industrial activities, including liquid waste treatment, solid waste treatment and disposal, noise, vibration and other environmental liabilities [16].

Table 2 Supplier selection

	Supplier selection	Scale							
10	Does the selection of new suppliers take environmental criteria into account?	1	2	3	4	5	E	D	O
11	Are new company suppliers required to prove their environmental licenses, operating permits and environmental certificates?	1	2	3	4	5	E	D	O
12	Is the company's new suppliers required to implement an environmental management system?	1	2	3	4	5	E	D	O
13	Is a prior visit to new suppliers' addresses to assess their environmental performance?	1	2	3	4	5	E	D	O

Table 3 Collaboration of Suppliers

	Collaboration of suppliers	Scale							
14	Does your company set environmental goals with its suppliers?	1	2	3	4	5	E	D	O
15	Does your company work with your suppliers to reduce the environmental impact of businesses?	1	2	3	4	5	E	D	O
16	Does your company hold seminars, meetings or lectures with its suppliers on environmental awareness?	1	2	3	4	5	E	D	O

Source Research data

Table 4 Supplier evaluation

	Suppliers evaluation	Scale							
17	Does your company conduct audits on suppliers to track their environmental performance?	1	2	3	4	5	E	D	O
18	Does your company define environmental criteria relevant to your industry and pass them on to your suppliers?	1	2	3	4	5	E	D	O
19	Does your company track the effective date of your suppliers' environmental licenses, operating permits, and environmental certificates?	1	2	3	4	5	E	D	O
20	Does your company evaluate the performance of its suppliers based on environmental criteria?	1	2	3	4	5	E	D	O

Source Research data

Table 5 Customer selection

	Customer selection	Scale							
21	Does the selection of new customers take environmental criteria into account?	1	2	3	4	5	E	D	O
22	Are new company customers required to prove their environmental licenses, operating permits and environmental certificates?	1	2	3	4	5	E	D	O
23	Are new customers required to help implementation of an environmental management system?	1	2	3	4	5	E	D	O
24	Is a prior visit to new customers' addresses to assess their environmental performance?	1	2	3	4	5	E	D	O

Source Research data

Table 6 Collaboration with customers

	Collaboration with customers	Scale							
25	Does your company set environmental goals with its customers?	1	2	3	4	5	E	D	O
26	Does your company work with your customers to reduce the environmental impact of businesses?	1	2	3	4	5	E	D	O
27	Does your company hold seminars, meetings or lectures with its customers on environmental awareness?	1	2	3	4	5	E	D	O

Source Research data

Table 7 Customer evaluation

	Customer evaluation	Scale							
28	Does your company conduct customer audits to track their environmental performance?	1	2	3	4	5	E	D	O
29	Does your company define the environmental criteria relevant to your industry and pass them on to your customers?	1	2	3	4	5	E	D	O
30	Does your company track the effective date of your customers' environmental licenses, operating permits, and environmental certificates?	1	2	3	4	5	E	D	O
31	Does your company evaluate customer performance based on environmental criteria?	1	2	3	4	5	E	D	O

Source Research data

The technical report renewal and environmental license of operation intends to follow the legislation, presenting a Technical Report of Working Conditions—LTCAT, an Environmental Risk Prevention Program—PPRA, as well as fire brigade training. The results of the "environmental management stage" are presented in Table 1.

Concerning to the evidences, interviews, documents (technical report of renewal of environmental permit of operation and manual of good manufacturing practices) and observations were collected. Thus, each issue of the "Environmental Management" stage was composed of at least two evidences.

It is noteworthy that the industry surveyed, however, does not have an environmental management system implemented. For [11] the environmental management system of a company consists of the set of responsibilities, procedures, processes and organizational means in order to adopt the environmental policy.

An environmental management system would probably contribute to advances in areas where the company still needs to improve, such as: greater discussion among sectors on environmental management, better eco-efficiency and an important contribution by the interviewed manager with a view that the Environmental performance of the company can be considered a competitive advantage. The results found fall short of the evidence demonstrated by Micheli et al. [17], in which manufacturing companies implement sustainable initiatives in their supply chain. Even though few studies have provided clear empirical evidence on the real impact of these initiatives on company performance, the results are clear to aid the development of the GSCM.

The industry has developed throughout its 28 years of activity, internal manuals on good manufacturing practices. The purpose of these manuals is to define the documentation required for licensing and to establish criteria for the presentation of environmental plans, programs and projects for the implementation of small, medium and large industrial activities, including treatment of liquid waste, treatment and disposal of solid waste, noise, vibrations and other environmental liabilities. The "Environmental Management" stage achieved the best performance among the other seven stages with an average of 4 points on the Likert scale, which reaches a maximum of 5.

The results of the second stage "Supplier Selection" are shown in Table 2.

Choosing an appropriate supplier is a crucial strategic direction for reducing the environmental impact of supply chain management for companies [11]. During the selection of suppliers the environmental issue is not emphasized, previous visits to know the origin of the product, as well as incentives for the development of an environmental management system, are necessary actions.

Supplier selection plays have important role in managing supply chain, traditionally criteria such as price, quality, flexibility, and others [7]. It is noteworthy that articles that address sustainability as criteria for suppliers are scarce in the literature. The results helped to understand the principles of supplier selection proposed by Wong [18], who states that the ecological supply chain focuses on reducing the environmental impact during product delivery and on satisfying the level of customer service.

The stage "supplier selection" achieved an average of 1 point on the Likert scale; demonstrating few issues addressed related to the environmental supply chain.

The results of third stage "collaboration with suppliers" are presented in Table 3.

Companies need to work with suppliers to improve supply chain management practices [6]. The stage "collaboration with suppliers" averaged 1 point on the Likert scale, which demonstrates the absence of actions related to collaboration with suppliers. The company is concerned with internal issues, not fostering strategies with suppliers regarding environmental supply chain management. The absence of a collaborative relationship with sustainable suppliers shows a worrying result, as according to Li et al. [19] the relationship with sustainable suppliers strengthens the purchasing company's own environmental performance, and this relationship tends to be replicated to its customers.

The results of fourth stage "supplier assessment" are presented in Table 4.

The search for products that have less environmental impact is linked to the origin of the raw material; consequently, its suppliers need to supply products that do not contain hazardous and toxic substances [5]. Of concern is the lack of supplier performance reviews, which is closely related to the previous stage "collaboration with suppliers", because without such collaboration it will be difficult to evaluate them. Therefore, it is relevant to use tools that can assist in the assessment of suppliers regarding their sustainable capacity [20]. The stage "supplier assessment" achieved an average of 1 point on the Likert scale.

The results of the fifth stage "customer selection" are presented in Table 5.

Environmental conservation is gaining prominence among managers around the world, and customers play a key role in demanding products that respect the environment [8, 14]. Taking into account customer environmental criteria (wholesale and retail) strengthens the supply chain. The stage "customer selection" achieved an average of 1 point on the Likert scale.

The results of the sixth stage "customer collaboration" are presented in Table 6.

Organizations have sought to adopt procedures that include policies and tools that go beyond regulatory compliance, such as environmental management systems and life cycle assessment [4]. It is extremely important to develop seminars, meetings or lectures with its clients on environmental awareness. The raising awareness and passing on environmental values to the wholesale and retail sector, possibly the end consumer will benefit, adding value to the environmental supply chain. The stage "customer collaboration" achieved an average of 1 point on the Likert scale.

The results of the last stage "customer evaluation" are presented in Table 7.

Implementation of green supply chain management (GSCM) arises in response to customer demand for environmentally sustainable products and services and also in response to government environmental regulations [6]. The work carried out in the stages of selection, collaboration and evaluation of customers has significant effects on the GSCM, as it represents one of the extremes of the entire process, the benefits of which are reflected in an increase in confidence and market value of the company [21].

Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equality [10]. The proposed methodological model presents a strong tendency to environmental tripod, but with less intensity, the social and economic aspect is also approached.

During the evaluation it was evidenced strong rigor regarding the legislation, because if the company did not follow the current legislation, it could suffer legal sanctions. The surveyed industry follows the legislation of the state of Santa Catarina, FATMA, which made it possible to develop the technical report for renewal of the operating environmental license.

As shown in Fig. 2, of all seven stages suggested by the methodological model, the Environmental Management Stage has the highest average result (average 4), and the source of evidence through interviews, documents and observations, demonstrating that in this regard the company has a more solid development. All other stages had the same result average (mean 1), and the evidence originated from interviews.

After applying the methodological model and analyzing the results, it was relevant for the evaluation of the sustainable supply chain management level. The model can be replicated to all members of a supply chain, so the results can be analyzed in a broader and more integrated way (Fig. 1).

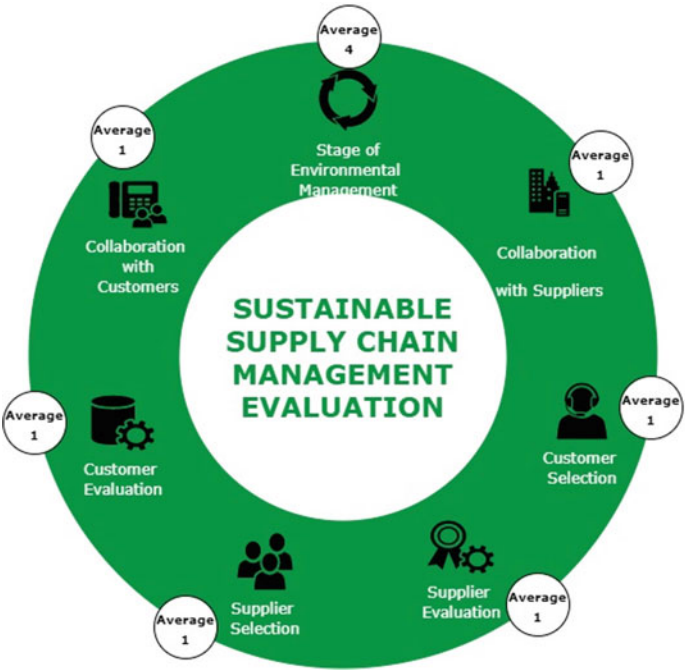


Fig. 2 Result of the sustainable supply chain management assessment. *Source* Research data

5 Conclusion

The construction and application of the model demonstrated that was possible to provide a more coherent view to support managers in their decisions with the analysis of the level of sustainability in the company.

Regarding to results in the first "Environmental Management" stage, the company presented a satisfactory average, due to legal issues and internal procedures. The environmental performance in the studied company could be considered an improvement for competitive advantage in its business.

Another highlight identified by the application of the model was the renewal of the environmental operating license and certifications of recyclable waste, lubricants, lamps and chemical waste. Such certifications are essential to the well-being of employees, the community and the environment. In the other hand, the strong presence of the waste issue leads the company to think more about environmental issues, in order not to suffer the sanctions, but having the concern turned to sustainable and, consequently, for supply chain management.

As suggestion for future work, it is proposed to involve all members of the selected company's sustainable supply chain, such as suppliers and customers. This may not be an easy task, but it can bring numerous real benefits to the process of recognizing the level of sustainable supply chain management, thereby providing greater environmental, social and economic gains.

References

1. Bai C, Sarkis J (2010) Green supplier development: analytical evaluation using rough set theory. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2010.01.016.
2. Azevedo SG, Carvalho H, Machado VC (2011) The influence of green practices on supply chain performance: a case study approach. Transportation Research Part E: Logistics and Transportation Review, https://doi.org/10.1016/j.tre.2011.05.017.
3. Bai C, Dhavale D, Sarkis J (2016) Complex investment decisions using rough set and fuzzy c-means: An example of investment in green supply chains. European Journal of Operational Research, https://doi.org/10.1016/j.ejor.2015.07.059.
4. Lozano R, Huisingh D (2011) Inter-linking issues and dimensions in sustainability reporting. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2010.01.004.
5. Chiou TZ, Chan HK, Lettice F, Chung SH (2011) The influence of greening the suppliers and green innovation on environmental performance and competitive advantage in Taiwan. Transportation Research Part E: Logistics and Transportation Review, https://doi.org/10.1016/j.tre.2011.05.016.
6. Green KW, Zelbst PJ, Meacham J, Bhadauria, VS (2012) Green supply chain management practices: impact on performance. Supply Chain Management, https://doi.org/10.1108/13598541211227126.
7. Govindan K, Khodaverdi R, Jafarian A (2013) A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2012.04.014
8. Lizot M, Andrade Júnior PP, Trojan F, Magacho CS, Thesari SS, Goffi AS (2020) Analysis of Evaluation Methods of Sustainable Supply Chain Management in Production Engineering Journals with High Impact. Sustainability, https://doi.org/10.3390/su12010270.

9. Chopra S, Meindl P (2010) Supply chain management: strategy, planning and operations. 4ª ed, Pearson Prentice Hall.
10. Ahi P, Searcy C (2013) A comparative literature analysis of definitions for green and sustainable supply chain management. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2013.02.018.
11. Tseng ML, Chiu AS (2013) Evaluating firm's green supply chain management in linguistic preferences. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2010.08.007.
12. Zaid AA, Jaaron AAM, Talib Bon A (2018) The impact of green human resource management and green supply chain management practices on sustainable performance: An empirical study. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2018.09.062.
13. Kuo RJ, Wang YC, Tien FC (2010) Integration of artificial neural network and MADA methods for green supplier selection. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2010.03.020
14. Mangla SK, Govindan K, Luthra S (2016) Critical success factors for reverse logistics in Indian industries: a structural model. Journal of Cleaner Production, https://doi.org/10.1016/j.jclepro.2016.03.124.
15. Miles MB, Huberman AM (1994) Qualitative Data Analysis. Sage Publications.
16. FATMA (2019) Normative instruction 04/2014. http://www.fatma.sc.gov.br/conteudo/instrucoes-normativas. Cited 30 dez 2019.
17. Micheli GJL, Cagno E, Mustillo G, Trianni A (2020) Green supply chain management drivers, practices and performance: A comprehensive study on the moderators. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2020.121024.
18. Wong JT (2020) Dynamic procurement risk management with supplier portfolio selection and order allocation under green market segmentation. Journal of Cleaner Production. https://doi.org/10.1016/j.jclepro.2019.119835.
19. Li S, Qiao J, Cui H, Wang S (2020) Realizing the environmental benefits of proactive environmental strategy: The roles of green supply chain integration and relational capability. Sustainability. https://doi.org/10.3390/su12072907.
20. Roy SA, Ali SM, Kabir G, Enayet R, Suhi SA, Haque T, Hasan, R, (2020) A framework for sustainable supplier selection with transportation criteria. International Journal of Sustainable Engineering. https://doi.org/10.1080/19397038.2019.1625983.
21. Melkonyan A, Gruchmann T, Lohmar F, Kamath V, Spinler S (2020) Sustainability assessment of last-mile logistics and distribution strategies: The case of local food networks. International Journal of Production Economics. https://doi.org/10.1016/j.ijpe.2020.107746.

Logistic Regression Model for Predicting Cost Performance According to Benefits Management Effort in New Product Development Projects

Gladston Luiz da Silva and Sanderson César Macêdo Barbalho

Abstract This study gathered data from a sample of 35 Brazilian companies that develop new products and have PMOs in their organizational structure. Previous analyses show that Benefits Management (BM) is the only PMO function that is related to project performance in triple constraint, specifically the cost performance. This paper focuses on BM function to an in-depth understanding of its potential for improvements in cost performance. Logistic regression shows how impacted cost performance can be for each increment of effort in BM. Results can be used as a hypothesis for BM improvement according to predicted results on cost performance.

Keywords Benefits management · New product development · Project performance · Project management offices · Logistic regression

1 Introduction

Project Management Institute [1] compiles success rate data from 2011 to 2018 showing a stable result of among 60–70% of projects meeting their original goals/business intents, 55–60% completed within the original budget, 50–55% completed on time.

The Project Management Office (PMO) is a structure that provides important support to project managers (PM), especially in the provision of management methodologies and multi-project administration. Some studies [2, 3] show that awareness of performance in cost, time and quality of projects managed in organizations that have PMOs is better than in organizations without those structures (also see [4–6]). Other research has shown that PMOs are not static structures, nor do they have a fixed set of functions independent of the organization where they work.

G. L. da Silva
Exact Sciences Institute, University of Brasília, Brasília, DF 70910-900, Brazil

S. C. M. Barbalho (✉)
Technology College, University of Brasília, Brasília, DF 70910-900, Brazil
e-mail: sandersoncesar@unb.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_19

Instead, PMOs are strongly determined by the company's business and by the project performance objectives [7–11].

Triple constraint is a traditional concept in project management, also called the iron triangle, outlined for instance in the PMBOK® Guide [1] which suggests the use of the Earned Value Analysis (EVA) method as a way to control project progress. The method was developed by NASA to monitor its contracts and incorporates indicators that encompass synergistic management of scope, time, and cost [12]. Using it, a project can succeed in delivering the contracted scope, on schedule, and at planned costs.

A general survey regarding the impact of PMO functions on triple restriction indicators showed that the only function with any significant correlation to any indicator was the Benefits Management (BM) function which is an activity embraced by the program management concept [13–16] and has been nowadays a research agenda in project management field [1, 17, 18]. The indicator in question was cost performance. That result is fully discussing in [19, 20]. This paper extends the previous analysis by proposing a logistic regression model for predicting cost improvements according to the BM efforts level for the sample of researched companies.

The next section describes the article's main theoretical framework and then follows a discussion of the research methods and a presentation of the gathered data and analysis. In section five there is a discussion and finally some theoretical and practical considerations regarding the research and the prospects for its further development.

2 Literature Review

2.1 Project Management Offices in New Product Development

Ulrich and Eppinger [21] argues that the product development process is operated throughout different projects. Clark et al. [22] works are the pioneering study in the analysis of new product development performance. Those authors analyzed the 1980s automotive industry treating the performance of NPD projects as a reflection of the long-term capabilities of the company. They establish the total quality of the product, the development of lead-time, and productivity as the key NPD performance criteria. They also state that PMOs function as a liaison organization among the different company areas. Barbalho and Rozenfeld [23] presents a reference model for developing complex products, according to literature best practices.

Success is a theme that should be addressed carefully as there is not only product success, defined by financial performance, customer value, company's sales percentage of products launched in recent years, time to investment return, market share and product quality [24–27]. Contemporary studies also value the project success, addressing the stakeholders' perception of success, impact to the customer and the team, and the company's preparation for the future [28, 29] in line to balanced-scorecard theory [30].

Project Management Office (PMO) is an organizational structure to facilitate the activities of project management and obtain improvements in the organization's strategic and tactical management [31]. It has been studied in different contexts relating its activities to project performance. Dai and Wells [2] identified more effective PM practices for registration of lessons learned and the application of PM methodologies and techniques in companies with PMO.

Hobbs and Aubry [32] analyzed the presence and degree of importance of 27 different PMO functions and roles. They grouped functions and roles in the following groups: (a) Monitoring and controlling activities of project performance; (b) Development of skills and project management methodologies; (c) Multi-project management; (d) Strategic management; and (e) Organizational learning. For [32], monitoring and controlling project performance are the most important activities within the PMO.

Liu and Yetton [33] considers PMO has a contingent effect on project performance. Spelta and Albertin [34] states indeed of previous research that arguing that the main PMO contributions are related to project time, cost, and quality, their research identifies portfolio control as the main driver of PMO adoption. Unger et al. [35] found PMOs' controlling functions were the explanation for the quality of project portfolio management. Spalek [36] states difficulty in demonstrating the benefit of PMOs, but argue that when companies successfully operate their PMO, they positively influence industrial engineering performance in long-term planning. Aubry [37] states PMO transformations have a direct impact on project and business performance. Barbalho et al. [20] demonstrates how PMOs support improvements in triple constraints, and [11] suggests a trade-off among project performance in time versus stakeholders' satisfaction in project-based organizations.

2.2 Project Success, Benefits Management, and PMOs

Benefits management (BM) literature has a foundation in a critical view of project success. According to [38], BM "… originally developed in the 1980s and 1990s because of a need to understand the return on investment from IT spend and overcome the limitations of traditional investment appraisal techniques" (p. 2). As projects were scrutinized under the iron triangle standpoint, the whole understanding was that stakeholders' satisfaction would like another framework for effective project evaluation.

Some effort lies in developing a complete and consensual BM process, since the beginning [39, 40]. Badewi [29] proposes a project benefits governance framework to integrate measures of project and benefits success. Laursen and Svejvig [41] links benefit to the concept of value: while "… the iron triangle is a classic and commonly applied standard for judging output success, the judgment of outcomes is more scattered, and it might suggest that research on value creation is still developing" (p. 5).

The work of [42] for example concludes that BM practices are positive predictors to Project success on the creation of strategic value for the business, a conclusion corroborated by [39]. Badewi [29] found that deliver on time and within budget has a strong correlation to comply with desired benefits. Musawir et al. [18] analyses project governance as a direct influencer of project success and indirect leverage for the benefits management process. Jørgensen [43] found that practices of benefits planning and benefits management during the project execution increase the success rate of software projects in terms of time, cost, quality, and productivity.

Breese et al. [15] brings benefits as a concept linked to projects and value. While a project "… deliver capabilities, it is the combination of all the necessary projects within a program which results in benefits being optimized to create value. Portfolio Management then maximizes value across the portfolio of programs" (p. 12). Consequently, handling the concept of benefits means to bring program and portfolio management to the theoretical framework for understanding the organizational phenomena of projects. A previous report of the study presented here shows BM as the PMO function most strongly related to project performance, and mainly to project cost compliance [19, 20]. The present paper explores that result according to an expanded theoretical standpoint relating project, programs, and portfolios, and specifically, the BM function and their relation to other PMO functions and variables identified in the survey.

Such discussions show that both PMO structuration and benefits management practices are connected to project success and can be well managed for improving the probability of good results, outcomes, and the last benefits the company wants from their projects. The next section presents our research methods.

3 Method

The research methodology adopted for this study was an exploratory and quantitative survey with a descriptive analysis to conclude the survey diagnosis concerning the main functions performed by PMOs and their impacts on companies that develop new products. In this study, the references of [44, 45] were considered to plan data gathering and analysis.

The survey initially focused on companies that develop new products in the state of São Paulo, in Brazil, but it has been extended to other states of the country through a snowball approach in networks of NPD experts and Brazilian chapters of Project Management Institute (PMI). A set of 38 responses were gathered from which 35 were validated.

According to the tasks performed by PMOs, respondents had to indicate a score on a Likert scale from one to five, for the degree of PMO effort in the company for each statement. The study analyzed 31 PMO functions, each of them had a label to facilitate analysis by respondents.

In the questionnaire, the respondents also made statements about their perception of the project performance considering the indicators for analyzing the triple constraint. The statements do not directly relate the PMO functions to performance, thus, it was possible to make a more assertive and isolated analysis of the problems of project performance in the respondents' companies. As over PMO function, the perception of project performance was also answered using the five levels, with five (answer "5") being related to a higher agreement as to better results on that metric and one (answer "1") related to lower agreement. These answers were correlated to conclude which PMO functions could help companies to improve their project success metrics.

The answers were the basis of statistical analysis and the calculation of the correlation between PMO functions and NPD's project performance in cost, time, and scope as well as analyzing their significance. Data were downloaded into an MS© Excel datasheet, duly treated, and then uploaded into SAS© software. A Spearman correlation and multiple tests were performed by applying the Holmmel, Hochberg, and FDR tests [46–48] as described on [20].

After the aforementioned analysis, the only function statistically related to one performance metric was "benefits management" correlated to "cost performance". As continuing to understand the data gathered from the non-probabilistic sample of 35 companies, the present study performs a protocol for identifying how sensitive was "cost performance" according to variations in "benefits management" effort, according to an Ordinal Logistic Regression procedure. This analysis can be applied in data analysis in which response is presented in categories with scores. In this context, the regression for categorical variables occurs to verify the relationship between a variable response Y with a set of covariates or explanatory variables X1, X2, …, XP, which can be continuous or discrete. Every 31 PMO functions were used as explanatory variables as a way to confirm previous analyses and for implementing logistic regression.

To study the relationship between the presence and absence of the response, it is used the relationship called Odds Ratio (OR), where a odds is represented by $\frac{\theta(\boldsymbol{x})}{1-\theta(\boldsymbol{x})}$, whose Napierian logarithm results in the connection function Logit

$$Logit = ln\left\{\frac{\theta(\boldsymbol{x})}{1-\theta(\boldsymbol{x})}\right\} \tag{1}$$

By the aforementioned linear equation, it is perceived that logit is the binding function that establishes the relationship between the mean and the linear predictor. For this model, the estimation of the parameters occurs through the likelihood function which, given a random sample (y_i, x_i), i = 1, 2, …, n, is defined by:

$$L(\beta) = \prod_{i=1}^{n}[\theta(x_i)]^{y_i}[1-\theta(x_i)]^{1-y_i}, \tag{2}$$

which solution to the equations is performed using numerical methods, such as Newton-Raphson.

McCullagh [49] proposed the Proportional Odds (PO) and Proportional Hazards models for ordinal nature data, in addition to present multivariate extensions for general linear models and extensions for nonlinear models. Peterson and Harrell [50] extended the PO models proposed by McCullagh to the Partial Proportional Odds (PPO) models, that allow non-proportional OR to a subset of exploratory variables. The PO model is used in this work to analyze ordinal variables, which proportionality assumption considers that the coefficients of the covariates are the same in all categories of the response, that is, the relationship between the vector of covariates x and the response variable y is response levels independent. In this situation, the interest is in calculating the accumulated probability until the *j*th level of the response variable, taking into account the following model:

$$P\left[Y_j \leq j|\boldsymbol{x}\right] = exp\left\{\frac{\alpha_i + \sum_{k=1}^{p}\beta_k X_k}{1 + exp\left(\alpha_i + \sum_{k=1}^{p}\beta_k X_k\right)}\right\} \tag{3}$$

This model is considered k − 1 cutoff points of the categories and the *j*th (j = 1, …, k − 1) cut-off point is based on the comparison of accumulated probabilities as shown below.

$$\begin{aligned}\pi_j\left(\boldsymbol{x}_j\right) &= ln\left\{\frac{Pr(Y=1|\boldsymbol{x}) + Pr(Y=2|\boldsymbol{x}) + \cdots + Pr(Y=j|\boldsymbol{x})}{Pr(Y=j+1|\boldsymbol{x}) + Pr(Y=2|\boldsymbol{x}) + \cdots + Pr(Y=k|\boldsymbol{x})}\right\} \\ &= ln\left\{\frac{\sum_{i=1}^{j} Pr(Y=i|\boldsymbol{x})}{\sum_{i=j+1}^{k} Pr(Y=i|\boldsymbol{x})}\right\}\end{aligned}, \tag{4}$$

where $\pi_j\left(\boldsymbol{x}_j\right) = \alpha_j + \left(\beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p\right)$, $j = 1, 2, \ldots, k-1$ and $\alpha_1 \leq \alpha_2 \leq \ldots \leq \alpha_k$.

For the cases of non-compliance with the proportionality assumption for the covariate coefficient of the response categories, were adjusted PPO models. In this case, the relationship between the covariate vector x and the response variable y dependent on response levels, and the coefficient γ is the effect associated with each *j*th cumulative Logit adjusted by the other covariates, where

$$\begin{aligned}\pi_j\left(\boldsymbol{x}_j\right) = \alpha_j + \left(\beta_1 + \gamma_{j1}\right)x_1 + \cdots + \left(\beta_q + \gamma_{jq}\right)x_q \\ + \cdots + \left(\beta_p + \gamma_{jp}\right)x_p, \quad j = 1, 2, \ldots, k-1\end{aligned}$$

and $\alpha_1 \leq \alpha_2 \leq \ldots \leq \alpha_k$.

The following section presents the descriptive analysis of higher and lower BM effort companies and PO and PPO model adjustments to explain the cost performance variation, considering independent variables as being the levels of effort to BM functions.

4 Results

Firstly, the PO model was adjusted to explain the indicator cost performance, considering all covariates related to the structure and functions of project offices, that is, X1 to X31 representing all PMO functions researched. For the selection of covariates of the model, the procedure stepwise was performed, and only the covariate Benefits Management (X4) was considered eligible ($\chi^2_{(1)} = 6.3735$, P-Value < 0.0116) confirming [20].

Besides, the assumption of the equality of the coefficients for the five levels of cost performance was rejected ($\chi^2_{(3)} = 8.559$, P-Value < 0.0299). The PPO model considered to explain the variation cost performance proved to be appropriate, as well as the Likelihood Ratio ($\chi^2_{(4)} = 12.3898$, P-Value = 0.0147). To the significance of the joint distribution of the covariate, Score ($\chi^2_{(4)} = 13.6904$, P-Value = 0.0084) and Wald ($\chi^2_{(4)} = 9.9664$, P-Value = 0.0410), indicates rejection of the hypothesis that the parameter vector is zero.

The results of the PPO adjusted model are shown in Table 1, which presents the estimates of the model parameters, the standard errors for the estimated parameters, and the results of the Wald test for the significance of the parameters.

Based on these results, the adjusted function-responses are given by the following expression

$$\hat{\pi}_1 = \frac{exp(-5.2332 + 1.5277 \cdot X_4)}{1 + exp(-5.2332 + 1.5277 \cdot X_4)} \tag{5}$$

$$\hat{\pi}_2 = \frac{exp(0.6932 - 1.1646 \cdot X_4)}{1 + exp(0.6932 - 1.1646 \cdot X_4)} \tag{6}$$

$$\hat{\pi}_3 = \frac{exp(1.6870 - 0.8478 \cdot X_4)}{1 + exp(1.6870 - 0.8478 \cdot X_4)} \tag{7}$$

Table 1 PPO adjusted model for cost performance (X_{67}) according to the variation of BM (X_4)

Variable	X_{67}	Gl	Estimate	Standard error	Wald χ^2
Intercepts	1	1	−5.2332	2.7486	3.6947
	2	1	0.6932	0.9798	0.5005
	3	1	1.6870	0.8363	4.0688*
	4	1	3.9699	1.3473	8.6828**
X_4	1	1	1.5277	1.3543	1.2725
	2	1	−1.1646	0.6123	3.6181
	3	1	−0.8478	0.4014	4.4610*
	4	1	−1.0510	0.4878	4.6416*

* P-Value < 0.05
** P-Value < 0.01

$$\hat{\pi}_4 = \frac{exp(3.9699 - 1.0510 \cdot X_4)}{1 + exp(3.9699 - 1.0510 \cdot X_4)} \tag{8}$$

According to the equations reached on the logistic model, if the initial cost performance is “5”, one can increase the effort to BM, but nothing probably will happen to cost performance, once it is already “5”. On the other side, if the initial “cost performance” is “1”, increments in BM effort can improve significantly the results in terms of cost performance. In general, these results confirm the odds ratios estimates, showing that on average:

- the chance of a company that has very low performance (“1”) on costs to move to low performance (“2”) increases 360.8% at each level of effort increment in Benefits Management. That is, in our sample, almost certainly, an incremental effort on BM will improve a very low performance on costs;
- the chance of a company that has a low performance on costs (“2”) move to a moderate performance (“3”) increases 31.2% at each level of effort increment in BM;
- the chance of a company that has a moderate performance on costs (“3”) move to high performance (“4”) increases 42.8% at each level of effort increment in BM function;
- the chance of a company that has a high performance on costs (“4”) move to very high performance (“5”) increases 35.0% at each level of effort increment in BM function.

Odds ratio curves reflect the traditional situation in which how much better a process is, how difficult is to improve it. Therefore, data suggest an impact of at least 31.2% of increment in cost performance only improving the PMO services on BM function. If the company has a very low-cost performance, invest in BM function can result in radical improvements of most than four times the initial condition. But, if the company has already good cost performance, investing in BM function into the PMO umbrella can increase costs without an immediate result.

5 Discussion

According [17] in the editorial of the special issue in BM of the Int J Proj Manag, a current challenge is “… suggesting a distinctive benefit management process…” (p. 2). For this purpose, it has two different approaches in the literature. The first is some kind of a specific process “… that needs to be led by a Project Owner in parallel and collaboration with the project management process” (p. 2). This distinctive process is in development with some contributions for defining its steps and main phases by a group of researchers mainly from England and Australia [15, 18, 42]. This proposal has 12 steps in their last versions and runs concurrently to the project management process.

Another approach more effectively integrated to project management standards are used by [29, 43, 51]. These authors indirectly [29, 43] or directly [51] suggest BM be another knowledge area for project management, according to, for example, the PMBOK Guide. One and the other approach has challenges in terms of bureaucracy and time-consuming procedures. What is best for this: increase the charge of current project managers or implement a parallel structure that needs to align its processes and results to the first one?

We consider that our research opens a new possibility to this endeavor that is allocate BM function as a practice for PMOs to run. It can improve the way PMO help companies to reach their strategic issues and support the project managers to maintain focus on project efficiency. Rather than a phased approach or tools and techniques-based implementation, we suggest that BM can be shown as an effort level dimension of PMO activities. Depending on the initial level of cost performance, as much effort, a PMO devotes to this function, as much cost performance the company can achieve.

6 Conclusions

The two main discussions about benefits management in the context of projects, programs, and portfolios are who must be in charge of BM in a company and what the best BM process for effective business realization is. Our data suggest that PMOs can be in charge of BM, and if so, it can improve cost performance. For the second issue, our data points for the potential of spending effort on BM procedures as a way to improve cost performance. Future research can delineate which kind of BM procedures are those, which can impact positively on costs.

Our data support the proposition of the BM process as a driver for cost performance. Every statistical analysis we did in our sample points to this relation. The logistic regression method allows confirming that despite having an impact on costs, benefits management as performed by project management offices, does not impact time or scope performance. Research of [29] detected that "… a strong significant correlation was found between delivering on time and within budget and delivering the desired benefits". Despite not being researched as a specific project output, maybe companies that have more effort in BM deliver better benefits. As data show that these companies have higher cost performance, one can tell a direct relation among benefit outputs and costs. A subject for future researches.

In general, the results outline a practical implication. Instead of allocating project resources to be used in monitoring and systematizing EVA indicators, these resources and functions could be allocated to the PMO for enabling it to orientate goals and control costs in a way that would have an impact on all the projects in a given business area. Functions needed by individual projects could be replaced by functions centrally performed by the PMO and that would have a direct positive impact by reducing cost overheads.

The fact that the sample in this research was non-probabilistic and the set of companies composing the sample was small constitute limitations for the study. Accordingly, the conclusions and reflections set out in the body of the text must be viewed with reservations and seen as being propositions for future work. Another limitation concerns the type of projects addressed by the study given that product development projects are very different from civil engineering or infrastructure projects in general and from projects for implanting information systems or making organizational changes. In these cases, the conclusions drawn in this paper should serve merely as suggestions of actions that need to be carefully monitored to avoid mistakes. Researches could be undertaken with PMOs in companies in the above-mentioned areas to verify whether, and in what conditions the results displayed here are repeated.

References

1. Project Management Institute (PMI), 2017. Project Management Body of Knowledge - PMBOK. 6th Edition. Pennsylvania. Project Management Institute.
2. Dai, C. X., and Wells, W. G., 2004. An exploration of project management office features and their relationship to project performance. Int J Proj Manag, 22(7), 523–532.
3. Julian, J., 2008. How project management office leaders facilitate cross-project learning and continuous improvement. Project Management Journal, 39(3), 43–58.
4. Taylor, H., Artman, E., and Woelfer, J. P., 2012. Information technology project risk management: bridging the gap between research and practice. Journal of Information Technology, 27(1), 17–34.
5. Martin, N. L., Pearson, J. M., and Furumo, K. A., 2007. Is Project Management: Size, Practices and the Project Management Office, Journal of Computer Information Systems, 47(4), 52–60.
6. Kutsch, E., Ward, J., Hall, M., and Algar, J., 2015. The contribution of the project management office: A balanced scorecard perspective. Information Systems Management, 32(2), 105–118.
7. Aubry, M., Hobbs, B., Müller, R., and Blomquist, T., 2010a. Identifying forces driving PMO changes. Project Management Journal, 41(4), 30–45.
8. Aubry, M., Müller, R., Hobbs, B., and Blomquist, T., 2010b. Project management offices in transition. Int J Proj Manag, 28(8), 766–778.
9. Bredillet, C., Tywoniak, S., and Tootoonchy, M., 2018. Why and how do project management offices change? A structural analysis approach. Int J Proj Manag, 36(5), 744–761.
10. Aubry, M., and Brunet, M., 2016. Organizational design in public administration: Categorization of project management offices. Project Management Journal, 47(5), 107–129.
11. Barbalho, S. C. M.; Toleldo, J. C.; Silva, I. A., 2019. The effect of stakeholders' satisfaction and project management performance on transitions in a project management office. IEEE ACESS, 7, pp. 169385–169398
12. Garel, G., 2013. A history of project management models: From pre-models to the standard models. Int J Proj Manag, 31(5), 663–669.
13. The Cabinet Office (TCO), 2011. Managing Successful Programmes. 4th Edition. The Stationery Office, London. 301 pp. ISBN: 9780113313280
14. Rijke, J., Herk, S., Zevenbergen, C., Ashley, R., Hertogh, M., and ten Heuvelhof, E., 2014. Adaptive programme management through a balanced performance/ strategy oriented focus. Int J Proj Manag, 32(7), 1197–1209.
15. Breese, R., Jenner, S., Serra, C. E. M., and Thorp, J., 2015. Benefits management: Lost or found in translation. Int J Proj Manag, 33(7), 1438–1451.

16. Sales, L. B., Barbalho, S. C. M., 2020. Identifying System Archetypes in Order to Comprehend and Improve the Program Management Practices in Organizations. IEEE Transaction on Engineering Management, 67(1), 163–173.
17. Zwikael, O., 2016. Int J Proj Manag special issue on "project benefit management". Int J Proj Manag. 34(4), 734–735.
18. Musawir, A., Serra, C. E. M., Zwikael, O., and Ali, I., 2017. Project governance, benefit management, and project success: Towards a framework for supporting organizational strategy implementation. Int J Proj Manag, 35(8), 1658–1672.
19. Barbalho, S. C. M., Carvalho, V. G., Silva, G. L., and Toledo, J. C., 2016. Analyzing the impact of the functions of Project Management Offices on triple constraints performance of new product projects. Product: Management & Development, 14(2), 85–94.
20. Barbalho, S. C. M., da Silva, G. L., and de Toledo, J. C., 2017. The impact analysis of functions of Project Management Office on performance of triple constraint of new-product development projects. Dirección y Organización, (61), 19–31.
21. Ulrich, K.T., Eppinger, S.D., 2008. Product design and development. McGraw-Hill Inc. New York, United States. 366 pp. ISBN: 9780072471465.
22. Clark, K. B., Fujimoto, T., and Cook, A., 1991. Product development performance: Strategy, organization, and management in the world auto industry (pp. 121–161). Boston, MA: Harvard Business School Press.
23. Barbalho, S. C. M.; Rozenfeld, H., 2013. Modelo de referência para o processo de desenvolvimento de produtos mecatrônicos (MRM): validação e resultados de uso. Gestão & Produção (UFSCAR. Impresso), v. 20, pp. 162–179.
24. Cooper, R. G., and Kleinschmidt, E. J., 1995. Benchmarking the firm's critical success factors in new product development. J Prod Innov Manag: An International Publication of the Product Development & Management Association, 12(5), 374–391.
25. Griffin, A., and Page, A. L., 1996. PDMA success measurement project: recommended measures for product development success and failure. J Prod Innov Manag, 13(6), 478–496.
26. Kahn, K. B., Barczak, G., and Moss, R., 2006. Perspective: establishing an NPD best practices framework. J Prod Innov Manag, 23(2), 106–116.
27. Chiesa, V., and Frattini, F., 2007. Exploring the differences in performance measurement between research and development: evidence from a multiple case study. R&D Management, 37(4), 283–301.
28. Carvalho, M. M., Patah, L. A., and de Souza Bido, D., 2015. Project management and its effects on project success: Cross-country and cross-industry comparisons. Int J Proj Manag, 33(7), 1509–1522.
29. Badewi, A., 2016. The impact of project management (PM) and benefits management (BM) practices on project success: Towards developing a project benefits governance framework. Int J Proj Manag, 34(4), 761–778.
30. Kaplan, R. S., and Norton, D. P., 1996. The Balanced Scorecard: Translating Strategy into Action. Boston: Harvard Business School Press. ISBN: 978-0875846514.
31. Müller, R., Drouin, N., Sankaran, S., 2019. Modeling Organizational Project Management. Project Management Journal. V. 50(4), pp. 499–513.
32. Hobbs, B., and Aubry, M., 2007. A multi-phase research program investigating project management offices (PMOs): the results of phase 1. Project management journal, 38(1), 74–86.
33. Liu, L., and Yetton, P., 2007. The contingent effects on project performance of conducting project reviews and deploying project management offices. IEEE Transactions on Engineering Management, 54(4), 789–799.
34. Spelta, A. G., and Albertin, A. L., 2012. Project management offices in the IT Area: A context–discriminant model for their establishment. Information Systems Management, 29(1), 40–54.
35. Unger, B. N., Gemünden, H. G., and Aubry, M., 2012. The three roles of a project portfolio management office: Their impact on portfolio management execution and success. Int J Proj Manag, 30(5), 608–620.
36. Spalek, S., 2013. Improving industrial engineering performance through a successful project management office. Inzinerine Ekonomika-Engineering Economics, 24(2), 88–98.

37. Aubry, M., 2015. Project management office transformations: Direct and moderating effects that enhance performance and maturity. Project Management Journal, 46(5), 19–45.
38. Breese, R., 2012. Benefits realization management: Panacea or false dawn?. Int J Proj Manag, 30(3), 341–351.
39. Chih, Y. Y., and Zwikael, O., 2015. Project benefit management: A conceptual framework of target benefit formulation. Int J Proj Manag, 33(2), 352–362.
40. Zwikael, O., Chih, Y. Y., and Meredith, J. R., 2018. Project benefit management: Setting effective target benefits. Int J Proj Manag, 36(4), 650–658.
41. Laursen, M., and Svejvig, P., 2016. Taking stock of project value creation: A structured literature review with future directions for research and practice. Int J Proj Manag, 34(4), 736–747.
42. Serra, C. E. M., and Kunc, M., 2015. Benefits realization management and its influence on project success and on the execution of business strategies. Int J Proj Manag, 33(1), 53–66.
43. Jørgensen, M., 2016. A survey on the characteristics of projects with success in delivering client benefits. Information and Software Technology, 78, 83–94.
44. Bussab, W.O., Morettin, P.A. (2014) Estatística básica. 6th edition. Saraiva. São Paulo. 540 pp. ISBN: 978-8502207998
45. Heiberger, R.M., Holland, B., 2004. Statistical Analysis and Data Display. Springer-Verlag, 1st. edition, New York. 730 pp. ISBN: 978-1-4757-4284-8.
46. Hommel, G., 1989. A comparison of two modified Bonferroni procedures. Biometrika, 76(3), 624–625.
47. Hochberg, Y., 1988. A sharper Bonferroni procedure for multiple tests of significance. Biometrika, 75(4), 800–802.
48. Benjamini, Y., and Hochberg, Y., 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. Journal of the Royal statistical society: series B (Methodological), 57(1), 289–300.
49. McCullagh, P., 1980. Regression models for ordinal data. Journal of the Royal Statistical Society: Series B (Methodological), 42(2), 109–127.
50. Peterson, B., and Harrell Jr, F. E.,1990. Partial proportional odds models for ordinal response variables. Journal of the Royal Statistical Society: Series C (Applied Statistics), 39(2), 205–217.
51. Mossalam, A., and Arafa, M., 2016. The role of project manager in benefits realization management as a project constraint/driver. HBRC Journal, 12(3), 305–315.

Extraction of Soluble Solids of Soursop (*Annona muricata*) and Marolo (*Annona crassiflora* Mart.) Seeds Using Different Solvents and Processes

Evandro Galvão Tavares Menezes, Fabiana Queiroz, and Ana Cristina Moreira Andrade Araújo

Abstract The Brazilian Cerrado has native species with great potential for oil extraction, which can be applied in the food and pharmaceutical industries. Several studies have shown the feasibility of replacing the solvent hexane industrially used in vegetable oil extraction. The hexane as solvent shows high yield and selectivity of oil extraction, however, this can be harmful to human health and the environment, it is necessary to develop cleaner and economically viable technologies. In this paper, the oil extraction of marolo and soursop seeds was evaluated using different solvents (acetone, ethanol, isopropanol, and hexane), and three different techniques (ultrasound, shaker, and Soxhlet) and enzymatic aqueous extraction. The highest extraction yields for all solvents were obtained through Soxhlet extraction. In the Soxhlet extraction, the highest extraction yield was obtained with hexane. When compared to shaker extraction, ultrasonic-assisted extraction favored the oil extraction from marolo and soursop seeds using hexane, and favored the extraction of soursop oil using acetone. Enzymatic extractions showed low extraction yields (8.82 g/100 g of marolo seeds and 11.15 g/100 g of soursop seeds). The results indicate the potential of solvents and alternative processes in the extraction of oil from Cerrado seeds.

Keywords Shaker · Ultrasound · Soxhlet · Enzymes

1 Introduction

Brazil presents a vast amount of regional and seasonal native fruits. The Cerrado is a region with a great diversity of vegetal species, being rich in fruit species. Many of the Cerrado fruits are characterized by exotic sensorial characteristics, very appreciated, besides showing nutritional and functional properties. The processing of these fruits

E. G. T. Menezes (✉)
Federal University of Viçosa, Rio Paranaíba 38810000, Brazil
e-mail: evandrogtmenezes@gmail.com

F. Queiroz · A. C. M. A. Araújo
Federal University of Lavras, Lavras 3720000, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_20

in the form of juices, frozen pulps, jams, jellies and others is an important source of income for the region. During its manufacture, large amounts of waste are generated. One of the residues generated is the seed, and many fruits from Cerrado have seeds rich in oil and bioactive such as phenolics, carotenoids, vitamins, among others, compounds that can be economically exploited [1–5].

The main solvent used industrially in the oil extraction is hexane, which has a nonpolar aliphatic chain, showing several advantages, such as low latent heat of vaporization, high oil solubility and selectivity, and low corrosiveness. However, there are also disadvantages associated mainly with environmental, safety and health issues [6, 7], besides the low selectivity in the extraction of some bioactive compounds of interest.

Over the years, several solvents or extraction processes have been studied as alternatives to hexane replacement, such as ultrasonic-assisted extraction [8, 9], extraction using supercritical fluid [10, 11], pretreatment by microwave [12], enzymatic aqueous extraction [13], extraction with hot water [14], extraction using other solvents, such as acetone, isopropanol, ethanol [1, 15, 16], among others.

Substitution of hexane by alternative solvents may be interesting, especially if the substitute is available on a large scale, at a low cost and with adequate extraction efficiency in order to become the process economically viable. Among substitutes, short-chain alcohols, especially ethanol and isopropanol, have been proposed as alternative extraction solvents because of their increased safety and the extraction of bioactive compounds together with the oil, so that the obtained extracts have larger amounts of antioxidant compounds and stability, relevant in several applications in the food and cosmetics area. These two solvents have the disadvantage of lower oil solubility and higher values of heats of vaporization when compared to the hexane. The solubility characteristics of ketones are similar to short-chain alcohols and show lower heats of vaporization than isopropanol and ethanol, and slightly higher than the hexane value, being one of the disadvantages the greater danger of causing fires than alcohols [7, 15, 17].

Aqueous extraction of seed oil has attracted increasing interest in recent years [18], since it is a less environmentally harmful, safer, cheaper process and can be used for the simultaneous extraction of oil and protein. However, the main disadvantage is the low oil recovery, besides the process can be improved by employing enzymes. The enzymatic aqueous extraction is an emerging and attractive technology for the oil industry compared to the conventional hexane extraction process [13]. During enzymatic aqueous extraction, an oil-rich emulsion is formed. In order to obtain a high extraction yield, the emulsion forming components should be separated. The emulsion is stabilized by proteins, phospholipids and carbohydrates that hinder the separation process [19, 20], but may be useful when it is desired to obtain an emulsion, e.g., in microencapsulation processes by spray drying.

Ultrasonic-assisted extraction is an efficient method for extraction and is an alternative to the conventional extraction technique, generally using lower temperatures and times, with potential application in the extraction of oils, essential oils, bioactive compounds, and other compounds [21].

The efficiency of this method has been attributed to the propagation of high-pressure waves and the cavitation effects [22]. According to Mulet et al. [23], when high-power ultrasonic waves are applied to a solid-liquid system, they cause compression and continuous expansion of the matrix molecules, which create a "sponge effect" that moves the liquid solvent through microchannels in the solid particles. The effect of cavitation is caused by the propagation of ultrasonic waves that result in the formation of bubbles within the medium, where the bubbles generated by cavitation inside the cell or near the cell surface can implode and generate a localized pressure, breaking the cellular structure and increasing the release of intracellular substances in the solvent [21]. This technique uses lower temperatures and extraction times and may favor the quality improvement of the obtained oils/extracts [24, 25].

The aim of this study was to compare the oil/soluble solid yields of marolo and soursop seeds using hexane, acetone, ethanol and isopropanol as solvents in Soxhlet, shaker and ultrasonic extraction processes and through enzymatic aqueous extraction.

2 Materials and Methods

Soursop (Annonamuricata) and marolo (Annonacrassiflora Mart.) fruits were purchased in Lavras, MG, Brazil, then washed, sanitized using hypochlorite solution (200 mg/kg) and manually pulped. The seeds were stored in polyethylene bags and frozen at −20.0 °C. For extraction, the seeds were dried in a vacuum oven for 48 h at 45 °C (absolute pressure = 16.8 kPa, Tecnal, TE-395 model, Piracicaba, SP, Brazil). The dried seeds were ground in order to obtain particle sizes ranging from 10 to 100 mesh (2 and 0.149 mm). The soursop and marolo seeds showed 29.5 ± 1.28% oil (dry basis) and the 31.13 ± 1.21% oil (dry basis), respectively. The solvents used in the extraction were: ethanol, isopropanol, acetone, and hexane, all manufactured by Dinâmica LTDA (Diadema, Brazil).

2.1 Soxhlet Extraction

For extraction in Soxhlet (Tecnal, São Paulo, Brazil), 10 g of dried and ground seeds were used for each 50 g of solvent (hexane, acetone, ethanol, and isopropanol) using an extraction time of 8 h. The extraction temperature of Soxhlet was kept constant in all the tests, being 5 °C above the solvent's boiling point [1]. The extraction flask was coupled to a column, which was operated at lower temperatures (through water circulation) in order to ensure complete condensation of the solvent. Three extractions were performed for each solvent.

2.2 Ultrasound Extraction

Three grams of dried and ground seeds were placed in falcon tubes and added with 15 g of solvent (hexane, acetone, ethanol, and isopropanol). Ultrasonic-assisted extraction in Ultracleaner (São Paulo, Brazil) bath was performed at the frequency of 44 kHz at room temperature (30 °C) for 60 min. The tests were performed in triplicate.

2.3 Shaker Extraction

The solid-liquid extraction with shaker was performed in 125 ml glass Erlenmeyer and the vials were capped with stoppers to prevent solvent loss. After the mixture of 6 g of seeds with 30 g of solvent (1:5 seed/solvent mass ratio; solvents: hexane, acetone, ethanol, and isopropanol), the assembly was incubated (Tecnal incubator, São Paulo, Brazil) at the constant temperature (35, 45, and 55 °C) under stirring of 120 rpm for 16 h, sufficient time to establish equilibrium. The tests were performed with three replicates.

2.4 Enzymatic Extraction

In the enzymatic extraction of the seed oil, 5 g of dried and ground seeds were used for 23 g of water and 2 g of enzyme preparation containing a mixture of enzymes. The pH of the medium was adjusted to 4.5 using 0.5 N NaOH solution and 0.5 N HCl, and the extraction was conducted in Erlenmeyer, incubated in an oven at 45 °C and stirring at 120 rpm for 24 h.

In the enzymatic preparation were used equal masses of the enzymes:

- Alcalase 2.4 FG (Novozymes, Bagsvaerd, Denmark). This enzyme is an alkaline endopeptidase with a reported activity of 2.4 AU/g, showing optimum activity at temperatures from 50 to 55 °C and pH from 7.5 to 8.5.
- Viscozyme L (Novozymes, Bagsvaerd, Denmark). This commercial product contains arabinase, cellulase, betaglucanase, hemicellulase, and xylanase, showing reported activity equal to 100 FBG/g. The optimum pH of the enzyme is 3.3–5.5 and temperature is equal to 40–50 °C.
- Novozym 33095 (Novozymes, Bagsvaerd, Denmark). This enzyme is a pectin lyase with pH and optimum temperatures equal to 3.2–4.5 and 35–45 °C. It has declared activity equal to 8620 PECTU/g.

After the incubation period, the extract was separated from the by centrifugation at 3500 rpm for 10 min. The lipid fractions of the residue of the slurry were determined in Soxhlet extractor by AOAC methodology after drying [26]. The lipid fractions in the extract were obtained by the difference between the initial concentration of oil in the seed and the concentration of oil in the residue. All extractions were performed in triplicate.

2.5 Extraction Yield

The oil extraction yield expressed in grams of oil extracted per 100 g of dried seeds was calculated according to the equation:

$$\text{yield} = 100\frac{m_o}{m_s} \tag{1}$$

where m_o is the extracted oil/soluble solids mass and m_s is the used seed dry mass.

2.6 Statistical Analysis

The experimental design for a different treatments was the completely randomized design (CRD). The results were analyzed by analysis of variance by the software SISVAR 5.1® [27]. For the effects of average comparison, the Tukey test was used at 5% probability.

3 Results and Discussion

3.1 Oil Extraction by Soxhlet

The yield of oil extracted from the seeds, expressed in g of oil/100 g of dried seeds, using different solvents in Soxhlet type extractor for marolo and soursop seeds are shown in Fig. 1. Seed grinding breaks the cell walls partially and extractions of the compounds present within the cells depend on the affinity for the solvents. From the tested solvents, hexane extracted the highest amount of oil from the marolo seed (32.36 g/100 g dry seeds) and the soursop seed (31.03 g/100 g dry seeds), being these values higher than the extraction by Soxhlet using petroleum ether, 31.1 g/100 g for marolo dried seeds and 29.5 g/100 g for soursop dried seeds (composition, % ether extract).

The isopropanol, acetone and ethanol solvents showed similar extraction yields for both seeds (5% significance). When comparing the extraction using hexane with ethanol extraction, the first extracted a larger oil amount, showing that the compounds to be extracted have higher affinities for hexane. The dipole moment resulting from

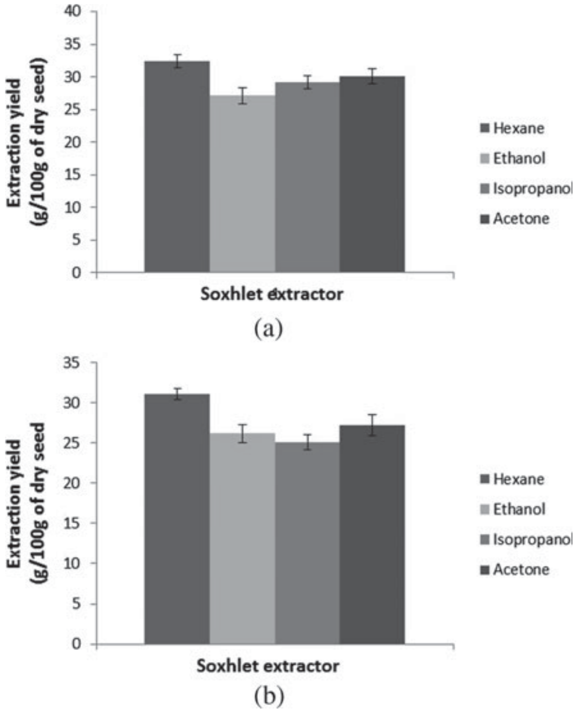


Fig. 1 Yield of the oil seed extraction by Soxhlet extractor: **a** marolo; **b** soursop

hexane is equal to zero, which favors the extraction of nonpolar compounds, such as the oils [1] present in marolo and soursop seeds. Oilseeds, in general, the extraction efficiency with hexane is higher than the other solvents, and the efficiency of other solvents, especially ethanol, isopropanol and acetone were influenced by raw material, besides the operating conditions.

Oliveira et al. [1], in the extraction of passion fruit seed oil by Soxhlet, using time equal to 16 h, obtained a higher extraction yield using solvent hexane (25.4 g of oil/100 g of solvent) compared to that obtained with isopropanol (15.5 g oil/100 g solvent), acetone (14.5 g oil/100 g solvent) and ethanol (14 g of oil/100 g of solvent. Yang et al. [28] extracted oils from *Sapium sebiferum* seeds by Soxhlet and showed that there were no significant differences when using ethanol, petroleum ether and hexane as solvents.

3.2 Oil Extraction Using Ultrasound

The yields of the ultrasound-assisted oil extraction (Fig. 2) for marolo and soursop seeds with hexane were 29.82 and 27.32 g of oil/100 g of dried seed, respectively, which are values higher than the other solvents with low extraction yields, a fact that may have occurred due to the lower oil solubility in these solvents at room

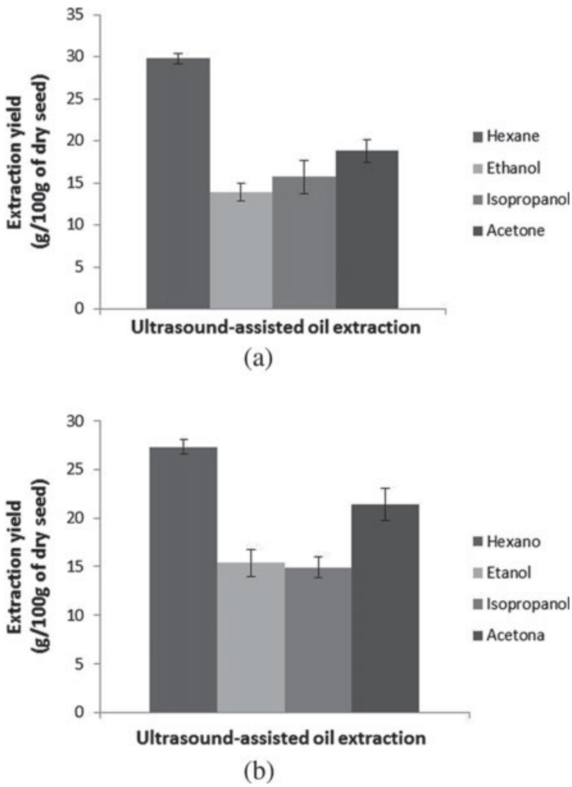


Fig. 2 Extraction yield of the seed oil assisted by ultrasound: **a** marolo; **b** soursop

temperature (30 ºC). Regarding the alternative solvents, acetone (18.81 g/100 g of marolo seeds, 21.36 g/100 g of soursop seeds) obtained higher extraction yields than ethanol (13.92 g/100 g of marolo seeds, 14.82 g/100 g of soursop seeds). In the marolo seed extraction, there was no significant difference between the use of acetone and isopropanol and between isopropanol and ethanol at 5% significance level. For soursop seed, there was no significant difference at 5% level between the ethanol and isopropanol yields, which were lower than the values obtained with acetone.

Ultrasound (UAE) utilization is an attractive option for oil extraction since yields can be increased using short extraction times and a low solvent volume. One of the benefits are due to cavitation (the formation, increase and implosion of bubbles during extraction) generated by ultrasound, which breaks the surface of the solid matrix, increasing the mass transfer rate and diffusive coefficient [21, 29].

The viscosity, surface tension and vapor pressure of solvents can affect cavitation and hence the extraction yield. The cavitation intensity decreases with increasing surface tension and viscosity [30]. Ethanol and isopropanol have higher viscosities (1.1 cP for ethanol and 2.05 cP for isopropanol) when compared to hexane and acetone (0.36 cP for acetone and 0.31 cP for hexane). The higher viscosity value harms cavitation. Regarding the surface tension, ethanol (2.23×10^{-2} N/m), acetone (2.37×10^{-2} N/m) and isopropanol (2.17×10^{-2} N/m) showed values higher than hexane (1.79×10^{-2} N/m), the increased surface tension increases the cohesive strength among solvent molecules, hindering the cavitation process [30]. The lower viscosity of acetone compared to ethanol may have favored the oil/soluble solid extraction of marolo and soursop seeds. The higher vapor pressure of the solvent may favor the creation of more bubbles, however, it may collapse with lesser intensity due to less pressure difference inside and outside the bubbles [5, 31]. From the tested solvents, the acetone has the highest vapor pressure followed by hexane, ethanol, and isopropanol, and this parameter under the experimental conditions may have influenced differently depending on the used solvent. Goula [21] in the study of ultrasound-assisted extraction of pomegranate seed oil and hexane as solvent, observed that the increase of the extraction temperature (range from 20 to 80 °C) and its vapor pressure significantly reduced the extraction yield.

Li et al. [32], extracting seed oil of Perilla using hexane assisted by ultrasound (frequency 50 kHz), studied the effect of time (10–20 min), temperature (30–50 °C), and seed/solvent ratio (1/5–1/9) in the extraction efficiency. After optimization of the operating conditions, the maximum extraction yield was 36.27 g/100 g of seed, under temperature of 41.26 °C, seed/solvent mass ratio of 1:7.02 and extraction time equal to 17.11 min. According to the authors, the perilla seeds showed initial oil content of 37.8%, representing 96% of extraction efficiency. Similar extraction efficiency was found in this study for the extraction with hexane assisted by ultrasound of marolo (95.9%) and soursop (92.6%) oil seeds.

Oliveira et al. [1], when extracted oil from passion fruit seeds (44 kHz, seed:solvent ratio (m/V) of 1:4, temperature 40 ºC and time of 60 min), found extractions equal to 23.8 g/100 g of seed for acetone, 16.6 g/100 g of seeds for ethanol, 15.1 g/100 g of seeds for isopropanol, and 16.9 g/100 g of seeds for hexane. Results from solvent efficiency were different from those found in the present study.

Hu et al. [33], verifying the solvent influence on the ultrasound-assisted extraction of safflower oil (35 °C, seed:solvent mass ratio of 1:7 and time of 40 min), obtained higher yield for hexane solvent (27 g/100 g of seeds), which showed a much higher extraction yield than ethanol (12 g/100 g seeds).

Extraction experiments with ultrasound use two different systems; the ultrasonic cleaner, where the containers used for the extraction are placed, and the ultrasound probe, which is immersed in the extraction container [34]. The use of the ultrasonic cleaner (used in this study) has the ultrasound intensity diminished because it is attenuated by the water contained in the bath and the walls of the glass utensils used as containers for the extractions.

However, the use of ultrasound and hexane as solvent allowed achieving yields similar to those obtained by Soxhlet extraction in a short period, however, using ethanol, isopropanol and acetone, the yields were lower than the Soxhlet extraction values (item 3.1) and generally in shaker extraction (item 3.3). In the soursop seed extractions with acetone, the values of the shaker yields were lower, even when performed at higher temperatures.

3.3 Shaker Extraction

Table 1 shows the results obtained from the extraction of oils/soluble solids from marolo and soursop seeds in batch using the shaker. The highest extraction yields of marolo and soursop seeds were obtained with hexane as solvent at all evaluated temperatures. The lowest extraction yields for marolo and soursop seeds were obtained with ethanol at 35 °C.

The soluble solids extraction yield of marolo seed using ethanol increased by 4.67 g of soluble solids/100 g of seeds by increasing the temperature from 35 to 45 °C, and an increase of 1.4 g/100 g of seeds by increasing from 45 to 55 °C. In the soursop seed extraction, a lower of temperature effect was observed, with a yield increase of 2.15 g of soluble solids/100 g of seed by increasing the ethanol temperature from 35 to 45 °C, without a significant effect on the temperature increase from 45 to 55 °C. The soluble solids yields of marolo using isopropanol and acetone did not show significant differences, being higher than the values obtained with the ethanol in all studied temperatures.

In the soursop seed extraction using isopropanol as solvent, the temperature did not influence the extraction yields, and represented the lowest yields among the tested solvents, being that there was no significant difference in the values obtained using ethanol and acetone at 35 ºC. When analyzing each solvent in the three studied different temperatures, it can be observed that the extraction using ethanol, hexane and acetone showed the same behavior in relation to the temperature increase, and there was no significant difference in the yield between the extractions performed at 45 and 55 °C, since they were higher than the extractions conducted at 35 °C.

Table 1 Extraction yields using shaker for marolo and soursop seeds (g of soluble solids/100 g of seeds)

T (°C)	Ethanol	Hexane	Isopropanol	Acetone
Marolo seed				
35	$17.51 \pm 1.09^{c,3}$	$29.47 \pm 0.62^{b,1}$	$22.57 \pm 0.75^{c,2}$	$21.96 \pm 0.63^{a,2}$
45	$22.18 \pm 0.37^{b,3}$	$30.82 \pm 0.42^{a,1}$	$26.22 \pm 0.95^{b,2}$	$26.19 \pm 0.70^{b,2}$
55	$23.58 \pm 0.52^{a,3}$	$30.99 \pm 0.29^{a,1}$	$28.29 \pm 0.69^{a,2}$	$27.78 \pm 1.51^{b,2}$
Soursop seed				
35	16.13 ± 0.25^{b2}	25.08 ± 0.71^{b1}	16.36 ± 0.46^{a2}	16.99 ± 0.93^{b2}
45	18.28 ± 0.76^{a23}	26.47 ± 0.37^{a1}	16.97 ± 0.65^{a3}	19.35 ± 0.38^{a2}
55	18.93 ± 0.82^{a2}	26.85 ± 0.85^{a1}	16.74 ± 0.72^{a3}	20.01 ± 0.70^{a2}

Averages followed by the same letters in the same column did not show statistical differences by Tukey test at 5% probability
Averages followed by the same numbers in the same row did not show statistical differences by Tukey test at 5% probability

Franco et al. [35] observed an increase in solubility of rubiginous oil in ethanol with increasing temperature. According to the authors, although solubility increases with increasing temperature for ethanol, it will be higher in hexane, which has higher capacity to extract nonpolar compounds, allowing the use of lower solid-solvent ratios in the extraction.

Oliveira et al. [1], when studied the extraction of passion fruit seeds in processes using Shaker (40 °C, seed:solvent ratio of 1:4 and time of 16 h), resulted in extraction yields of 17.4 g/100 g of seeds for acetone, 13.7 g/100 g of seeds for ethanol, 17 g/100 g of seeds for isopropanol, and 23.6 g/100 g of seeds for hexane.

The joint analysis of the average values of the extraction yields for the different solvents and processes showed that, for the marolo seed extraction, the hexane solvent obtained the best yield and similar values regardless of the extraction method used. In relation to the oil extractions of soursop seeds with hexane, it was observed that Soxhlet extraction yielded the highest yield (30.35 g/100 g seeds). Extraction with hexane solvent and using ultrasound showed extraction yield similar to extractions in Shaker at any temperature (35, 45, and 55 °C), ranging from 27.32 to 25.08 32 g of oil/100 g of seeds.

When a solute has low solubility in a solvent, the extraction yield is limited to the solubility value, being necessary to employ large amounts of solvent to solubilize the solute altogether. The values of the extraction yields obtained by Soxhlet using ethanol, isopropanol and acetone were higher than other methods due to the higher temperatures used and successive solvent washes.

3.4 Enzymatic Extraction

The enzymatic extractions (Table 2) showed extraction yields equal to 8.82 g of oil/100 g of seeds for marolo (28.36% of oil extracted) and 11.15 g of oil/100 g of seeds for soursop (37.79% extracted oil). In the enzymatic extraction, it can be considered that different experimental conditions (particle size of the material, solid/liquid ratio, enzyme concentration, extraction time, oil matrix composition, temperature, pH, among other factors) affect the obtained yield.

Different results for the extraction processes, using enzyme, are found in the literature. Latif et al. [13] extracted oil from moringa seeds and obtained extraction yields equal to 22.5 g/100 g of seeds (69.44% extraction yield) for protease Protex 7L and 20.9 g/100 g of seeds (64.5%) for Viscozyme L.

Table 2 Efficiency of the enzymatic extraction of the oil from the Cerrado fruit

Seeds	Ether extract in the cake g oil/100 g seeds	Yield g oil/100 g seeds
Marolo	22.28 ± 1.36	8.82
Soursop	18.35 ± 1.95	11.15

According to Li et al. [36] times higher than 30 min do not increase the enzymatic aqueous extraction by solubility of soluble solids present in perilla seeds, being 81.74% the highest yield of obtained oil. In the same study, the authors showed that increasing the temperature to values higher than 30 ºC, the extraction yield also increased.

Compared with other extraction processes used in this study, the enzymatic extraction was the one that obtained the lowest oil extraction yield. With regard to these extractions, it is necessary to carry out new studies with the objective of optimizing the enzymatic extraction process and obtaining higher extraction yields.

4 Conclusion

When investigating the extraction of oil/soluble solids of marolo and soursop seeds using alternative solvents (acetone, isopropanol, and ethanol) and hexane, we verified the technical viability of alternatives for the conventional extraction of the soluble solids of seeds, being that the type of seed can influence the choice of solvent and process. The highest extraction yield was obtained using hexane through Soxhlet extraction for both seeds. The Soxhlet extraction yields of soursop and marolo seeds with acetone, isopropanol and ethanol were similar. For the oil extraction present in marolo and soursop seeds by stirring in Shaker, the increase in temperature from 45 to 55 °C did not favor the extraction. When compared to the solvents under the temperature of 45 °C for marolo seeds, hexane obtained the highest yield, where the alternative solvents that obtained the highest yields were acetone and isopropanol. For the soursop seeds under the same conditions, the alternative solvents that extracted the most were acetone and ethanol. When using the ultrasound technique, it can be observed the highest extraction yield for the hexane for both seeds. Ultrasound-assisted extraction, using the hexane solvent, becomes an alternative to the conventional process due to the use of low temperatures and smaller times. The ultrasound-assisted extraction process was not as efficient for the other solvents (ethanol, isopropanol, and acetone) under the employed conditions, obtaining yields lower than the extraction in the shaker, except for extraction of marolo seed with acetone. The extractions by the enzymatic method showed the lowest extraction yields, and there is a need to optimize these processes.

References

1. Oliveira, R. C., Barros, S. T. D., Gimenes, M. L.: The extraction of passion fruit oil with green solvents. Journal of Food Engineering 117 (4), 458–463 (2013).
2. Oliveira, R.A., Neves, S. C., Ribeiro, L. M., Lopes, P. S. N., Silverio, F. O.: Storage, oil quality and cryopreservation of babassu palm seeds. Industrial Crops and Products 91, 332–339 (2016).
3. Luzia, D. M. M., Jorge, N.: Bioactive substance contents and antioxidant capacity of the lipid fraction of *Annona crassiflora* Mart. seeds. Industrial Crops and Products 42, 231–235 (2013).

4. Santana, F.C., Shinagawa, F. B., Araujo, E. S.: Chemical Composition and Antioxidant Capacity of Brazilian *Passiflora* Seed Oils. Journal of Food Science 80 (12), 2647–2651 (2015).
5. Zhang, Y. S., Zhao, Y. W.: Study on ultrasonic wave extraction of kiwifruit seed oil. Journal Chinese Cereals Oils 21(1), 116–118 (2006).
6. Dagostin, J. L. A., Carpine, D., Corazza, M. L.: Extraction of soybean oil using ethanol and mixtures with alkyl esters (biodiesel) as co-solvent: kinetics and thermodynamics. Industrial Crops and Products 74, 69–75 (2015).
7. Tir, R., Dutta, P. C., Badjah-Hadj-Ahmed, A. Y.: Effect of the extraction solvent polarity on the sesame seeds oil composition. European Journal of Lipid Science and Technology 114 (12), 1427–1438 (2012).
8. Khoei, M., CHEKIN, F.: The ultrasound-assisted aqueous extraction of rice bran oil. Food Chemistry 194 (1), 503–5072016.
9. Pereira, M.G., Hamerski, F., Andrade, E. F., Scheer, A. P., Carazza, M. L.: Assessment of subcritical propane, ultrasound-assisted and Soxhlet extraction of oil from sweet passion fruit (*Passiflora alata* Curtis) seeds. The Journal of Supercritical Fluids 128, 338–348 (2017).
10. Porto, C. da, Decorti, D., Natolino, A.: Microwave pretreatment of *Moringa oleifera* seed: Effect on oil obtained by pilot-scale supercritical carbon dioxide extraction and Soxhlet apparatus. The Journal of Supercritical Fluids 107, 38–43 (2016).
11. Prado, J.M., Dalmolin, I., Carareto, N.D.D., Basso, R.C., Meirelles, A.J.A., Oliveira, J.V., Batista, E.A.C., Meireles, M.A.A.: Supercritical fluid extraction of grape seed: Process scale-up, extract chemical composition and economic evaluation. Journal of Food Engineering 109(2), 249–257 (2012).
12. Ren, G., Zhang, W., Sun, S.D., Dun, X., Zhang, Z.S.: Enhanced extraction of oil from flaxseed (*Linum usitatissimum* L.) using microwave pre-treatment. Journal of Oleo Science 64(10), 1043–1047 (2015).
13. Latif, S., Anwar, F., Hussain, A.I., Shahid, M.: Aqueous enzymatic process for oil and protein extraction from *Moringa oleifera* seed. European Journal of Lipid Science and Technology 113 (8), 1012–1018 (2011).
14. Ribeiro, M.C., Vilas Boas, E.V. de B., Riul, T.R., Pantoja, L., Marinho, H.A., Santos, A.S.: Influence of the extraction method and storage time on the physicochemical properties and carotenoid levels of pequi (*Caryocar brasiliense* Camb.) oil. Ciência e Tecnologia de Alimentos 32 (2), 386–392 (2012).
15. Rodrigues, C.E.C., Aracava, K.K., Abreu, F.N.: Thermodynamic and statistical analysis of soybean oil extraction process using renewable solvent. International Journal of Food Science & Technology 45 (11), 2407–2414 (2010).
16. Zhang, F., Rhee, K.C., Koseoglu, S.S.: Isopropyl alcohol extraction of cottonseed collets: Efficiency and performance. Journal Food Lipids 9 (2), 147–160 (2002).
17. Russin, T.A., Boye, J.I., Arcand, Y., Rajamohamed, S.H.: Alternative Techniques for Defatting Soy: A Practical Review. Food and Bioprocess Technology 4(2), 200–223 (2011).
18. Campbell, K.A., Glatz, C.E., Johnson, L.A., Jung, S., De Moura, J.M.N., Kapchie, V., Murphy, P.: Advances in aqueous extraction processing of soybeans. Journal of the American Oil Chemists' Society 88, 449–465 (2011).
19. Chabrand, R.M., Glatz, C.E.: Destabilization of the emulsion formed during the enzyme-assisted aqueous extraction of oil from soybean flour. Enzyme and Microbial Technology 45(1), 28–35 (2009).
20. Li, Y., Sui, X., Qi, B., Zhang, Y., Feng, H., Zhang, Y., Jiang, L., Wang, T.: Optimization of ethanol-ultrasound-assisted destabilization of a cream recovered from enzymatic extraction of soybean oil. Journal of the American Oil Chemists' Society 91, 159–168 (2014).
21. Goula, A. M.: Ultrasound-assisted extraction of pomegranate seed oil – Kinetic modeling. Journal of Food Engineering 117(4), 492–498 (2013).
22. Vilkhu, K., Mawson, R., Simons, L., Bates, D.: Applications and opportunities for ultrasound assisted extraction in the food industry - A review. Innovative Food Science & Emerging Technologies 9 (2), 161–169 (2008).

23. Mulet, A., Carcel, J.A., Sanjuan, N., Bon, J.: New Food Drying Technologies – Use of Ultrasound. Food Science and Technology International 9(3), 215–221 (2003).
24. Li, H., Pordesimo, L., Weiss, J.: High intensity ultrasound-assisted extraction of oil from soybeans. Food Research International 37(7), 731–738 (2004).
25. Lou, Z., Wang, H., Zhang, M., Wang, Z.: Improved extraction of oil from chickpea under ultrasound in a dynamic system. Journal of Food Engineering 98 (1), 13–18 (2010).
26. Association of Official Analytical Chemistral. Official methods of analysis of the association of official analytical chemistry.17. ed. Washington: AOAC (2005).
27. Ferreira, D. F. SISVAR.: um programa para análise e ensino de estatística. Revista Symposium 6, 36–41 (2008).
28. Yang, X.Q., Pan, H., Zeng, T., Shupe, T.F., Hse, C.Y.: Extraction and characterization of seed oil from naturally grown Chinese tallow trees. Journal of the American Oil Chemists' Society 90, 459–466 (2013).
29. Tavares, G.R., Massa, T.B., Gonçalves, J.E., da Silva, C., dos Santos, W.D.: Assessment of ultrasound-assisted extraction of crambe seed oil for biodiesel synthesis by in situ interesterification. Renewable Energy 111, 659–665 (2017).
30. Lee, S.Y., Fu, S.Y., Chong, G.H.: Ultrasound-assisted extraction kinetics, fatty acid profile, total phenolic content and antioxidant activity of green solvents' extracted passion fruit oil. International Journal of Food Science & Technology 50(8), 1831–1838 (2015).
31. Hromádková, Z., Kováčiková, J., Ebringerová, A.: Study of the classical and ultrasound-assisted extraction of the corn cob xylan. Industrial Crops and Products 9, 101–109 (1999).
32. Li, H.Z., Zhang, Z.J., Hou, T.Y., Li, X.J., Chen, T.: Optimization of ultrasound-assisted hexane extraction of perilla oil using response surface methodology. Industrial Crops and Products 76, 18–24 (2015).
33. Hu, A.J., Feng, Q.Q., Zheng, J., Hu, X.H., Wu, C., Liu, C.Y.: Kinetic model and technology of ultrasound extraction of safflower seed oil. Journal of Food Process Engineering 35 (2), 278–294 (2011).
34. Chemat, F., Rombaut, N., Meullemiestre, A., Turk, M., Perino, S., Fabiano-Tixier, A.S., Abert-Vian, M.: Review of Green Food Processing techniques. Preservation, transformation, and extraction. Innovative Food Science & Emerging Technologies 41, 357–377 (2017).
35. Franco, D., Sineiro, J., Pinelo, M., Núñez, M.J.: Ethanolic extraction of Rosa rubiginosa soluble substances: Oil solubility equilibria and kinetic studies. Journal of Food Engineering 79 (1), 150–157 (2007).
36. Li, H., Zhang, Y., Sui. D., Zhang. Y., Feng, H., Jiang, L.: Ultrasound-assisted aqueous enzymatic extraction of oil from perilla (Perilla frutescens L.) seeds. Cyta-Journal of Food 12(1), 16–21 (2014).

Framework Proposal to Organize Sustainability Strategies Towards a Transition to the Circular Economy

Márcia M. C. Bacovis, Daniel Nascimento-e-Silva, Míriam Borchardt, and Pedro Antônio de Melo

Abstract This study aims to propose a structure to organize sustainability strategies for Schools of Thought in the circular economy, to guide the introduction of circularity in the companies' business model, meeting the needs of researchers and managers. In the research, the systematic bibliographic method was used to analyze scientific articles on the circular economy, level of analysis, stock of knowledge on circular economy and the perspective of diachronic analysis, seeking to understand its evolution over time; the data were organized with the aid of a synthesizing table, where the characteristics of each school of thought were gathered and then interpreted with the content analysis technique, seeking meaning for all terms cataloged in the same semantic field. The strategies were organized in the stages of the technical cycle of the Systemic Diagram of the Ellen MacArthur Foundation (EMF). The conclusion shows that the structure created can guide the transition to an era of a more circular economy.

Keywords Circular economy · Strategies for circularity · Cradle to cradle · Closed-loop supply chain · Schools of thought

M. M. C. Bacovis (✉) · D. Nascimento-e-Silva
Federal Institute of Education, Science and Technology of Amazonas, Manaus, AM 69075-351, Brazil
e-mail: mmbacovis@ifam.edu.br

M. Borchardt
Vale do Rio dos Sinos University (UNISINOS), São Leopoldo, RS 93022-000, Brazil

P. Antônio de Melo
Federal University of Santa Catarina, Florianópolis, SC 88040-900, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_21

1 Introduction

In the context of the limited supply of natural resources, the increase in cost pressures and the need for economic sustainability, environmental and political restrictions in supply chain management and environmental problems have gained importance and have encouraged companies to seek more sustainable economic models [1]. The depletion of non-renewable resources is followed by ecological and social impacts, driven by the intense consumption of products and the incorrect disposal of waste [2].

Even though several improvements have occurred in recent decades, such as the increase in eco-efficiency [3]; the emergence of eco-innovation in products, processes and new technologies [4]; research that extends the scope beyond a company's boundaries, addressing green practices in supply chains [5], research on sustainable supply chain management (SSCM) applying modeling techniques [6], structure to guide the decision processes in SSCM [7], a hybrid model of multicriteria decision analysis (MCDA) of sustainability performance [8]; these are insufficient to reduce the significant linearity of production chains. A new paradigm appears with the proposed solution to minimize the entry of raw material and the generation of waste, in the circular economy [9–11].

In this context, it is possible to identify several proposals to promote circularity, such as Industrial Symbiosis [12], Industrial Ecosystems [13], Product-Service Systems [14] and Eco-efficiency [3]. These practices come from organized schools of thought, which promote sustainability in industrial production. They are: Industrial Ecology [15], Closed-loop supply chain [16], Cradle to Cradle [17], Biomimicry [18], Performance economics [9, 19], Natural capitalism [20], Blue economy [21] and Regenerative Project [22]. However, implementing the concept of CE is a challenging task, given the mentality and linear structures prevalent in industry and society [10]. The research questions that guide this study are:

Q1: What are the strategies and practices of the CE Schools of thought that guide the implementation of the circular model?

Q2: How can these strategies and practices be organized into a framework, facilitating understanding for implementation?

The objective of this article is to propose a framework that organizes the strategies promoted by schools of thought (ST), to guide the transition to the Circular Economy (CE). The specific objectives are (1) to describe the characteristics of schools of thought and their overlap with CE; (2) identify strategies that can be used to guide the transition to the circular model, and (3) organize the strategies according to the steps of the Ellen MacArthur Foundation Systemic Diagram (EMF). The relevance of this work is justified by the fact that the literature points to the lack of research that guides the transition actions based on CE principles [23].

2 Methodology

This research is exploratory, based on a systematic literature review and was carried out in three stages: search, selection, and analysis of studies [24]. The first stage began with the search for studies to learn about the current state of research on CE and to determine the theoretical constructs that guide the study to identify strategies and practices for the implementation of the basic circular model based on the assumptions of ECCE schools of thought. The combination of "Circular Economy" with the terms "Biomimicry, Closed-Loop Supply Chain, Cradle to Cradle, Blue Economy, Regenerative Design, Natural Capitalism and Performance Economy" was used in the search string. The resulting articles were also used to identify more relevant works (snowball technique). The databases used were Scopus and Web of Science, using the period between January 2000 and July 2019 as the time frame. This resulted in 1248 publications considering the two databases. Filters for document types were defined for "peer-reviewed articles" in English, reducing the number to 310 articles in Scopus and 240 in Web of Science. Editorials and articles from remote disciplines such as medicine were excluded. Figure 1 shows the steps followed in step 1.

In the second stage, filters were applied to select the articles. The first filter took as a criterion the readings of the titles of the articles found, as well as their identification with the theme of the work and exclusion of articles in duplicate. After the selection of articles by the criterion of reading the titles, 127 papers were selected, considered the closest to the research theme. Then, the second filter was applied, reading and analyzing the abstracts of the selected articles and those that did not have an affinity with the theme of the work were discarded.

After reading the abstracts, 44 articles were analyzed, of which a large part was used in structuring the theoretical basis and used in the process of codifying strategies for establishing the Circular Economy (Fig. 2).

In the third stage of the research, the content analysis process [25] was carried out, identifying sustainable strategies and practices proposed by the TS of the CE. The building blocks of the CE proposed by the Ellen MacArthur Foundation [9] were also considered for the identification of strategies/practices, namely: product and system design, new business models, reverse flows and enablers. These strategies were submitted to three Brazilian specialists on the CE theme to be validated.

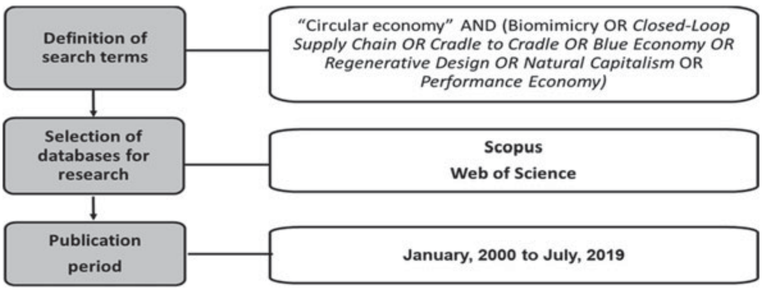


Fig. 1 Search strategy

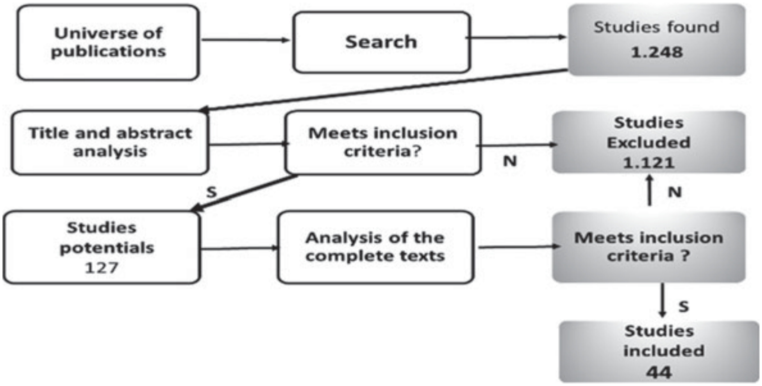


Fig. 2 Search, selection and coding process

3 Circular Economy: Strategies of Schools of Thought

Several studies [9, 11], claim that the concept of Circular Economy is based on a fragmented collection of ideas derived from some scientific fields, including emerging fields, with roots in different disciplines and schools of thought [23], which provide several strategies and practices that promote sustainability in industrial production.

The first school is the **Industrial Ecology (IE)**, which deals with patterns of material and energy flows inside and outside industrial systems, including technological dynamics [10]. The key elements of Industrial Ecology are biological analogy, systemic perspectives, technological changes, cooperation, dematerialization, eco-efficiency, and research and development [26, 27]. The **Cradle to Cradle (C2C) school** is based on the proposal that products can be designed in such a way that their constituent materials circulate indefinitely in biological or technical systems when using energy from renewable sources [17]. **Performance Economy** is a “self-replenished economy”, based on a closed loop system, which results in the circulation of materials through sequential product life extension activities [19]. Emphasizes the design of durable products, guarantees strategies for extending the product’s useful life and defends the sale of the product’s service—and not the physical product itself [19], which started the idea of a Service System Product-Service System. **Regenerative Design** has the premise of being restorative and regenerative in principle [22]. The recovery of materials and products should not be dealt with at the end of their useful life, but be contemplated from the design, through the choice of renewable materials or design for disassembly [28]. Regenerative Design, in the context of CE, requires central skills in a circular design to facilitate the disassembly of products and which allows them to recondition, remanufacture, reuse and recycle each of them, that is, to guarantee its use in a cascade [9]. The **Closed Loop Supply Chain (CLSC)** proposes the “closing of the loops” through the “R” frameworks and Reverse logistics. The literature points to several structures of the “R” framework: like the 3Rs [29, 30], of the 4R (reduce, reuse, recycle and recover), 6R (reduce, redesign, reuse, remanufacture, recycle, recover) [31], and even 9R proposals (refuse, reduce, redesign, reuse, repair, remanufacture, recondition, recycle, recover) [32]. **In Biomimicry**, the innovation process can and should be inspired by the knowledge of natural processes. Nature is a great source of inspiration for innovation [18]. Biomimicry is an innovation inspired by nature, in which there is no waste [9, 30]. **Blue Economy** emphasizes that waste does not exist: nutrients, matter, and energy have a ripple effect; by-products can be used for new product development [21]. The innovative business model and competitiveness are two characteristics of the Blue Economy that serve as motivation for ECCE. **Natural Capitalism** refers to the world's natural assets, such as air, water, soil, wildlife, and other living organisms. The model argues that the interests of the environment and companies are not mutually exclusive, but overlapping [20, 30]. Table 1 presents the key strategic concepts and practices advocated by the TS, as well as the key references that empirically support each body of knowledge.

4 Results and Discussions

Some strategies identified during the literature review are present in more than one school of Thought (ST). The Eco-efficiency strategy, derived from Industrial Ecology, is understood as a strategy for the company to create value and reduce the environmental impact [3]. Resource-efficient production saves them for other purposes or uses in future generations. Eco-efficacy, from the Cradle to Cradle School (C2C), implies the transformation of products and associated material flows so that they form a supportive relationship to ecological systems and future economic growth. In this case, the objective is not to minimize the flow of materials from the cradle to the grave, but to generate cyclical metabolism, from the cradle to the cradle. Eco-efficacy should be the goal in a circular system.

- Symbiosis Industrial involves industries traditionally separated in a collective approach of competitive advantage and the physical exchange of materials, energy, water, and/or by-products, through cooperation between companies [13]. An important characteristic of Industrial Ecology and CE is the cooperation between actors within and between the technical and biological cycles. This allows win-win solutions to be built, adding value to the chains [10, 11].
- In the Cradle to Cradle approach, product design is identified as crucial in the design of sustainable circular systems. Efforts to close the material cycle by C2C design approaches have been researched since 1990 [10]. In line with the ST of the Regenerative Project, the Cradle to Cradle approach (from cradle to cradle) mimics natural ecosystems from a perspective of toxicity and design. The "durability" in C2C and EP can be achieved by extending the useful life of the products; adoption of new business models based on user-oriented services (for example, product leasing and pooling); reuse of products and components; and diffusion of material recycling [33, 34].

Table 1 Reference framework with strategies for circularity from the schools

Schools	Practices	Description of the practice	Authors
Industrial ecology	*Systemic approach*	*Explain how parts influence each other as a whole and the relationship of the whole to the parts*	[3, 12, 26, 27, 34]
	Cooperation	Collaboration and cooperation are essential in closed-loops that turn waste into useful resources	
	Industrial symbiosis	*A process-oriented solution concerned with transforming the waste output from one process into raw material to another process or product line*	
	Eco-efficiency	The strategy adopted by the company to promote the application of environmental, social, and economic sustainability practices throughout the product cycle	
	Technological changes	*Technological changes and information technologies play an important role in the transition to the circular economy*	
Cradle to cradle (C2C)	C2C design	To close the cycle, products must be developed so that they can be regenerated and reused	[9, 17, 28–30, 38, 39]
	Minimize waste	*It means reducing waste by closing the loop; reduce losses of valuable materials; and develop industrial processes with less waste*	

(continued)

Table 1 (continued)

Schools	Practices	Description of the practice	Authors
	Eco-efficacy	Product transformation and its associated material flow to form a supportive relationship with ecological systems and enable future economic growth	
	Reverse logistics	*Return of post-sale or post-consumption waste for a new application, in the same or another process*	
	Energy recovery	Recover energy from by-products or waste by technologies such as incinerators and biogas exploitation	
Performance economics	Design for durability	Enlarges the useful life of developed products	[9, 14, 19, 28–30]
	Design for reliability	*Develops products with a design that ensures reliability, with an adequate product or component life, aims to reduce the number of failures and extend their service life*	
	Dematerialize	Reduce the use of raw material in manufacturing but the performance remains unaltered	
	Product service system (PSS)	*A product service system (PSS) integrates products and services to enhance value to users*	
	Shared economy	Expands the efficient use of underutilized resources, which fulfills its social function	
Biomimicry	*Nature inspired products*	*Designers should draw on organisms, biological processes, and ecosystems as a way to solve human problems*	[4, 9, 18, 30, 33, 40, 41]

(continued)

Table 1 (continued)

Schools	Practices	Description of the practice	Authors
	Nature-inspired processes	In biomimicry, nature inspires products and processes	
	Return to nature	*In CE, the resources used in the production of goods must be recovered and returned to nature. The principle of regeneration aims to restore, retain, and restore the health of ecosystems*	
	Eco-innovation	Green innovation assists in environmental sustainability as it promotes changes in the way we produce with less environmental impact	
Blue economy	Co-product generation	Materials produced during the primary production process of the main product from the same input (resources)	[9, 21, 29, 30]
	Co-products use	*The use of co-products contributes to sustainability in industries*	
	Increased competitiveness	Investments in social and environmental initiatives are no longer an additional cost but an opportunity for innovation and competitiveness	
	Use of renewable energies	*It relies on natural resources with a utilization rate lower than the renewal rate, such as solar, wind, hydro, geothermal, among others*	

(continued)

Table 1 (continued)

Schools	Practices	Description of the practice	Authors
Regenerative design	Design for disassembly	Design that considers the need for disassembly, which facilitates the repair and remanufacturing of end-of-use returns as well as recycling	[9, 22, 28, 30, 35, 36, 42, 43]
	Modular design	*Design that develops products composed of functional modules, so that they can be updated with new features. Modules can be individually refurbished or replaced, increasing product longevity*	
	Resource reuse	It involves the use of fewer resources and less workforce to produce new products from virgin materials or even to recycle and discard products	
	Energy performance	*It involves the use of less energy to produce new products from virgin materials or even to recycle and discard products*	
	Material selection	This refers to the preference, in the process of acquisition and production, for pure materials, which offer easier classification at the end of life of products	
Closed-loop supply chain	Reduce	Includes input reduction and use of natural resources; reduction of emission levels; loss reduction of valuable materials	[9, 26, 32–34, 37]

(continued)

Table 1 (continued)

Schools	Practices	Description of the practice	Authors
	Reuse	*It means using a product again for the purpose for which it was originally designed and produced, with little improvement or alteration*	
	Remanufacture	Remanufacturing ensures that products meet original performance specifications by restoring and replacing components	
	Refurbish	*It consists of updating a used product, replacing parts that are failing or likely to fail soon*	
	Recycle	Recycling is any recovery operation whereby waste is reprocessed into products, materials, or substances, whether for original or other purposes	
Natural capitalism	Land use optimization	Proper management of solid waste decreases the pressure on natural resource consumption and impacts on the soil for landfill disposal	[9, 20, 30, 33, 34, 44, 45]
	Optimization water use	*The company must manage the use of water, making treatment and reuse*	
	Business model change	Sustainable business models allow to close and narrow loops and dematerialize products for sustainable development solutions	

– The strategy of using energy from renewable sources is present in three schools of thought: C2C, Regenerative Design, and Blue Economy. The use of energy from renewable sources provides compliance with the first principle of ECCE: preserving and improving natural capital, controlling finite stocks, and balancing the flow of renewable resources. Thus, natural capital must be valued by reducing its use to the minimum necessary. For Bradley [35], the energy and resources used must come primarily from renewable sources. In this context, eco-innovation, present in C2C and Biomimicry, is becoming a theoretical reference for strategic development, which can lead to an increase in productivity and an improvement in competitive advantage at the company level.
– The "return of used" strategy is carried out through the reverse logistics of post-consumer products. The expansion in the return on used products is explicitly related to companies' sustainability efforts; it increases the environmental performance of manufacturing operations and generates new profit opportunities and competitive advantages for all parties involved in supply chain operations [36].
– The Reduce, Reuse, and Recycle strategies present in CLSC, are possible strategies to be implemented through changes in the company's business model and a good Reverse Logistics strategy, with collection points or in partnership with the technical assistance of the products.

Moving to a CE requires organizations to innovate their business models [20]. In this sense, the change in the business model proposed by Natural Capitalism, Blue Economy, and Performance Economy can be promoted through the Product Service System (PSS), Shared Economy, and Dematerialization strategies—the latter promotes collaborative consumption.

At the School of Regenerative Design, there are several design strategies: Circular Design (C2C and regenerative), Design for Disassembly, and Modular Design. For Moreno et al. [28], designers are responsible for defining how products and services are designed and built. According to these authors, the design of most products is far from circular because it follows the linear pattern of resource use. It is worth noting that the design of circular products needs to consider the chosen business model.

The strategies from each school of Thought can be organized in the stages of the Systemic Diagram proposed by the Ellen MacArthur Foundation, which explains that, in the CE, there are two types of flows: that of biological nutrients and that of technological nutrients. Figure 3 presents a proposal for grouping technological nutrients. For strategies related to product design to be contemplated, a step called "Research and Development" was inserted between the steps of "Extraction of Natural Resources" and "Manufacturing of the Parties".

In the "Natural Resources Extraction" stage, the strategies of natural capitalism were included: land-use optimization, water use, and consumption reduction (of non-renewable resources).

In the "Research and Development" (R&D) stage, there is the definition of the design to be used, according to the company's business model: Regenerative/Circular Design, Disassembly Design, Modular Design, renewable resources, eco-innovation, design for durability. Product design is identified as crucial in the design of sustainable

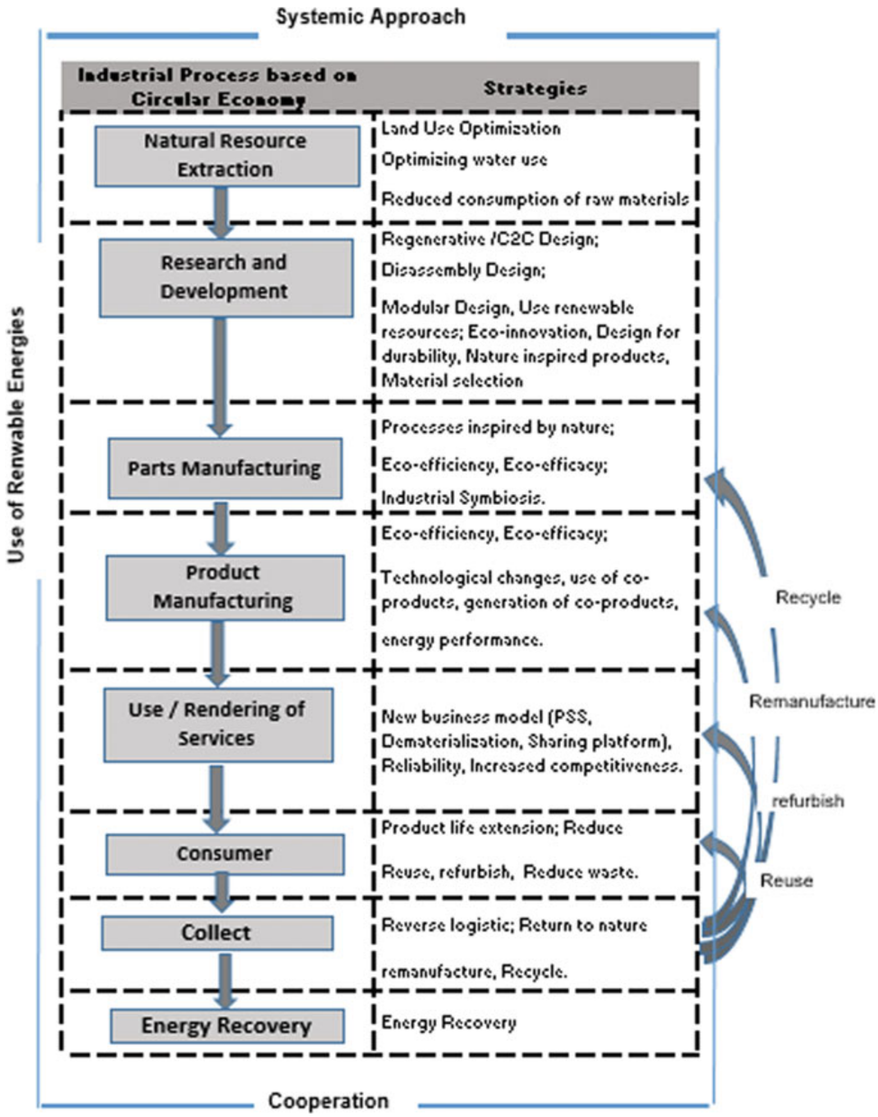


Fig. 3 Proposed framework

circular systems, especially in connection with the research of critical materials [10]. Design strategies need to go hand in hand with the company's business model [28].

In the "Manufacturing of the Parts" stage, there are Biomimicry strategies (processes inspired by nature, products inspired by nature), eco-efficiency, eco-efficacy in addition to the Industrial Ecology strategy (Industrial Symbiosis).

In the "Product Manufacturing" stage, there are EIIE strategies, such as Eco-efficiency and technological changes; C2C (Eco-efficacy) strategies, Blue Economy strategies: use of co-product, generation of co-product and energy performance, related to Regenerative Design. Considering that the predominant business models, products, and supply chains were developed to operate in linear systems, they are unable to meet the dynamics of closed-loop systems [10].

In the Use/Service Provision Stage, there are the Blue Economy strategies—increasing competitiveness and changing the business model; and Performance Economy strategies: PSS, Dematerialization, Shared Economy, and Reliability. Gusmerotti et al. [37] consider that business models can be considered as the blocks for the transition to the circular model: (1) "circular supplies"—using renewable energy and bio-based and/or fully recyclable inputs; (2) "resource recovery"—recovery of useful resources from materials, by-products or waste; (3) "product life extension"—extending product life cycles, repairing, updating and reselling them, as well as through innovation and product design focused on durability; (4) "sharing platform"—connecting users of the product and encouraging use; (5) "products as a service (PSS)".

In the "Consumer Stage", the strategy is to extend the life of the product through reuse, remanufacturing, reconditioning the products, and reduce waste.

In the "Collection" stage, there are strategies for returning used (reuse, remanufacturing, reconditioning), returning to nature, and recycling (through Reverse Logistics).

In the "Energy Recovery stage", the challenge is to find ways to optimize all the energy sources available to the organization, especially those that are not yet perceived and used.

It should be noted that the strategies for a systemic approach, cooperation, and use of energy from renewable sources were not included in a single step, as they permeate all stages of the Systemic Diagram. The Ellen MacArthur Foundation [9] considers these strategies as enablers to leverage the ECCE.

5 Final Considerations

This article presents a frame of reference with 36 strategies from schools of Thought that can guide the transition to a more circular economy. It also presents a framework with the grouping of these strategies in the company's value chain, represented here in the Ellen MacArthur Foundation Systemic Diagram, to facilitate the understanding of how each of them can be used to assist companies, governments and society in the transition from the current model of production and consumption, rooted in the Linear Economy, for Circular Economy.

The findings exposed here aim to contribute to the body of knowledge on innovative strategies and practices that promote the circularity of products and compliance with the principles of CE. The proposed structure can guide which strategies can be followed and what should be done at each stage of production of goods and services.

To facilitate guidance for professionals and academics on how to evolve towards CE, the frame of reference and framework can be taken as a promising starting point. It is emphasized that it is necessary to validate these strategies with other researchers and professionals.

For future work, it is suggested that the proposed framework with the strategies and the framework be applied using real cases, assessing whether the strategies are well aligned in the phases of the EMF systemic diagram, to promote practical insights for possible improvements.

Finally, it is worth noting that the transition to a Circular Economy is not just equivalent to adjustments aimed at reducing the negative impacts of the Linear Economy—on the contrary, it represents a systemic change to generate long-term commercial and economic opportunities and environmental and social benefits.

References

1. Kazancoglu, Y., Kazancoglu, I., & Sagnak, M. (2018). A new holistic conceptual framework for green supply chain management performance assessment based on circular economy. *Journal of Cleaner Production*, 195, 1282–1299. DOI:https://doi.org/10.1016/j.jclepro.2018.06.015.
2. Ritzén, S., & Sandström, G. Ö. (2017). Barriers to the circular economy: integration of perspectives and domains. *Procedia CIRP*, 64, 7–12. DOI:https://doi.org/10.1016/j.procir.2017.03.005.
3. Huppes, G., & Ishikawa, M. (2009). Eco-efficiency guiding micro-level actions towards sustainability: ten basic steps for analysis. *Ecological Economics*, 68(6), 1687–1700.
4. Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, 45, 9–19.
5. Sellitto, M. A. (2018). Assessment of the effectiveness of green practices in the management of two supply chains. *Business Process Management Journal*, 24(1), 23–48.
6. Seuring, S. (2013). A review of modeling approaches for sustainable supply chain management. *Decision support systems*, *54*(4), 1513–1520.
7. Stindt, D. (2017). A generic planning approach for sustainable supply chain management-How to integrate concepts and methods to address the issues of sustainability?. *Journal of cleaner production*, *153*, 146–163.
8. Vivas, R., Sant'anna, Â., Esquerre, K., & Freires, F. (2019). Measuring sustainability performance with multi criteria model: A case study. *Sustainability*, *11*(21), 6113.
9. Ellen MacArthur Foundation, Zumwinkel, K., & Stuchtey, M. R. (2015). *Growth within: a circular economy vision for a competitive Europe*. Cowes: Ellen MacArthur Foundation.
10. Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: a comprehensive review in context of manufacturing industry. *Journal of Cleaner Production*, 115, 36–51.
11. Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, 143, 37–46.
12. Chertow, M. R. (2000). Industrial symbiosis: literature and taxonomy. *Annual review of* energy and the environment, 25(1), 313–337.
13. Parida, V., Burström, T., Visnjic, I., & Wincent, J. (2019). Orchestrating industrial ecosystem in circular economy: A two-stage transformation model for large manufacturing companies. Journal of Business Research, 101, 715–725.
14. Tukker, A. (2015). Product services for a resource-efficient and circular economy - A review. Journal of Cleaner Production, 97, 76–91. Disponível em https://doi.org/10.1016/j.jclepro.2013.11.049

15. Tukker, A. (2015). Product services for a resource-efficient and circular economy - A review. Journal of Cleaner Production, 97, 76–91. Disponível em
16. Krikke, H., Blanc, I., & Van De Velde, S. (2004). Product modularity and the design of closed-loop supply chains. California management review, 46(2), 23–39.
17. McDonough, W., & Braungart, M. (2010). Cradle to cradle: remaking the way we make things. New York: North Point.
18. Benyus, J. M. (2004). Biomimicry: what would nature do here? In Ausubel, K., & Harpignies, J. P. (Eds.) *Nature's operating instructions*: t*he true biotechnologies* (pp. 3–16). San Francisco: Sierra Club Books.
19. Stahel, W. (2010). *The performance economy*. New York: Springer.
20. Hawken, P., Lovins, A. B., & Hunter, L. (2013). *Natural capitalism: The next industrial revolution.* London: Routledge.
21. Pauli, G. A. (2010). The blue economy: 10 years, 100 innovations, 100 million jobs. Boulder: Paradigm Publications.
22. *Lyle, J. T. (1996). Regenerative design for sustainable development. John Wiley & Sons.*
23. Merli, R., Preziosi, M., & Acampora, A. (2018). How do scholars approach the circular economy? A systematic literature review. *Journal of Cleaner Production*, *178*, 703–722.
24. Kitchenham, B. (2004). Procedures for performing systematic reviews. *Keele, UK, Keele University*, *33*(2004), 1–26.
25. Bardin, L. (2006). *Análise de conteúdo*. Lisboa: Edições 70.
26. Silva, F. C., Shibao, F. Y., Kruglianskas, I., Barbieri, J. C., & Sinisgalli, P. A. A. (2019). Circular economy: analysis of the implementation of practices in the Brazilian network. *Revista de Gestão*, 26(1), 39–60.
27. Saavedra, Y. M., Iritani, D. R., Pavan, A. L., & Ometto, A. R. (2018). Theoretical contribution of industrial ecology to circular economy. Journal of Cleaner Production, 170, 1514–1522.
28. Moreno, M. et al. (2016). A conceptual framework for circular design. *Sustainability*, 8(9), 937.
29. Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, 11–32. DOI:https://doi.org/10.1016/j.jclepro.2015.09.007.
30. Geisendorf, S., & Pietrulla, F. (2017). The circular economy and circular economic concepts-a literature analysis and redefinition. *Thunderbird International Business Review*, 60, 771–782. Disponível em https://doi.org/10.1002/tie.21924.
31. Sihvonen, S., & Ritola, T. (2015). Conceptualizing ReX for aggregating end-of-life strategies in product development. Procedia Cirp, 29, 639–644.
32. Potting, J. et al. (2017). Circular economy: measuring innovation in the product chain. Sidney: PBL Publishers.
33. Bocken, N. M. P. et al. (2016). Product *design* and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), 308–320.
34. Elia, V., Gnoni, M. G., & Tornese, F. (2017). Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production*, 142, 2741–2751. DOI:https://doi.org/10.1016/j.jclepro.2016.10.196.
35. Bradley, R. et al. (2016). A Framework for Material Selection in Multi-Generational Components: Sustainable Value Creation for a Circular Economy. *Procedia CIRP*, 48, 370–375.
36. Homrich, A. S., Galvao, G., Abadia, L. G., & Carvalho, M. M. (2018). The circular economy umbrella: Trends and gaps on integrating pathways. Journal of Cleaner Production, 175, 525–543.
37. Gusmerotti, N. M., Testa, F., Corsini, F., Pretner, G., & Iraldo, F. (2019). Drivers and approaches to the circular economy in manufacturing firms. Journal of Cleaner Production, 230, 314–327.
38. Sellitto, M. A. (2018). Reverse logistics activities in three companies of the process industry. *Journal of Cleaner Production*, 187, 923–931.
39. Spring, M., & Araujo, L. (2017). Product biographies in servitization and the circular economy. Industrial Marketing Management, 60, 126–137.

40. Haidar, X. C. (2016). *Biomimicry and Circular Economy*. Disponível em https://www.researchgate.net/publication/305650307. Acesso em 26 jun. 2019.
41. Bocken, N. M. P. et al.. Taking the circularity to the next level: a special issue on the circular economy. Journal of Industrial Ecology, 21(3), 476–482. (2017).
42. Nobre, G. C., & Tavares, E. (2017). Scientific literature analysis on big data and internet of things applications on circular economy: a bibliometric study. *Scientometrics*, 111(1), 463–492.
43. Shaharudin, M. R. et al. (2017). Product return management: Linking product returns, closed-loop supply chain activities and the effectiveness of the reverse supply chains. *Journal of Cleaner Production*, 149, 1144–1156.
44. Lewandowski, M. (2016). Designing the business models for circular economy—Towards the conceptual framework. *Sustainability* 8(1), 43.
45. De Jesus, A. et al. (2018). Eco-innovation in the transition to a circular economy: An analytical literature review. *Journal of Cleaner Production*, 172, 2999–3018.

Application of Data Reconciliation in a Water Balance as a Tool for Reducing Water Use at a Public University in Brazil

M. S. L. Costa, R. M. Brito, H. S. Carvalho, R. A. Kalid, and M. A. F. Martins

Abstract This work proposes a data reconciliation (DR)-linked water balance at the Jorge Amado campus (CJA) of the Federal University of Southern Bahia (UFSB), located in the municipality of Itabuna, Bahia, Brazil. Thus, it is intended to support future policies to reduce water use at the university, as well as the establishment of strategies for continuous improvement and process control. To that end, this article maps, quantifies and qualifies water flows, taking into account measurement uncertainties, so that reconciliation can take place efficiently. As a result, inadequacies in the system were identified, such as the existence of under-measurement, the possibility of leaks, or misuse of water in the institution. In addition, a more reliable mass balance was established, reducing system uncertainty and closing existing imbalances attesting the effectiveness of DR in the system. Finally, the statistical evaluation of the data reconciliation residue is detailed and ways of continuing the research are proposed.

Keywords Measurement uncertainty · Quality of information · Hydrometer

1 Introduction

The scarcity of quality water and rising costs are a worldwide concern. For this reason, establishing efficient tools aimed at managing/optimizing the flow of water is essential [1]. In this context, the water balance stands out as a tool that maps water flows, inlets, and outlets, in order to identify opportunities for improvement or economic gains [2]. The water flow of the process can be measured directly or not

M. S. L. Costa · R. M. Brito · M. A. F. Martins
Federal University of Bahia, Salvador, Bahia, Brazil

H. S. Carvalho · R. A. Kalid (✉)
Federal University Southern of Bahia, Itabuna, Bahia, Brazil
e-mail: kalid@ufsb.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_22

[3], so that, when possible, flow measurement instruments should be installed. They provide an estimate of the observed variables, as they are subject to uncertainties, whether in the measurement procedure or the instruments used. However, due to the unavailability of measuring instruments in all water streams, some variables need to be estimated by alternative means, such as design data, specific observations, opinions of field experts, and so on. Regardless of the data sources, measured or estimated by other procedures, they have uncertainties that do not satisfy the balances of mass, energy and moment of the process; that is, there are imbalances or, in other words, the balance sheets are different from zero [4].

The methodology that aims to circumvent the imbalances, both to ensure that the information meets the restrictions determined in the process (deviation = 0) and to improve the distribution of existing uncertainties, is called data reconciliation [5]. Such a tool estimates the value of the currents based on the adjustment of the process measurements, which is achieved by minimizing the variables until the balance between the inputs and outputs is met [6]. The typical formulation of a data reconciliation problem, in the case of rate flows, is expressed according to the following optimization problem [7]:

$$min_{F_R} \sum_{i=1}^{N} \frac{(F_{Mi} - F_{Ri})^2}{u_i^2} \tag{1}$$

$$s.a.\ \rho\left(\sum_{i=1}^{L_z} F_{Ri}^{Z} - \sum_{i=1}^{M_z} F_{Ri}^{Z}\right) = 0, \quad z = 1, \ldots, Z, \tag{2}$$

where: F_{Mi}: mapped rate flows, in m^3/h; F_{Ri}: reconciled rate flows, in m^3/h; u_i: standard uncertainty of the mapped variable, in m^3/h; N: number of streams involved; L_Z: number of input streams of a unit z; M_Z: number of output streams of a unit z; z: referring to the unit; Z: number of units; ρ: water density, in kg/m^3.

Finally, it is important to emphasize that after reconciling the data, the residue obtained from the difference between mapped and reconciled data is tested. The intention is to assign statistical value to the data. If the system obeys the following assumptions: the process is at a steady-state; the model is perfect; the experiment was done well; the residue is adherent to Gaussian PDF and data is not self-correlated, then the optimization problem defined in (1) and (2) can be statistically interpreted [8].

To provide information on the more sustainable use of water at a university, this study maps the streams, quantifies and qualifies flows and reports on the effectiveness of data reconciliation. The work is organized as follows. Section 2 describes the methodology developed. In Sect. 3, the results are described and discussed. Finally, Sect. 4 points to the conclusions and future works.

2 Methodology

The case study was applied at the Federal University of Southern Bahia (UFSB), on the Jorge Amado campus, which is located in Itabuna, Bahia. The campus is supplied with water from the water supply company, Empresa Municipal de Água e Saneamento S.A. (EMASA). In order to sketch this process, after the description, Fig. 1 details each part.

Initially, it is necessary to map the water flow rates on the university campus, determining the directions and conditions of the process. It is relevant to know all the inputs and outputs, to name streams and equipment, to create an outline and a flowchart, looking for strategies that guide the creation of constraint equations representative of the process. This step was responsible for determining the preparation of a water balance.

Once the process is known, it is important to spend time and resources to implement a data collection system with a minimum of failures. To this end, the researchers provided training that allowed the operator to view the measurements on the instruments' dials and feed the spreadsheets with this information. Even following the premise of the experiment, if it is well done, and given a perfect model, there are human errors, atypical events or instrumental problems and these possibilities make it essential to attribute uncertainty to all the flows that make up the balance, relating it to the method from which this information was gathered.

When it comes to a quantitative method, where the measurements are derived from instruments, two main sources of uncertainty contribute to the total uncertainty of the measurement, types A and B described in the Evaluation of measurement data—Guide to the expression of uncertainty in measurement—GUM [9]. Type A is demonstrated by the dispersion of the observed values and, therefore, is calculated based on the standard deviation of the sample. Meanwhile, type B uncertainty contains information that is associated with a scientific judgment based on all available information

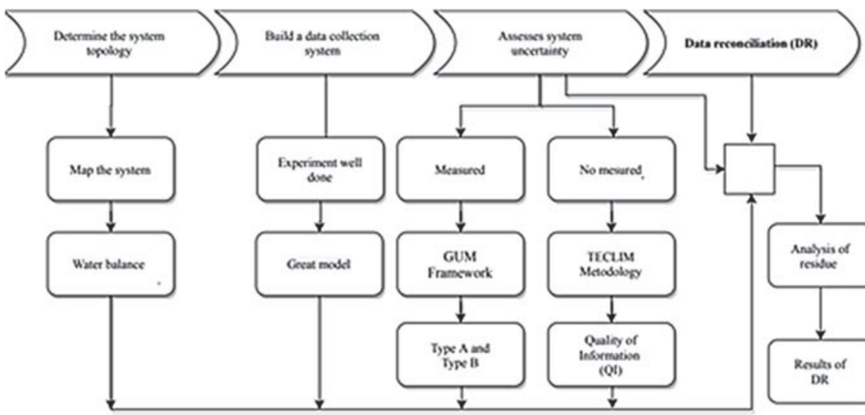


Fig. 1 Practical outline of the applied methodology

about the possible variability such as previous measurements, behavior and properties of materials and instruments, manufacturer's specifications, data provided in calibration certification, uncertainties attributed to the reference data extracted from the manuals. On the other hand, given the lack of total flow meters at all necessary points, a tool proposed by the research group TECLIM (Clean Technologies Network) at UFBA (Federal University of Bahia) is applied. The application of this study is very important, as it allows the solution of systems through the use of few measured aqueous flows and the other estimated values [10]. It establishes an association between the rate flow value indicated and a certainty range in which it was obtained, that is, a quality of information (QI) is attributed, where QI values between 0.4 and 10.0 are given for each aqueous current under consideration. Therefore, there is a relationship between uncertainty and QI [4, 11], as explained in Eq. 3:

$$QI_i = K\frac{F_{Mi}}{U_i} \tag{3}$$

where: QI_i Quality of information, dimensionless; K: proportionality factor, dimensionless; U_i: expanded uncertainty of the mapped variable, in m^3/h.

Finally, the data needs to be analyzed and reconciled, giving it greater data credibility, less uncertainty and the resolution of imbalances. For this, Eq. 1 was used as an objective function, where there is a relationship between the measured variables, with the reconciled variables and the instruments' variation or deviation. This reconciled flow is the variable decision.

The data reconciliation software used *nhemu_2020_0.R* was developed by Kalid [12]. The spreadsheets with data entry for the program and the database with measurements and other experimental information used in this work were compiled by Costa [13].

The results of the data reconciliation were evaluated to attest to their success and representativeness. The analysis of the results may present indicators in the system, leaks, needs for prioritization or maintenance.

The intention is to be able to effectively use the reconciled values in the optimization of management processes and strategies. According to Fontana [14], the reconciliation of water balance data is considered by several authors as a very effective method in helping to manage and use water. In this way, the reconciled variables can be used to economically optimize processes in order to improve the efficiency and profitability of the system.

3 Results and Discussion

The case study at UFSB-CJA took place from 18 June 2019 to 10 December 2019. The first step was to map the water flow rates, with the intention of building the sketch of the process (see Fig. 2). All system equipment and streams are described in Tables 1 and 2.

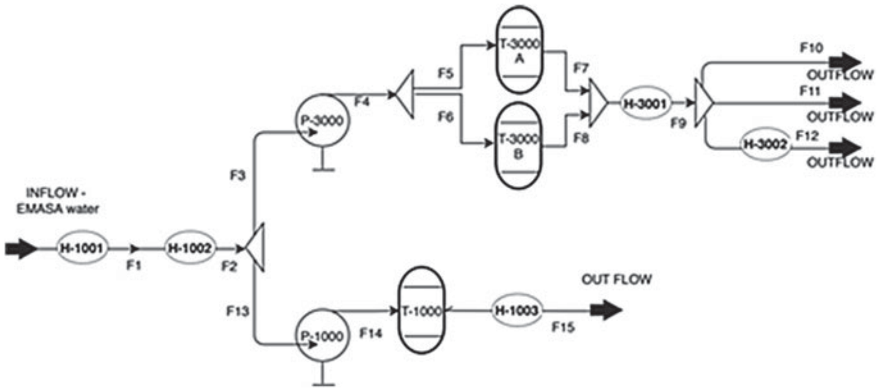


Fig. 2 Flow chart of the CJA-UFSB process

Table 1 Streams that make up the system

Streams	Status	Description
F1	Measured	Total water inflow from EMASA to CJA, accounted for by H-1001
F2	Measured	Total water inflow from CJA, accounted for by H-1002
F3	Estimated, not measured	Pumping water through the P-3000
F4	Estimated, not measured	Split current for T-3000A and T-3000B
F5	Estimated, not measured	Water inflow into the T-3000A
F6	Estimated, not measured	Water inflow into the T-3000B
F7	Estimated, not measured	Water outflow from the T-3000
F8	Estimated, not measured	Water outflow from the T-3000
F9	Measured	Flow of water destined for all pavilions, accounted for by H-3001
F10	Estimated, not measured	Flow of water destined for the administrative pavilion
F11	Estimated, not measured	Flow of water destined for the service pavilion
F12	Measured	Flow of water destined for the classroom pavilion, accounted for by H-3002
F13	Estimated, not measured	For the T-1000
F14	Estimated, not measured	Pumping water through the P-1000
F15	Measured	Flow of water destined for the rectory, accounted for by H-1003

Starting from Fig. 2, it is possible to determine the input and output streams of each control volume; then, it is possible to represent them through mass balances (constraint equations of the data reconciliation problem), such as Eqs. (4)–(12):

Table 2 Equipments and intruments that make up the system

TAG	Description
H-1001	EMASA's hydrometer records all water used
H-1002	UFSB's calibrated water meter records all water used
P-3000	Maneuver pump
T-3000A	Lower tank, with 1000 L capacity, feeds the pavilions
T-3000B	Lower tank, with 1000 L capacity, feeds the pavilions
H-3001	UFSB calibrated hydrometer records the water in all pavilions (class, administrative and service)
H-3002	UFSB calibrated hydrometer records the water used in the classroom pavilion
P-1000	Maneuver pump
T-1000	Upper tank, with 3000 L capacity, feeds the rectory
H-1003	UFSB calibrated hydrometer records the water used in the rectory

$$F_1 - F_2 = 0 \tag{4}$$

$$F_2 - F_3 - F_{13} = 0 \tag{5}$$

$$F_3 - F_4 = 0 \tag{6}$$

$$F_9 - F_5 - F_6 = 0 \tag{7}$$

$$F_9 - F_7 - F_8 = 0 \tag{8}$$

$$F_9 - F_{12} - F_{10} - F_{11} = 0 \tag{9}$$

$$F_{13} - F_{14} = 0 \tag{10}$$

$$F_{14} - F_{15} = 0 \tag{11}$$

$$F_2 - F_9 - F_{15} = 0 \tag{12}$$

where F: is the mass flow rate, in m^3/h.

Analyzing the data, they were classified and divided into two blocks: the data from Monday to Thursday (MT) and from Friday to Sunday (FS). It was found that the water use profile was different in the two cases, making it necessary to assign a standard uncertainty for each block. The difference between the averages of the blocks is significant. The division makes it possible to find more credible values for

Table 3 Coverage test to assess the representativeness of the mean between the blocks

Item	MT	FS	Unit
Flow rate	0.391	0.291	m^3/h
Standard uncertainty	0.022	0.047	m^3/h
Relative standard uncertainties	5.6	16.2	%

the small sample group, and data reconciliation will be done for the MT and FS block separately. Table 3 contains the results of the evaluation of the average of the H-1002 (reference water meter). The relative standard uncertainties (standard uncer-tainty divided by the value of the quantity) are satisfactory for MT (5.6%), and high for FS (16.2%), due to the great variability of water use. However, these results cannot be statistically interpreted, as discussed in Figs. 4, 5 and 6.

For both blocks, note the presence of flow rates measured by calibrated instruments (F_1, F_2, F_9, F_{12} *e* F_{15}) and the others estimated by other procedures. The measurements have uncertainties evaluated according to the GUM [9], the others use the concept of QI and its equivalence with uncertainty [4]. All uncertainty calculations, for both cases, can be found, in the spreadsheets "IJCIEOM_2020.MT.xlsx" and "IJCIEOM_2020.FS.xlsx" [13].

The sources of uncertainty associated with the instruments of this system are: (A) classified as Type A, an uncertainty component of experimental measurement; (B1) classified as Type B, obtained by consulting the calibration certificate of the hydrometers. For the H-1001, as it is an uncalibrated water meter, it was necessary to be rigorous when assigning the trend of the systemic condition imposed on the uncalibrated metering; and (B2) classified as Type B, associated with the resolution of the reference standard. All sources result in a single value, known as combined standard uncertainty. They have been demonstrated in Tables 4 and 5.

The definition of QI and equivalent uncertainty are shown in Table 6. The flows and the respective QI in Eq. 3 are also attributed, with the factor was considered equal to 0.098 [4]. In addition, for this study, due to the uncertainty values of the measured variables, it was necessary to be more rigorous in the QI estimates and to stipulate an interval starting from 0.4.

Tables 7, 8, and Fig. 3 show the values involved in the process before and after the application of data reconciliation (DR). Based on the results presented, the residue of

Table 4 Quantification of uncertainty for the MT block

Instrument	Type A/(m^3 h^{-1})	Type B/(m^3 h^{-1})		Standard uncertainty/(m^3 h^{-1})
		B1	B2	
H-1001		3.2E-02	2.9E-05	4.2E-02
H-1002		7.4E-04	2.9E-05	2.2E-02
H-1003		2.5E-03	2.9E-05	2.7E-02
H-3001		2.5E-03	2.9E-05	9.7E-03
H-3002		7.5E-04	2.9E-05	5.8E-03

Table 5 Quantification of uncertainty for the FS block

Instrument	Type A/(m^3 h^{-1})	Type B/(m^3 h^{-1})		Standard uncertainty/(m^3 h^{-1})
		B1	B2	
H-1001	3.3E-02	6.9E-02	2.9E-04	7.6E-02
H-1002	4.7E-02	7.4E-04	2.9E-04	4.7E-02
H-1003	1.8E-02	2.5E-03	2.9E-04	1.9E-02
H-3001	4.3E-03	2.5E-03	2.9E-04	5.0E-03
H-3002	3.2E-02	7.5E-04	2.9E-04	3.3E-03

Table 6 Definition of the origin of the observed values

Streams	Description	QI	MT	FS
			Standard uncertainty/(m^3 h^{-1})	Standard uncertainty/(m^3 h^{-1})
F3	Estimated by measure H-1002	0.4	2.4E-02	1.8E-02
F4	Estimated by measure H-1002	0.4	2.4E-02	1.8E-02
F5	Estimated by measure H-1002	0.4	7.0E-03	4.0E-03
F6	Estimated by measure H-1002	0.4	7.0E-03	4.0E-03
F7	Estimated by measure H-3001	0.4	7.0E-03	4.0E-03
F8	Estimated by measure H-3001	0.4	7.0E-03	4.0E-03
F10	Interview with an expert	0.4	5.0E-03	3.0E-03
F11	Interview with an expert	0.4	1.0E-03	1.0E-03
F13	Estimated by measure H-1002	0.4	2.4E-02	1.8E-02
F14	Estimated by measure H-1002	0.4	2.4E-02	1.8E-02

the measured streams are, in general, both small and satisfactory, while the residue of the unmeasured flow rates (F_3 to F_8, F_{10}, F_{11}, F_{13}, F_{14}) are more significant. There was a reduction of uncertainty by 38.5 % for the block called MT and 48.8 % for the FS, with all constraints met, that is, "imbalances", originating from the constraints equations became null (Table 9). It can, therefore, be said that the data reconciliation technique was successfully applied.

For both blocks, MT and FS, when analyzing the data after the reconciliation, that is, with more credible data and with less uncertainty, two streams draw attention: the

Table 7 Water balance for CJA before and after data reconciliation for block MT

Streams	Before DR			After DR			Residue	
	Flow observed/($m^3\ h^{-1}$)	Standard uncertainty/($m^3\ h^{-1}$)	Relative uncertainty/%	Flow reconciled/($m^3\ h^{-1}$)	Standard uncertainty/($m^3\ h^{-1}$)	Relative uncertainty/%	Residue/($m^3\ h^{-1}$)	Relative Residue/%
F1	3.5E-01	4.2E-02	12.2	3.5E-01	1.9E-02	3.4	-0.002	-0.7
F2	3.9E-01	2.2E-02	5.6	3.5E-01	1.9E-02	3.4	0.043	10.9
F3	2.0E-01	2.4E-02	12.3	1.6E-01	4.3E-03	3.7	0.079	40.5
F4	2.0E-01	2.4E-02	12.3	1.6E-01	4.3E-03	3.6	0.079	-6.7
F5	5.5E-02	6.7E-03	12.3	5.8E-02	5.2E-03	8.9	-0.004	-6.7
F6	5.5E-02	6.7E-03	12.3	5.8E-02	5.2E-03	8.9	-0.004	-6.7
F7	5.5E-02	6.7E-03	12.3	5.8E-02	5.2E-03	8.9	-0.004	-6.7
F8	5.5E-02	6.7E-03	12.3	5.8E-02	5.2E-03	8.9	-0.004	-6.7
F9	1.1E-01	9.7E-03	8.9	1.2E-01	4.3E-03	3.7	-0.007	-6.7
F10	4.0E-02	4.9E-03	12.3	4.3E-02	4.1E-03	9.7	-0.003	-6.7
F11	1.0E-02	1.2E-03	12.3	1.0E-02	1.2E-03	11.9	0.000	-1.8
F12	5.9E-02	5.8E-03	9.7	6.3E-02	4.5E-03	7.1	-0.004	-6.5
F13	2.0E-01	2.4E-02	12.3	2.3E-01	1.2E-02	5.0	-0.037	-15.8
F14	2.0E-01	2.4E-02	12.3	2.3E-01	1.2E-02	5.0	-0.037	-15.8
F15	2.0E-01	2.7E-02	10.4	2.3E-01	1.2E-02	5.0	0.029	12.6

Table 8 Water balance for CJA before and after data reconciliation for block FS

Streams	Before DR			After DR			Residue	
	Flow observed/(m^3 h^{-1})	Standard uncertainty/(m_3 h^{-1})	Relative uncertainty/%	Flow reconciled/(m^3 h^{-1})	Standard uncertainty/(m^3 h^{-1})	Relative uncertainty/%	Residue/(m^3 h^{-1})	Relative residue/%
F1	2.2E-01	7.6E-02	34.0	2.1E-01	1.0E-02	4.8		4.7
F2	2.9E-01	4.7E-02	16.3	2.1E-01	1.0E-02	4.8		26.3
F3	1.5E-01	1.8E-02	12.3	6.1E-02	2.4E-03	3.9		57.8
F4	1.5E-01	1.8E-02	12.3	6.1E-02	2.4E-03	3.9		57.8
F5	2.9E-02	3.5E-03	12.3	3.1E-02	2.8E-03	9.1		-5.7
F6	2.9E-02	3.5E-03	12.3	3.1E-02	2.8E-03	9.1		-5.7
F7	2.9E-02	3.5E-03	12.3	3.1E-02	2.8E-03	9.1		-5.7
F8	2.9E-02	3.5E-03	12.3	3.1E-02	2.8E-03	9.1		-5.7
F9	5.8E-02	5.0E-03	8.6	6.1E-02	2.4E-03	3.9		-5.7
F10	2.3E-02	2.9E-03	12.3	2.5E-02	2.4E-03	9.7		-5.9
F11	5.9E-03	7.2E-04	12.3	6.0E-03	7.1E-04	12.0		
F12	2.9E-01	3.3E-03	11.6	3.0E-02	2.6E-03	8.5		
F13	1.5E-01	1.8E-02	12.3	1.5E-01	1.0E-02	6.6		-5.2
F14	1.5E-01	1.8E-02	12.3	1.5E-01	1.0E-02	6.6		-5.7
F15	1.6E-01	1.9E-02	11.8	1.5E-01	1.0E-02	6.6		

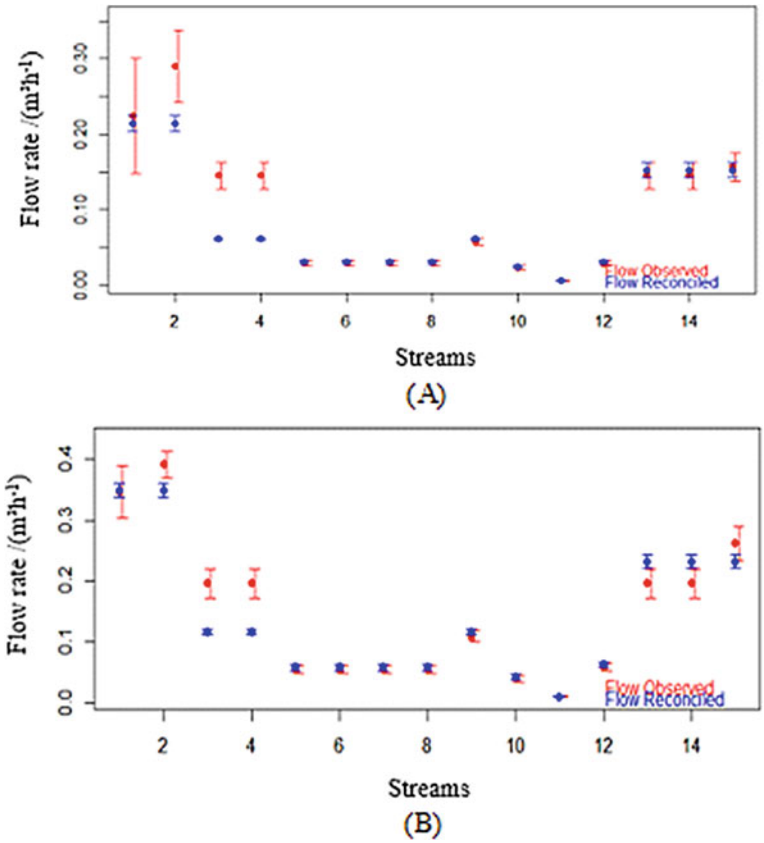


Fig. 3 Graphical representation of the observed and reconciled flow rate values in the CJA: **a** MT chart; **b** FS chart

stream F_2, measured by H-1002, has a larger measurement than that indicated by F_1; that is, the instrument of the water supply company, which is oversized, presents results inferior to that of the UFSB water metering.

Another exciting result is the flow F_{15}, measured by H-1003, which indicates a very high value of the total used by CJA-UFSB, so it is recommended that priority is given to the use of water in the Rectory of UFSB, where there are approximately 170 people. This difference was more significant for both blocks, and it can indicate a leak or waste on the part of the users.

Additionally, we proceeded to assess the residues. Figures 4 and 5 show the residue in a histogram and a Gaussian PDF equivalent; it is possible to observe that the residues are not Gaussian. The rate flows measured by the hydrometers showed little or no variation concerning zero. Shapiro Wilk test considering a 90% confidence level showed that PDF of residue is not Gaussian, the P-value was less than 0.005 for MT and FS.

Table 9 Results of restriction equations for CJA before and after data reconciliation for block MT and block FS

Imbalances	MT		FS	
	Before DR/(m^3 h^{-1})	After DR/(m^3 h^{-1})	Before DR/(m^3 h^{-1})	After DR/(m^3 h^{-1})
Equation (4)	-0.045	0.000	0.000	0.000
Equation (5)	0.000	0.000	0.000	0.000
Equation (6)	0.000	0.000	-0.087	0.000
Equation (7)	0.086	0.000	0.000	0.000
Equation (8)	0.000	0.000	0.000	0.000
Equation (9)	0.000	0.000	0.000	0.000
Equation (10)	0.000	0.000	0.000	0.000
Equation (11)	0.066	0.000	-0.012	0.000
Equation (12)	0.021	0.000	0.076	0.000

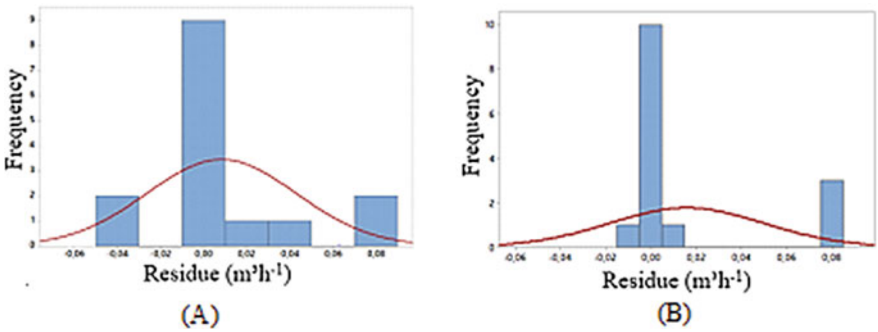


Fig. 4 Evaluation of data reconciliation residue through frequency and Gaussian PDF: **a** MT chart; **b** FS chart

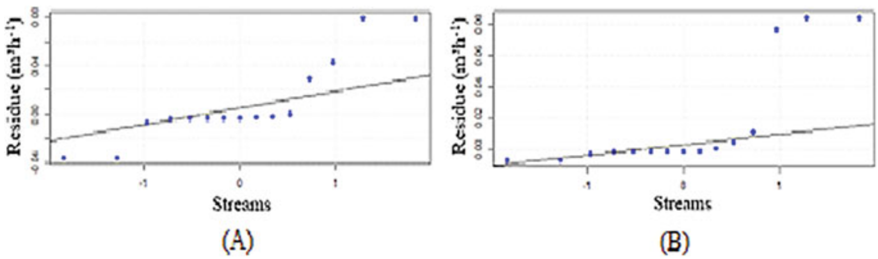


Fig. 5 Evaluation of data reconciliation residue through probability plot: **a** MT chart; **b** FS chart

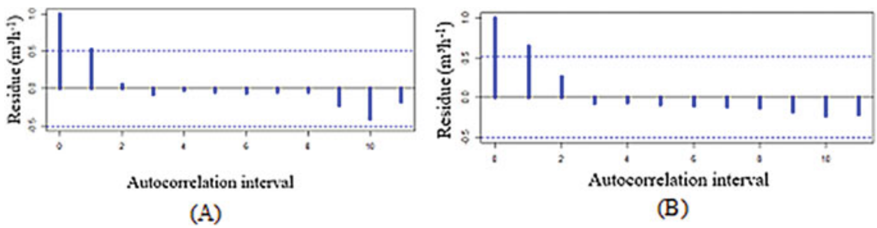


Fig. 6 Evaluation of data reconciliation residue through autocorrelation: **a** MT chart; **b** FS chart

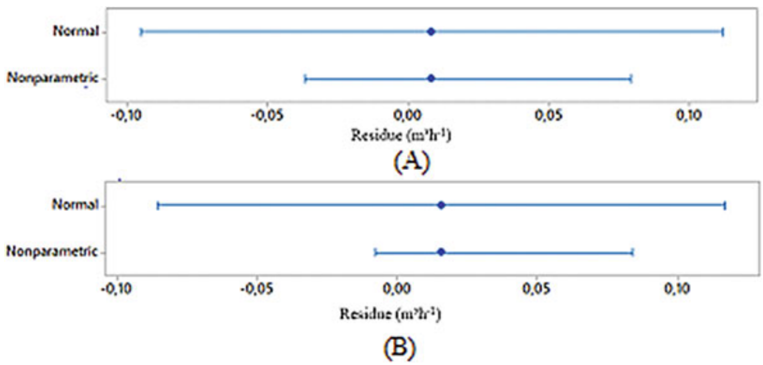


Fig. 7 T-test to parametric and nonparametric: **a** MT chart; **b** FS chart

On the other hand, in Fig. 6, the autocorrelation of residue is not significant for MT and for FS. So, it is possible to state that, they are not autocorrelated for both.

The last, Fig. 7 shows the T-tests to parametric and nonparametric, where both the averages of the residue is approximately zero.

The residues are autocorrelated and are not adherent to a Gaussian PDF. Therefore, they do not meet two hypotheses of the maximum likelihood method, necessary so that the results obtained by the weighted least squares method can be statistically interpreted. However, it is believed that with the continuity of the research and a greater amount of reconciled data, this behavior will be modified.

4 Conclusion

For this study, the classical data reconciliation was applied to the data measured by instruments and, for the estimated data, DR was supported by the TECLIM methodology. It is possible to conclude that when using the data reconciliation method, the obtained results are satisfactory for both blocks, MT and FS. Although the statistical tests performed indicate that, due to the high variability of the samples, the behaviors of the MT and FS data sets are statistically similar, with the accumulation of data this may no longer occur, so in the next works we will always present the results in three scenarios MT, FS and scenario with weekly data from Monday to Sunday. Also, the abnormal behavior of the residue is noteworthy, and it is not possible to interpret the results statistically. Other PDF of the residue will be proposed to solve the Maximum Likelihood problem in the continuation of this research.

The data reconciliation identified anomalous results (the measurement of the original instruments) and location to prioritize actions of more rational use of water (building of the Rectory of UFSB). In this sense, data reconciliation must continue to be performed periodically. Thus, it will be possible to better understand the profile of use, water reuse strategies; then, the information that will be used in the development of projects with university support will be more reliable.

The research has the potential to continue with specific studies on uncertainties, evaluating all sources and assessing the system's reliability; searching for water management strategies through campaigns, seminars, KAIZEN or others; achieving a reduction in data variability; study and evaluation of the entire UFSB system and equipment; outlining strategies for improvement and predictive maintenance, and the search for low-cost technologies that support water optimization.

References

1. Spank, U.; Schwärzel, K.; Renner, M.; Moderow, U.; Bernhofer, C.: Effects of measurement uncertainties of meteorological data on estimates of site water balance components. Journal of Hydrology, vol. 492, pp. 176–189 (2013).
2. Van Der Bruggen, B; Braeken, L.: The challenge of zero discharge: from water balance to regeneration. Desalination, vol. 188, pp. 177–183 (2006).
3. Spindler, A.: Structural redundancy of data from wastewater treatment systems. Determination of individual balance equations. Water Research, vol. 57, pp. 193–201 (2014).
4. Martins, M. A. F., Amaro C., Souza l., Kalid, R. A., Kiperstok, A.: New objective function for data reconciliation in water balance. Journal of Cleaner Production (2010).
5. Romagnoli, J A, Sánchez, M C.: Data processing and reconciliation for chemical process operations. 1nd edn. Academic Press Inc., vol. 2, pp. 270. San Diego (2000).
6. Câmara, M. M.; Soares, R. M.; Feital, T.; Anzai, T. K.; Diehl, F. C.; Thompson, P. H.; Pinto, J. C.: Numerical aspects of data reconciliation in industrial applications. Processes, vol. 5, pp. 1–38 (2017).
7. Crowe C M.: Reconciliation of process flow rates by matrix projection. AlChE Journal. vol. 32, pp. 616–623 (1986).
8. Schwaab, M M; Pinto, J C.: Análise de Dados Experimentais I: Fundamentos da Estatística e Estimação de Parâmetros. Rio de Janeiro (2007).
9. BIPM, IEC, IFCC, ILAC, ISO, IUPAC, IUPAP, OIML: Evaluation of measurement data — Guide to the expression of uncertainty in measurement — GUM. Joint Committee for Guides in Metrology — JCGM 100 (2008).
10. De Oliveira, G. L.; Kiperstok, A.; Kalid, R. A.; Esquerre, K. P. S. O. R.; Sales, E. A.: Metodologia TECLIM para uso racional de água na indústria: O banco de ideias no contexto da metodologia front-end loading. Engenharia Sanitaria e Ambiental (2016).
11. Oliveira, G.: A metodologia TECLIM para uso racional da água na indústria: uma proposta de sistematização. In: Tese de Mestrado em Engenharia Industrial. Salvador (2011).

12. Kalid, R. A.: Reconciliação de dados sem redundância de medição (Data reconciliation without measurement redundancy). 1nd edn. Zenodo (2020). Homepage, http://doi.org/10.5281/zenodo.3823305, last accessed 2020/05/23.
13. Costa, M. S. L., Brito, R. M., Carvalho, H. S., Kalid, R. A.: Spreadsheets: step by step of data reconciliation. 1st edn. Zenodo (2020). Homepage, http://doi.org/10.5281/zenodo.4001001, last accessed 2020/08/25.
14. Fontana, D., Kalid, R. A.; Sartori, I., Kiperstok, A., Silva, M., Sales, E. A., Filho, J. G. P., Perazzo, S.: Balanço hídrico – uma nova sistemática. In: 2th Congresso Brasileiro de Termodinâmica Aplicada – CBTERMO. Paraná (2004).

Disaster Response Assessment: The Case of the Civil Defense of the State of Rio de Janeiro, Brazil

Híngred Ferraz Pereira, Patrícia Alcântara Cardoso, and Adriana Leiras

Abstract Disaster response organizations need to be increasingly efficient to be able to serve the majority of people affected. In this scenario, disaster operations management must be very well managed and executed. Thus, this paper aims to apply a Maturity Model to evaluate disaster response processes of the Civil Defense of the State of Rio de Janeiro (Brazil) and analyze the organization's response capacity. We apply the Maturity Model based on a case study methodology, with a focal group interview in the organization. We conclude that the processes carried out by the Civil Defense have a general maturity stage equal to four in five. Besides, we can highlight six general level processes, as strengths of the organization and three others, as weaknesses that need attention in search for improvements.

Keywords Maturity model · Disaster response assessment · Civil Defense of the State of Rio de Janeiro · Humanitarian logistics

1 Introduction

Disasters are disruptions in the functioning of a community caused by calamitous events related to conditions of exposure, vulnerability, and capacity, resulting in human, material, economic, and/or environmental impacts or losses [1]. In 2019, 396 disasters struck worldwide, leading to 11,755 lives were lost, 95 million people affected, and U$$130 billion of losses recorded [2].

H. F. Pereira (✉) · A. Leiras
Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: hingred_ferraz@live.com

A. Leiras
e-mail: adrianaleiras@puc-rio.br

P. A. Cardoso
Federal University of Espírito Santo, Vitória, Brazil
e-mail: patricia.cardoso@ufes.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_23

These numbers show the importance and need for efficient disaster operations management for many sectors of society [3, 4]. Disaster operations management is the administration of resources and responsibilities of all organizations dealing with emergencies through all stages of the disaster (mitigation, preparedness, response, and recovery—[5]). The response phase seeks to reduce the effects of the unwanted event, that is, the use of resources and emergency procedures guided by plans for lifesaving [3, 6]. As the response phase is considered the most important [7] and related to the use of emergency resources, it is justified to be necessary to manage the processes of disaster response operations efficiently.

For better disaster operations management, Maturity Models (MMs) support the decision-making of stakeholders in long-term planning [8]. Bititci et al. [9] define MMs as matrix of practices that expose, for each organizational area, the level of formality, sophistication and insertion, from "ad hoc" to optimized practices. MMs set objectives to achieve a roadmap for the evolution of the process from the beginning to the most advanced stage through intermediaries [10]. Also, they allow managers to use the evaluation derived from their applications as an assessment and benchmarking to identify areas that need improvement in the organization [11]. Fernandez et al. [12] affirm that the implementation of an evaluation system generates adverse stakeholder reactions, however the MMs also allow the identification of critical points for improvement of the processes [13].

This study focused on the application of a maturity model for assessing disaster response operations. The model presented by Pereira et al. [14] was applied to the case study of Civil Defense of the State of Rio de Janeiro in Brazil (CDRJ), evaluating the processes carried out and identifying the strengths and weaknesses during the management of disaster response operations.

In addition to this introductory section, Sect. 2 presents the theoretical background. Section 3 describes the case study methodology applied in this study. The results of applying the model are present in Sect. 4. Conclusions and future research are discuss in Sect. 5.

2 Theoretical Background

The concept of MMs appeared in the 1970s in the information systems literature to manage its performance [9]. The best-known MM today was developed between the years 1986 and 1990 by the Software Engineering Institute together with Miter Corp., being a maturity structure called Capability Maturity Model (CMM). The model base on the knowledge obtained by evaluating software processes and feedback from sectors and governments and presents sets of best practices for various areas of the process for improving software development and maintenance [15].

An integration of CMM in the early 90s proposed the Capability Maturity Model Integration (CMMI) provide guidelines for improving the processes of organizations and the ability to manage the development, acquisition, and maintenance of products and services. The CMMI allows to evaluate the organizational maturity of the organizations, the capacity of the process area, establishes which improvements are a priority and allows the implementation of these improvements [16]. CMMI focused on software engineering, has led the development of several other MMs in other areas, and the concept of MM has widely adopted and used in different fields of management research.

Currently, the literature presents eight MMs focused on disaster operations management. The first model was presented in 2016 by Latif et al. [11] and is called the Infostructure Maturity Model (IMM). It allows assessing the infrastructure necessary for disaster management and has five stages applied in electric power supply companies.

Then, Mallek-Daclin et al. [17] developed the Field Hospital Maturity Model (FHMM), with five stages of maturity to offer good practices and recommendations to improve the implementation of field hospitals.

Gimenez et al. [18] presented an MM that provides a sequence of maturity stages to involve the city's stakeholders in the process of building resilience. The model consists of five stages of maturity and has two main objectives. First, it allows the model to be a reference for cities to identify their locations on the road to maturity and assess their current stage of maturity. Second, the model identifies the policies of those local governments that they need to comply with to involve different stakeholders in the process.

The Resilience Maturity Model (RMM) proposed by Hernantes et al. [10] assists local, regional, national and international authorities, policymakers, and critical infrastructure operators in operationalizing the cities' resilience-building processes. The model considers five maturity stages. Following the same line of resilient cities, Adeniyi et al. [19] developed a five-stage MM of resilience to floods focused on micro, small, and medium-sized enterprises (MSMEs).

Considering the management of organizational reliability, Agwu et al. [20] developed the Organizational Reliability Maturity Model (ORM^2) that maps organizations through various stages of organizational reliability. The ORM^2 is composed of five maturity stages under each principle of highly reliable organizations (concern with failures, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise).

The first model aimed specifically at the disaster response phase was proposed by Ma et al. [21]. The authors developed a five-stage model based on the CMM model that aims to assist continuous improvement during fire emergency management, public safety, and governance. They also proposed a plug-into improve the intelligence of the system, allowing for increased practicality.

The most recent MM for disaster operations is the Pereira et al. [14] which is applicable for the disaster management response phase. The MM allows organizations to assess their disaster response capacity, identifying their weaknesses, and allowing them to establish an action plan to improve response processes. This model differs from others because it is a more generic model and it can be applied to any response organization and to any type of disaster.

Table 1 Maturity models for managing disaster operations

Reference	Maturity model
Latif et al. [11]	Five stages ranging from no disaster control neither no coordination procedures to continually reviewed tasks and responsibilities
Mallek-Daclin et al. [17]	Five stages described according to three axes of interest: governance, logistics and care. The stages ranges from low consideration stages of the axis of interest to continuously improved axes
Gimenez et al. [18]	Five stages ranging from the stage in which the local government and emergency services only prepare for risk without the collaboration of other stakeholders to the stage in which all stakeholders are involved in a collaborative network
Hernantes et al. [10]	Five stages ranging from processes in which stakeholders work individually to strengthen resilience to processes in which stakeholders' efforts are coordinated, integrated and aligned with an action plan
Adeniyi et al. [19]	Five stages ranging from lack of knowledge of risks to its high understanding
Agwu et al. [20]	Five stages, ranging from lack of response and training plans to the robust emergency and communication plans
Ma et al. [21]	Five stages ranging from disordered processes and methods to optimized processes
Pereira et al. [14]	Five stages ranging from unmanaged processes to processes monitored and controlled by technology

Table 1 describes the stages of these eight maturity models designed to manage disaster operations.

3 Research Methodology

We apply the case study methodology proposed by Yin [22] as there is a need for a clear understanding and analysis of a phenomenon in a real situation. The case study method aims to deepen the investigations, in this study, on the topic of disaster response assessment. The phases of the case study described by Yin [22] and adapted for this study are:

- Plan: It consists in the adequacy of the method with the objective of the study [22]. With the application of the case study, it is allowed to investigate the maturity of the response processes carried out by the CDRJ.
- Project: It consists of an action plan that links the research questions of the study until its conclusion [22]. In this case, the MMs that could be used to assess the maturity of the CDRJ response processes were analyzed. After this analysis, the model proposed by Pereira et al. [14] was identified as the most appropriate to implement the plan. It is based on the process reference model proposed by Fontainha et al. [23] and on a structured literature review.

- Preparation: In this phase Yin [22] proposes the elaboration of a preparation protocol for data collection, containing the collection instrument and the procedures for its correct use. Therefore, the developed protocol contains the procedures for the elaboration of a questionnaire and its correct application. The questionnaire was developed on the SurveyMonkey platform. Then, six respondents compose the focus group.
- Data collection: In this phase, multiple sources of evidence are considered, such as observations, interviews, records of files, documents and physical artefacts [22]. In this study, the questionnaire applied as a form of an interview with a Civil Defense focal group, composed of six officers. These officers are members of the Civil Defense Study and Research Center (CEPEDEC), being two lieutenants colonels, one major, one captain and two 1st lieutenants. The interview lasted approximately 2 h and the interviewees responded by consensus on the investigated processes. The director of CEPEDEC coordinated the focus group.
- Data analysis: This phase consists of verifying, categorizing, classifying or recombining the evidence, according to Yin [22], it can perform using four different techniques: adaptation to the standard, construction of the explanation, analysis of time series or logical models of programs. The technique used in this study was pattern matching, in this case, the study developed by Pereira et al. [14], which in turn considers the study by Fontainha et al. [23]. The selected MM is used to analyze the results obtained with the application of the questionnaire.
- Sharing: This phase aims to expose the results found in the case study [22]. Section 4 presents these results.

4 Results

The model presented by Pereira et al. [14] bases on the reference process model proposed by Fontainha et al. [23]. For the creation of maturity stages and developments of its characteristics, the model bases on the work of Latif et al. [11] and Ma et al. [21]. The model proposed by Fontainha et al. [23] presents altered response process flows during disaster response operations and it consists of processes in two detailed levels: general level (9 processes) and partial level (62 processes).

The model proposed by Pereira et al. [14] presents five stages of maturity:

- Stage 1—No process mapping: There is no mapping of the performed processes;
- Stage 2—There is a basic process mapping: Basic, uncontrolled processes mapping, without technology, with few rules or without them. When the process performed, it usually occurs in sectorial levels of the organization. There is not any documentation nor procedures;
- Stage 3—There is a detailed process mapping: Detailed mapping of the process under analysis, but still without control and use of technology. The process performed out at the organizational level; i.e., there is no relationship between the organizations involved in the process. And there are no applicable documents or procedures;

- Stage 4—There are process monitoring and control: Detailed process management with monitoring and control, but not yet using technology. The process performed at the organizational aggregate level; i.e., there is a relationship between the organizations involved in the process. There are specific documents and procedures at the basic level;
- Stage 5—There is a controlled process by technology: Detailed process mapping using technology monitoring and control. There are documents and procedures specific to each process, and these are detailed.

For the application of the disaster response assessment model proposed by Pereira et al. [14], there are seven steps to be followed:

1. Analysis of the performance of the general level processes: In this step, the interviewees must answer which processes are performed by the organization and as an answer option, they had: **Yes**, if the organization performs the general level process and **No** if the organization does not perform the general level process;
2. Analysis of partial level processes (only of processes performed at a general level): For those processes of general level, the partial level presented, and the respondents' answer which ones were performed by the organization. The response options are: **Yes**, if the organization performs the partial level process, **No**, if the organization does not perform the partial level process and **It is not in the scope** if it were not the obligation of the organization;
3. Assignment of maturity stages to partial level processes (SPLP): The respondent analyzes each partial level process and the maturity stages proposed by Pereira et al. [14], which most fit. The stages presented above.
4. Assignment of the weighting of the partial level processes (WPLP): The interviewees inform a percentage that they consider relevant regarding the importance of carrying out the analyzed process. In the end, the sum of the partial level processes of each general level process must be equal to 100%. Only processes performed are considered and weighted.
5. Calculation of the maturity stage of the general level process (SGLP): With the maturity stages of the partial level processes and the weighting, the stages of each general level process were calculated. The calculation made with the following equation:

$$\text{SGLP} = \sum(\text{SPLP} * \text{WPLP}) \tag{1}$$

6. Assignment of the weighting of the processes of the general level (WPGL): The interviewees inform a percentage that they consider pertinent regarding the importance of carrying out the analyzed process. In the end, the sum of the general level processes must be equal to 100%. Only processes performed are considered and weighted.
7. Calculation of the organization's final maturity stage (FMS): With the process maturity stages at the general level and in the weighting, the organization's final

maturity stage for the disaster response operation can calculate. The calculation is made with the following equation:

$$\mathrm{FMS} = \sum(\mathrm{SGLP} * \mathrm{WPGL}) \tag{2}$$

It should consider that, for calculations of the maturity stage in steps 5 and 7, when the result is a fractional number, it rounds it down, considering a more conservative stage.

Figure 1 shows the result of the application of steps 1, 2, 3, and 4 of the model in the CDRJ.

With steps 3 and 4 applied (assignment of maturity and weighting stages for partial level processes), step 5 is applied, calculating the maturity stage of the general process. Figure 2 shows this calculation.

After calculating the maturity stages for the processes at the general level, step 6 was applied, which is the assignment of weighting for the processes at the general level. In the same way that the maturity stage was calculated for the partial level processes, shown in Fig. 2, a final stage was calculated for the organization regarding the disaster response operation. Figure 3 shows steps 6 and 7. Bearing in mind that the value found as the maturity stage of the disaster response operation may have been rounded, depending on the value found.

Only the application of the 7 steps for the first general level process (Recognition of the disaster occurrence) was presented. Still, these steps were applied to all the other eight processes presented.

Thus, in summary, the results of the Civil Defense processes of the State of Rio de Janeiro are:

- performs the nine general level processes presented;
- of the 62 partial level processes, seven are not within the scope of the organization, and only one should be executed, but it is not. That is, the organization performs a total of 54 partial level processes;
- the partial level processes performed out were allocated in steps 3, 4 and 5;
- most of the partial level processes performed out, approximately 70% of the processes, were allocated to the most mature stage, 5;
- the other partial level processes performed out were allocated equally (15%) in stages 3 and 4.

With the application of the 7 steps of the model to all processes in the CDRJ, there is maturity stage 4 for the organization's disaster response operations. The high number of partial-level processes carried out by the organization allocated to the most mature level (5) justifies the high maturity stage generated. So concluded that there is a detailing of the organization's disaster response processes, with control and monitoring, but without the use of technology. Besides, processes are being carried out in aggregate on the response organizations, and the documents and procedures are specific at a basic level.

General level processes	1st Step
1) Recognition of the disaster occurrence	Performs
2) Assessment of the current situation	Performs
3) Search and rescue	Performs
4) (R)establishing infrastructure in the response	Performs
5) Resource request for the response	Performs
6) Resource transport during the response	Performs
7) Service to the population	Performs
8) Demobilization of the operations	Performs
9) Response support operations	Performs

Partial level processes	2nd Step
1.1) Identifying changes in local features	Performs
1.2) Communicating the event to higher levels	Performs
1.3) Triggering alarms	Performs
1.4) Evacuating risk areas with activated alarms	Not in scope
1.5) Implementation of containment measures of protection	Not in scope

Partial level processes	3rd Step	4th Step
1.1) Identifying changes in local features	5	0.40%
1.2) Communicating the event to higher levels	5	0.30%
1.3) Triggering alarms	5	0.30%
1.4) Evacuating risk areas with activated alarms	-	-
1.5) Implementation of containment measures of protection	-	-

Fig. 1 Application of steps 1, 2, 3, and 4 in the CDRJ

Partial level processes	5th Step = $\sum$(SPPL * WPPL)
1.1) Identifying changes in local features	5 * 0.4 = 2.0
1.2) Communicating the event to higher levels	5 * 0.3 = 1.5
1.3) Triggering alarms	5 * 0.3 = 1.5
1.4) Evacuating risk areas with activated alarms	-
1.5) Implementation of containment measures of protection	-
Total	5.0

Fig. 2 Application of step 5 in the CDRJ

General level processes	Calculated general level	6 th Step	7th Step ∑ (SPPL * WPPL)
1) Recognition of the disaster occurrence	5	0.11%	5 * 0.11 = 0.55
2) Assessment of the current situation	5	0.11%	5 * 0.11 = 0.55
3) Search and rescue	5	0.14%	5 * 0.14 = 0.70
4) (R)establishing infrastructure in the response	3	0.08%	3 * 0.08 = 0.24
5) Resource request for the response	5	0.10%	5 * 0.10 = 0.50
6) Resource transport during the response	3	0.10%	3 * 0.10 = 0.30
7) Service to the population	3	0.14%	3 * 0.14 = 0.42
8) Demobilization of the operations	5	0.08%	5 * 0.08 = 0.40
9) Response support operations	5	0.14%	5 * 0.14 = 0.70
Total			4.36 = **4**

Fig. 3 Application of steps 6 and 7 for general level processes

Also, of the nine general level processes performed by the organization, six are carried out in stage 5. That is, in the more mature stage, the processes are mapped in detail, having monitoring and control and using technology. Then being the strengths of the organization, the processes: Recognition of the disaster occurrence; Assessment of the current situation; Search and rescue; Resource request for the response; Demobilization of the operation; and Response support operations.

The other three processes, considered weak points of the organization, were allocated to stage 3. Being processes carried out with detailed mapping, but without control and the use and technology. These processes are (R)Establishing infrastructure in the response; Resource transport during the response, and Service to the population.

5 Conclusions

For response operations to save the largest number of people and minimize the effects of disasters, organizations need to be increasingly efficient. Considering the response phase as the most important [17] and complex [7], this study aims to apply a MM to assess the Civil Defense disaster response of the State of Rio de Janeiro.

The model proposed by Pereira et al. [14] is the most recent in the literature and it is specific to the response phase of disaster management, being the chosen model for the application in the case study. It assesses nine processes at a general level, subdivided into 62 processes at a partial level.

When carrying out a case study to apply the model, it was possible to conclude that the studied organization performs all nine general level processes and 54 partial level processes. Besides, it was possible to calculate the maturity stage of these specific processes and a general stage regarding the organization's response operation.

Most of the partial level processes were allocated to the most mature stage of the model (stage 5), directly interfering in the final stage of the response processes. The evaluated organization resulted in a general stage of maturity equal to 4, is considered a stage of high maturity, with detailed, controlled, and monitored processes, in addition to executions at the aggregate level of the organizations.

Another issue that we can highlight with the application of the model was the strengths and weaknesses of the analyzed organization. Six processes at a general level were considered strong points, as they were allocated to the most mature stage of maturity, they are Recognition of the disaster occurrence; Assessment of the current situation; Search and rescue; Resource request for the response; Demobilization of the operation.

The remaining three processes are considered weaknesses as they coincidentally have the lowest maturity stage found in the organization's processes (stage 3). These processes need more attention and seek improvements to reach higher stages, being: (R)Establishing infrastructure in the response; Resource transport during the response; Service to the population.

Although the study carried out fulfilled its objective, resulting in the maturity stage of the CDRJ, the study had a limitation. The model was applied with only one focus group using the case study methodology.

It is suggested that future research should apply the model studied in other disaster response organizations, such as Civil Defenses in other states. That way, it will be possible to compare the results in addition to the application of different research methods, such as action research.

Acknowledgements Coordination for the Improvement of Higher Education Personnel (CAPES) [Finance Code 001].

References

1. UNISDR. Disaster Reduction and Sustainable Development: understanding the links between vulnerability and risk related to development and environment. Geneva: UN. http://gfmc.online/wp-content/uploads/ISDR-WSSDBackground-Paper-Version-June-2002-2.pdf, last accessed 01/15/2020.
2. CRED - Centre of Research for the Epidemiology of Disasters. Disaster* Year in Review 2019, https://www.cred.be/publications, last accessed 05/13/2020
3. Santos, R. S., Borges, M. R., Gomes, J. O., Canos, J. H: A cooperative assessment of the response capability of emergency organizations. In 2008 12th International Conference on Computer Supported Cooperative Work in Design IEEE. 1085–1090 (2008).
4. Kovács, G., Tatham, P.: Humanitarian logistics performance in the light of gender. International Journal of Productivity and Performance Management, 58(2), 174–187 (2009).
5. Van Wassenhove, L. N.: Humanitarian aid logistics: supply chain management in high gear. Journal of the Operational research Society, 57(5), 475–489 (2006).

6. Altay, N., Green III, W. G.: OR/MS research in disaster operations management. European journal of operational research, 175(1), 475–493. (2006).
7. Santos, R. S., Borges, M. R., Canós, J. H., Gomes, J. O.: The assessment of information technology maturity in emergency response organizations. Group Decision and Negotiation, 20(5), 593–613. (2011).
8. Latif, A. A., Arshad, N. H., Janom, N.: Design and validation of Infostructure maturity model survey through rasch techniques. 95(23), 6483–6493 (2017).
9. Bititci, U. S., Garengo, P., Ates, A., Nudurupati, S. S.: Value of maturity models in performance measurement. International journal of production research, 53(10), 3062–3085. (2015).
10. Hernantes, J., Maraña, P., Gimenez, R., Sarriegi, J. M., Labaka, L.: Towards resilient cities: A maturity model for operationalizing resilience. Cities, 84, 96–103 (2019).
11. Latif, A. A, Arshad N. H., Janom, N.: An infostructure maturity model (IMM): Conceptual framework. International Information Institute (Tokyo). Information, 19(10B), 4897. (2016).
12. Fernandez, N. S., Scavarda, L. F., Leiras, A., Hamacher, S.: Diseño de sistemas de medición de desempeño de proveedores: experiencias de un caso de estudio. Production, 22(1), 43–57 (2012).
13. McCormack, K., Ladeira, M. B., de Oliveira, M. P. V.: Supply chain maturity and performance in Brazil. Supply Chain Management: An International Journal (2008).
14. Pereira, H.F., Cardoso, P.A., Leiras, A.: Maturity Model for Disaster Response Operations. In: 2020 MIT SCALE Latin America Conference, 2020, Boston, EUA. 2020 Scale Latin American Conference, 2020. (2020).
15. Paulk, M. C., Curtis, B., Chrissis, M. B., Weber, C. V.: Capability Maturity Model for Software, Version 1.1. Tech Report CMUSEI-93TR-24, Software Engineering lnstitute. (1993).
16. Team, C. P. Capability maturity model® integration (CMMI SM), version 1.1. CMMI for Systems Engineering, Software Engineering, Integrated Product and Process Development, and Supplier Sourcing (CMMI-SE/SW/IPPD/SS, V.1. 1). (2002).
17. Mallek-Daclin, S., Daclin, N., Dusserre, G., Lhéritier, B., Blanchard, J., Arnaud, I.: Maturity model-driven assessment of Field Hospitals. IFAC-PapersOnLine, 50(1), 4642–4647. (2017).
18. Gimenez, R., Labaka, L., Hernantes, J.: A maturity model for the involvement of stakeholders in the city resilience building process. Technological Forecasting and Social Change, 121, 7–16. (2017).
19. Adeniyi, O., Perera, S., Ginige, K., Feng, Y.: Developing maturity levels for flood resilience of businesses using built environment flood resilience capability areas. Sustainable Cities and Society, 51, (2019).
20. Agwu, A. E.. Labib, A., Hadleigh-Dunn, S.: Disaster prevention through a harmonized framework for high reliability organizations. Safety science, 111, 298–312. (2019).
21. Ma, G., Tan, S., Shang, S.: The evaluation of building fire emergency response capability based on the CMM. International journal of environmental research and public health, 16(11), 1962. (2019).
22. Yin, R. K.: Estudo de caso: planejamento e métodos – 2nd edn Bookman, Porto Alegre (2001).
23. Fontainha, T. C., Silva, L. O., Leiras, A., Bandeira, R. A. M., Scavarda, L.F.R.R.: Process management and models for disaster response, PUC-RIO-CTC-DEI, Rio de Janeiro, pp. 34. (2018).

Lean Demand Management: Application in a National Health Department

Thiago A. Souza, Maximiliano das Chagas Marques, Frederico Correa Tarrago, Erno Harzheim, and Rui M. Lima

Abstract Demand management is essential for any organization and seeks to balance demand and productive capacity with a focus on customer orders. Thus, raising and studying in detail the demands is necessary in order to plan the daily operations, independently of being manufacturing or services, private or public sectors. Lean Thinking is a philosophy that emerged in the manufacturing field to improve production systems performance, simultaneously reducing operational wastes. This article aims to apply Lean principles to demand management in a Brazilian government department responsible for managing strategic health projects. Through interviews with managers 1027 monthly demands were raised in the department, of which 308 are demands requested and executed internally and 719 are transversal between various sectors. In addition, 42–45% of such demands are related to advisory and administrative support, taking the department's focus on processes that add value, such as Policies and Norms, Regional Monitoring, Qualification and Accreditation, and Projects and Studies. Regarding Lean waste, after the survey of demands, the operations related to the main demands showed waste according to the Ohno classification: 32% were classified as overprocessing, waiting 28%, and overproduction and defects/quality 14% each. This panorama demonstrates the need for better demand management so that the processes focus on delivering value, overcoming the resistance of employees as an obstacle.

T. A. Souza (✉) · R. M. Lima
Department of Production and Systems, Algoritmi Centre, School of Engineering, University of Minho, Guimarães, Portugal
e-mail: thiagosouza.uem@gmail.com

M. das Chagas Marques
Public Health, Universidade do Vale do Rio dos Sinos, São Leopoldo, Brazil

F. C. Tarrago
School of Production Engineering, Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre, Brazil

E. Harzheim
Department of Social Medicine, School of Medicine, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_24

Keywords Lean healthcare · Public management · Demand · Ministry of health · Wastes

1 Introduction

The need to match variations in demand with organizations' production capacity is one of the main challenges that managers face in any service sector [1]. Demand management seeks a balance between capacity and demand, by integrating customer needs, ensuring system efficiency, and better use of productive resources [2, 3].

Demand management refers to the control of service entrance ratios, but the simplest way towards balancing is through the control of exit ratios, made by monitoring and maintaining installed capacity, where managers use devices such as management of work schedules, reduced working hours and training in multiple tasks for employees, with the aim of planning, smoothing and avoiding differences between peak and non-peak demand periods [2].

In this sense, meeting the needs of customers requires a synchronization of efforts in business activities, ranging from order management, to the operations' value chain, to the distribution. For this, the adoption of Lean Thinking becomes a helpful tool in the search for value creation and elimination of waste in any organization [4].

The application of demand management and Lean concepts has been shown satisfactory results in all types of companies, from manufacturing and logistics, to public organizations, with results in reducing inventory levels, improving asset utilization, improving availability of the product, and systematization of the dimensioning of personnel in public agencies [3, 5].

The Ministry of Health, the national management body of the Unified Health System (SUS) in Brazil, is administratively divided into six secretariats, among which is the Primary Health Care Secretariat (SAPS), responsible for the management of the National Health Policy Primary Health Care, which links three departments, one of them the Strategic Programmatic Actions Department (DAPES), in which actions were developed to apply this study.

This article aims to present an application case from the Lean perspective, related to the survey of demands in a Brazilian government department responsible for managing strategic projects at the Ministry of Health.

2 Bibliographic Reference

2.1 *Public Management*

Public management integrates fields of knowledge, such as administration, political science and economics [6]. In Brazil, the debate for State management reform and focus on the principles of results-based management began in the 1990s, with what was called the New Public Administration (NPA) emerging from the crisis diagnosis and the Consensus recommendations from Washington to Latin American countries [7]. NPA, a term coined by British and Australian political scientists, guides its management actions on organizational design using innovative ideas, techniques and tools for the organization [8], as well as the incorporation of themes from the private sector into the context of organizations [9].

A decentralized management, with a greater focus on the client, is different from a rigid and bureaucratic hierarchical management, in which the client's interests are only incidental and the attention in intermediate controls, most of the times, unnecessary [10]. Thus, there is a clear need for planning and execution with a systemic and managerial view for public management, associated with the production chain managed in the different links [11].

In the Brazilian Unified Health System (SUS), decentralized and solidary management among the federated entities (Union, States/ Federal District and Municipalities), brings elements of complexity in the conduct of the actions and services of the Health Care Network, with even more expressive demands for the professionalization of management.

2.2 Lean Thinking Focused on Demand Management

Lean Thinking, originating from the Toyota Production System, has as main objective to see and eliminate waste in the processes, increasing the aggregation of value and increasing its throughput [4, 12]. The philosophy of improvement has been applied in recent years in the field of health around the world. The initial applications in the USA and UK, where it was renamed Lean Healthcare, showed increased efficiency, clinical results and customer satisfaction [13].

From the focus on adding value, Lean has as its premise the elimination of waste in the processes. Seven general wastes in productive systems are categorized by Ohno [12]: Overproduction, Waiting, Transport, Overprocessing, Inventory, Motion and Defects/Quality. An eighth waste emerges as "Unused Human Capital" [14].

The Lean Thinking applied to services is effective when its operations are planned and improved according to demand and production capacity [15]. In this sense, meeting the needs of customers (internal and/or external) should be a priority for planning the productive capacity of organizations [3]. For this purpose, some premises must be followed for adequate Demand Management, such as the study, attendance of demand, and integrating processes [16].

3 Method

A case study presents the study's focus on answering questions of "how" and "why", without manipulating the behavior of the people involved and to explain contextual conditions relevant to real life [17]. The phases of a case study include: (i) planning, (ii) data collection and (iii) data analysis [18]. This study presents a case related to the application of the study of demands in a Brazilian government department, responsible for the management of strategic health projects, within the scope of Primary Health Care (PHC).

The Strategic Programmatic Actions Department (DAPES), linked to the Primary Health Care Secretariat (SAPS) of the Brazilian Ministry of Health, has the mission of "coordinating the formulation, articulating and inducing policies in the Life Cycles and Mental Health, oriented to the Brazilian population". The department is divided into three major cost centers: (1) General Coordination of Life Cycles—CGCIVI; (2) General Coordination of Mental Health—CGMAD, and (3) Shared Services Center—CSC, comprising a staff of approximately 120 professionals, according to the scheme in Fig. 1.

As SAPS was a newly created secretariat in the 2019–2022 management of the Brazilian government, with a focus on primary care, its departments and processes have gone through structuring and planning cycles.

In this sense, the responsible secretary, together with the department's board, raised the need to study internal demands and critically analyze their routine, so that the improvements were strategically oriented between the balance of demand and the capacity of the sector, as well as the preparation for process mapping.

As a working method, using the principles of Dubé and Paré [18], the steps of the case study were outlined according to Table 1.

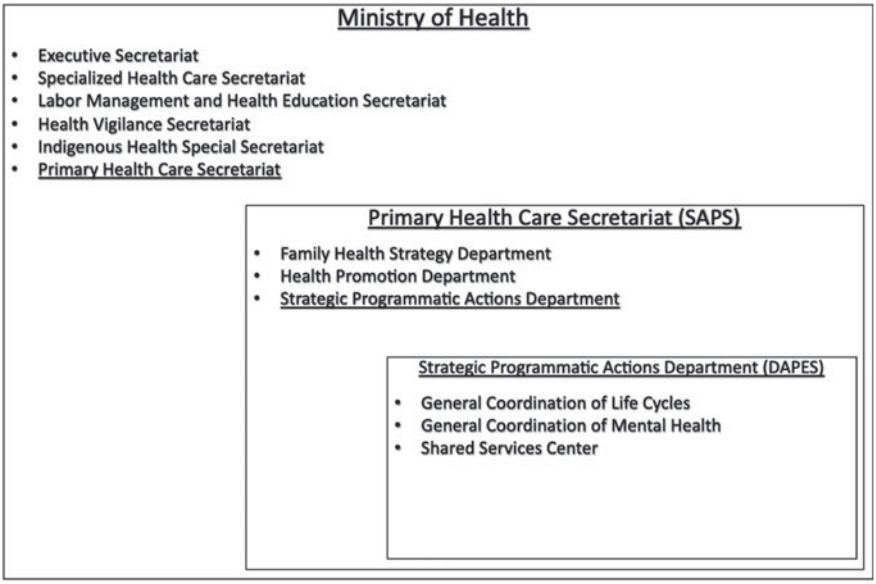


Fig. 1 DAPES/SAPS/Ministry of Health

Table 1 Work method

Phases [18]	Study steps
Planning	Definition of the objective and investigation team focused on surveying and categorizing demands, as well as waste classification
Data collection	Survey of demands by cost center through interviews with coordinators and team leaders
Data analysis	Categorization of demands by priority process groups in the department and classification of Lean waste. Critical analysis of the data obtained, discussion between researchers and the department's board and creation of a main countermeasures roadmap

In the first stage, the objective was defined to raise and categorize the existing demands in the department and the team was chosen to conduct the process internally, being three analysts and two researchers of the study, the study being carried out in three months.

In the second stage, the study team interviewed six coordinators and leaders internally through a semi-structured interview to raise and categorize the existing demands in the vision of the leaders. After that, the team together with the researchers analysed the responses and crossed the data collected in a qualitative way to start the third stage.

In the data analysis stage, the demands were separated into two distinct types: (i) Own Demands—where the claimant area is also the executor and (ii) Transversal Demands—where the demand is originated in one area and executed by another. This separation allowed the researchers of the study to see the level of interaction and maturity between the areas.

Still in the analysis stage, the demands were categorized according to the macro-processes pre-defined in the department's strategic map. For the CGMAD and CGCIVI cost centers, they were categorized into five different macroprocesses:

(i) Policies and Norms—Standardization, implementation and execution of health policies;
(ii) Regional Monitoring—Monitoring the implementation of the Policy in the regions of the country through epidemiological and managerial indicators;
(iii) Qualification and Accreditation—Qualification and Accreditation of services necessary for the implementation of the Policy;
(iv) Projects and Studies—Studies and research on health for the formulation and review of policies, as well as strategic projects for inducing public policies; and
(v) Advisory—administrative activities and legal accessory obligations.

For the CSC, there was a categorization into eight different macroprocesses, related to administrative and support processes shared with the thematic coordination, being: (i) Planning and Finance; (ii) Secretariat; (iii) Legal, Risks and Compliance; (iv) Data and Epidemiology; (v) Communication and Events; (vi) Administrative Support; (vii) Execution of Contracts and (viii) Continuous Improvement.

4 Results

The Demand Study of the department object of this case totaled 1027 activities classified as monthly requests of some kind of demand or manifestation by the operational teams of the CGCIVI and CGMAD coordinations, and of the CSC, of which 308 were categorized as their own, and 719 as transversal.

When observing the proportional distribution of demands in the CGCIVI, CGMAD, and CSC coordinates, there are those produced and executed in the area itself, in 58%, 73% and 18% of the total monthly volume, respectively (Fig. 2).

To the extent that the capacity to generate demands and their execution can express the levels of institutional autonomy in the areas, CGMAD perceives a preponderance of activities of its own nature, higher than those observed in CGCIVI, and greater in proportion to those seen in the CSC.

This disparity, apparently, is linked to the historical maturity of CGMAD, compared to the operational processes of CGCIVI and CSC, in addition to the nature of final deliveries, which include Psychosocial Care actions and services, such as psychiatry and psychology outpatient clinics, in the case of first, without the equivalent in the subsequent two, more focused on administrative and conceptual activities.

In addition, the predominant majority of the CSC's demands are still transversal across the department's areas, a consequence of the incipient implantation at the time of the Demand Study.

When classified in relation to the macroprocess categories, 42% to 45% of the demands of the thematic coordinations (CGCIVI and CGMAD) are directed to advisory activities, which comply with administrative routines and accessory legal obligations, with a suggestion of low responsiveness in final activities, focused on people-centered care, health actions and services (Fig. 3).

It is observed, empirically in the approach to the coordinators, that there is inefficiency due to ignorance of roles, functions and operational processes, in general with

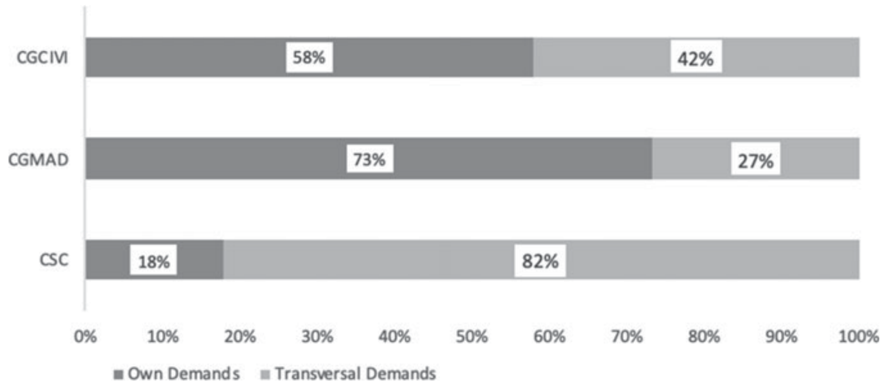


Fig. 2 General demands

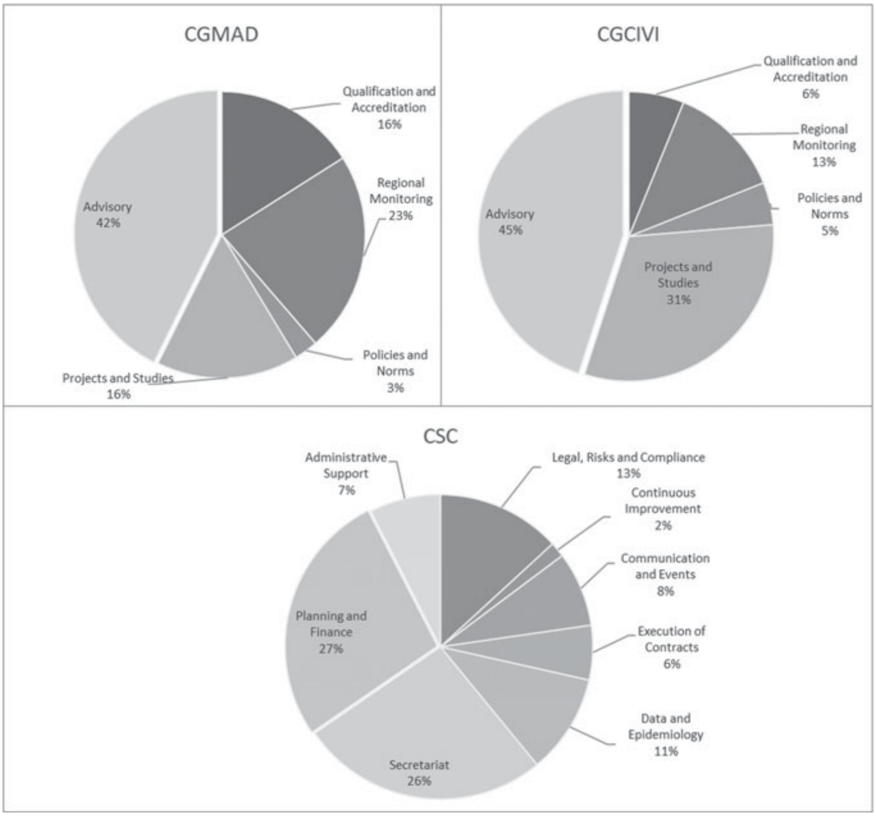


Fig. 3 Demands classified by macroprocess (CGCIVI, CGMAD and CSC)

the demands generated in the CSC pushing the activities to CGCIVI and CGMAD, with a reduction in the focus of finalistic deliveries, that is, public health policies for the population.

This can be identified in the preponderance of advisory actions, to the detriment of policy and norm-building activities, typical of a regulatory body, national manager of the Unified Health System (SUS), or the asymmetry between CGCIVI, which has a high volume of demands in studies and projects, while CGMAD, driven by the actions and services it anchors, has the second largest group of activities in regional monitoring (Fig. 3).

Still, when stratified the specific CSC macroprocesses, a greater volume of demands linked to "Planning and Finance" is identified, due to legal mechanisms and institutional pressure for budget management, to the "Secretariat", standardized as a hub for external requests, and the "Legal, Risks and Compliance" consequence of the need for compliance and attention to the regulatory frameworks (Fig. 3).

After classification of the demands, the operations related to processing those demands were analyzed and wastes identified. These wastes were categorized according to the types of wastes used in the context of the Lean Thinking. The relative importance of the wastes are presented in Fig. 4. As can be observed, 32% were classified as overprocessing, 28% as waiting, overproduction and defects/quality as 14% each, and finally, unused Human capital as 12%. It may be highlighted that the first two types of wastes represent 60% of the department's total wastes (Fig. 4).

Part of the explanation for this panorama stems from the waste due to "Overprocessing". Due to the confusion of operational flows, dual functions, overlap, and rework between the activities of the CSC and the coordinators. It was also identified operations defined internally without connection with actual deliveries, whose thematic agenda overlaps with the specific administrative flows and portfolio of each area.

Regarding the waste of "Waiting", in addition to excess processing, there was an intense fragmentation of activities, low definition of process governance roles, the lack of SLA, too much formalization and documentation of activities, and the destructive and inoperative CSC.

As for "Overproduction", a consequence of an excessively abstract portfolio, with no clarity as to the products and services requested by customers in each area, they lead to a large amount of impressions, documents disconnected from the value-added chain, new orders and disconnected delivery tasks.

The wastes described as "Defects/Quality" are strongly linked to the rework resulting from the wastes previously mentioned, in addition to non-conformities in deliveries as a result of the low standardization of processes, in addition to discrepancies between the products presented and the expectations of internal and external customers.

Finally, the waste classified as "Unused Human Capital" can be attributed to the continuous learning curve resulting from the low definition of functions, lack of a matrix of competencies and continuous qualification of the teams, which has an excessively expanded scope of action.

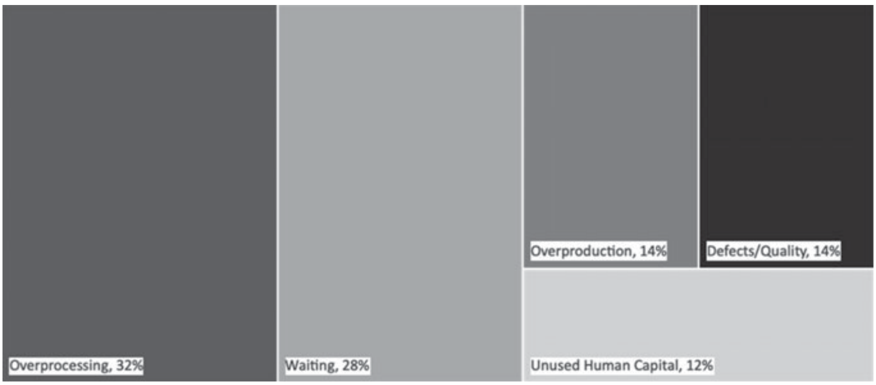


Fig. 4 Demands classified by Lean wastes

In summary, the analysis shows that the department, in terms of its thematic coordinations, has lost focus on core activities and is making more efforts in advisory activities, due to the historical institutional nature, and peculiarities of public management, linked to accessory legal obligations that do not affect other types of organizations.

The experiences presented in this study can be seen in an application of Lean in the Danish public sector [19]. Such similarities present the team's resistance initially and the results of process improvement as evident. An important point, perceived in the two studies, is that regardless of the applied change management technique, these technologies encourage process improvement and must manage resistance among employees.

5 Conclusion

Evidence demonstrates that improvement approaches must exist in public organizations mainly due to the large hierarchical structures present, and in that sense, techniques for improving operations such as Lean must be planned and implemented [20].

This study demonstrated a case about raising demands in public health management department, qualitatively making the method feasible as a basis for a managerial diagnosis. In the specific case of DAPES, the diagnosis pointed out inefficiencies related to the lack of internal flow designs, an unstructured CSC with a large volume of demands, a low focus on core activities related to Life Cycle and Mental Health Policies (core of the department) and waste related to improper processing and natural public service bureaucracies. Such analyzes guide future managerial actions in terms of planning, process mapping, role definitions and CSC consolidation in line with the thematic coordinations (CGCIVI and CGMAD).

The study's findings contribute to the statement made about a decade ago by Motta [21] about the existence of traditional management processes and low modernization in the Brazilian government, requiring a structural, procedural and holistic reform, it is necessary to overcome these challenges for the sustainability of the business. As future research, we suggest a study that correlates the demands and activities of the department with its suppliers and clients, in addition to research related to the mapping of processes and the definition of governance roles in departments of public companies.

Acknowledgements This work was partially supported by FCT—Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

References

1. Jack, E. P., & Powers, T. L.: A review and synthesis of demand management, capacity management and performance in health-care services. International Journal of Management Reviews, 11(2), 149–174 (2009).
2. Klassen, K. J., & Rohleder, T. R.: Demand and capacity management decisions in services. International Journal of Operations & Production Management (2002).
3. Melo, D. D. C., & Alcântara, R. L. C.: A gestão da demanda em cadeias de suprimentos: uma abordagem além da previsão de vendas. Gestão & Produção, 18(4), 809–824 (2011).
4. Womack, J. P., & Jones, D. T.: Lean thinking—banish waste and create wealth in your corporation. Journal of the Operational Research Society, 48(11), 1148–1148 (1997).
5. Silva, C. D. O., Paula, F. C. R. D., Cabral, L. R., & Chaves, L. S.: Planejamento de força de trabalho no governo de Minas Gerais: inovações no levantamento de demanda de pessoal e otimização na provisão de recursos humanos (2012).
6. Walker, R. M., Boyne, G. A., & Brewer, G. A. (Eds.).: Public management and performance: Research directions. Cambridge University Press (2010).
7. Paula, A. P. P. D.: Administração pública brasileira entre o gerencialismo e a gestão social. Revista de administração de empresas, 45(1), 36–49 (2005).
8. Ewan, K. M. S. P. O.: New public management: Current trends and future prospects. Psychology Press (2002).
9. Lane, J. E.: New public management: an introduction. Routledge (2002).
10. Hughes, O. E.: Public management and administration: An introduction. Macmillan International Higher Education (2012).
11. Motta, P. R. D. M.: O estado da arte da gestão pública. Revista de Administração de Empresas, 53(1), 82–90 (2013).
12. Ohno, T.: Toyota production system: beyond large-scale production. CRC Press (1988).
13. D'Andreamatteo, A., Ianni, L., Lega, F., & Sargiacomo, M.: Lean in healthcare: a comprehensive review. Health policy, 119(9), 1197–1209 (2015).
14. Liker, J. K.: The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer McGraw-Hill Education (2004).
15. Spiller, E. S.: Gestão dos serviços em saúde. Editora FGV (2015).
16. Hilletofth, P., Ericsson, D., & Christopher, M.: Demand chain management: a Swedish industrial case study. Industrial Management & Data Systems (2009).
17. Yin, R. K.: Case study research design and methods third edition. Applied social research methods series, 5 (2003).
18. Dubé, L., & Paré, G.: Rigor in information systems positivist case research: current practices, trends, and recommendations. MIS quarterly, 597–636 (2003).
19. Pedersen, E. R. G., & Huniche, M.: Determinants of lean success and failure in the Danish public sector. International Journal of Public Sector Management (2011).
20. Esain, A., Williams, S., & Massey, L.: Combining planned and emergent change in a healthcare lean transformation. Public Money and Management, 28(1), 21–26 (2008).
21. Motta, P. R.: A modernização da administração pública brasileira nos últimos 40 anos. Revista de Administração Pública, 41(SPE), 87–96 (2007).

Simultaneous Data Reconciliation and Parameter Estimation Applied to a Heat Exchange Process

T. C. Rosario, R. A. Kalid, and D. D. Santana

Abstract The reduction of energy consumption in industrial plants requires a good mapping of the quantities involved in the production processes. The validation of measurements made in a plant through data reconciliation, having mass and energy balances as process constraints, is a useful technique to ensure greater credibility to these measurements. More qualified data offers greater confidence to use them in procedures such as estimating process model parameters of an industrial plant. In some cases, it is necessary to reconcile data and estimate parameters simultaneously, for example, when reconciling specific heat data that depends on temperature and are estimated through a model. Thus, this article presents a study of simultaneous data reconciliation and parameter estimation applied to a heat exchange process, comparing two solution methods available in the literature: (i) the decoupled solution and (ii) coupled solution. It was also observed that the quality of experimental data impacts the estimated model parameters. Finally, a residual analysis was performed to evaluate the statistical significance of the results.

Keywords Data reconciliation · Parameter estimation

1 Introduction

The evaluation of energy consumption of a plant depends on process quantities such as flow rates and temperatures. They are measured through instruments that have finite accuracy and are subject to failure, consequently, providing only an estimate of the true value of the observed quantity. Such measurement uncertainties may cause the data not to comply with process constraints, such as mass and energy balances, generating "imbalances" in the system [1].

T. C. Rosario · D. D. Santana
Federal University of Bahia, Salvador, Bahia, Brazil

R. A. Kalid (✉)
Federal University Southern of Bahia, Itabuna, Bahia, Brazil
e-mail: kalid@ufsb.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_25

One way to circumvent such “imbalances” is to use the data reconciliation technique (DR), which aims to adjust the observed data to satisfy the constraints imposed by mass, energy and moment balances [2].

The reconciled data obtained after the application of DR can be used in the parameter estimation technique (PE) of process models [3, 4]. Moreover, in some cases, DR and PE can occur simultaneously (SDRPE), characterizing a class of problems called “error in variables” (EVM) approach, in which the uncertainty present in dependent and independent quantities is considered [2, 5].

It is common to find in the literature works that present the solution of a problem that involves simultaneous data reconciliation and parameter estimation [6–9]. However, many of them do not compare the results obtained with other solution methods. This comparison is important because it can help to decide which method is more appropriate for a class of problems.

Thus, this article presents a comparison between two solution methods (decoupled and coupled) for the simultaneous data reconciliation and parameter estimation on a steady-state model. The case study was applied to a heat exchange process and the calculation routines were developed using Python [10].

2 Literature Review

2.1 Data Reconciliation Problem

The main objective of using the DR technique is to increase the credibility of the data obtained by measurement of process quantities. The importance of this is that the use of unskilled data can lead to problems in the operation of a plant, loss of product specification, financial losses, or high operating costs [11].

The traditional DR problem can be considered as the procedure to optimize experimental estimates so that the adjusted values comply with conservation laws and other constraints [12, 13]. Therefore, considering the following premises: (i) the experiment was well done; (ii) the model is optimal and known; (iii) the process is in steady-state; (iv) the residues are randomly distributed with zero mean; (v) the experimental covariance matrix is known and diagonal; and (vi) the residues are independent and follow a normal distribution. Then, the optimization problem is described by:

$$\min_{x_R} (x_0 - x_R)^T U_{xx}^{-1} (x_0 - x_R), \tag{1}$$

subject to:

$$G(x_R) = 0, \tag{2}$$

where x_0 is the vector of the observed quantities, x_R is the vector of the reconciled quantities, U_{xx} is the covariance matrix of the observed quantities and $G(x_R)$ are the constraints.

The data obtained after the application of the DR can be used in the PE procedure which is described in Sect. 2.2.

2.2 Parameter Estimation Problem

A fundamental problem in many scientific works is to correlate data by building models. For this, it is necessary to define [14]: (i) the structure of the model, and (ii) the parameters of the model. The model structure can be defined based on existing cases in the literature or using statistical tools and the parameters can be obtained by applying parameter estimation techniques.

Estimating parameters consists in changing the parameters, using a model as a reference, until the predictions of the model are as close as possible to the experimental data, respecting the measurement uncertainties [14]. So, it is important, when possible, to apply the DR for experimental data to it to become more consistent with the process.

In order to assess how close to the model predictions are the experimental data, it is necessary to define a metric. One of the most used metrics is the weighted least squares, which allows adding statistical value to the estimation procedure [15].

Thus, consider the Maximum Likelihood method with premises [15]: (i) the experiment was well done; (ii) the model is optimal with parameters unknowns; (iii) the process is in steady-state; (iv) the residues are randomly distributed with zero mean; (v) the experimental covariance matrix is known and diagonal; (vi) the residues are independent and follow a normal distribution; and (viii) negligible measurement uncertainties of independent quantities when compared to the measurement uncertainties of dependent quantities. Then, the optimization problem is described by

$$\min_{\theta} (y_0 - y_m)^T U_{yy}^{-1} (y_0 - y_m), \tag{3}$$

subject to:

$$y_m = g(x_0, \theta), \tag{4}$$

where y_0 is the vector of the observed dependent quantities, y_m is the vector of the values predicted by the model, x_0 is the vector of the observed independent quantities, U_{yy} is the covariance matrix of the dependent quantities and θ is the vector of parameters.

It is important to mention that if the previous premises are fulfilled, then the obtained model and the estimated parameters can be statistically interpreted.

In some cases, it is necessary to reconcile data and estimate parameters at the same time, characterizing the SDRPE problem which is described in Sect. 2.3.

2.3 Simultaneous Data Reconciliation and Parameter Estimation Problem

SDRPE is the process where DR and PE occur simultaneously, so both reconciled quantities and estimated parameters are decision variables of the same optimization problem. In this approach, the eighth premise to obtain Eq. (3) is not applied, because the measurement uncertainties of dependent and independent quantities are relevant to the problem.

One can use a method that provides a coupled resolution of DR and PE, for which the dependent and independent classification for the quantities has only a didactic meaning, or a method where DR and PE are decoupled [5]. Based on this, TJOA and BIEGLER [3] proposed a method using decoupled sequential quadratic programming. WEISS et al. [16] presented a "two-stage" alternative in which PE is resolved in an external loop, while DR is resolved in an internal loop using successive linearization.

It is worth mentioning that in SDRPE problems it is necessary to include all decision variables in the same objective function. Thus, considering the objective functions already discussed above (see Eqs. (1) and (3)), the optimization problem takes the following form:

$$\underset{x_R,\, y_R,\, \theta}{\min}\left[(x_0 - x_R)^T U_{xx}^{-1}(x_0 - x_R) + (y_0 - y_R)^T U_{yy}^{-1}(y_0 - y_R)\right], \tag{5}$$

subject to:

$$G(x_R, y_R, \theta) = 0. \tag{6}$$

3 Methodology

The first step to applying reconciliation is to model the system, in this work the case study involves a simplified heat exchange process, which besides mass and energy balances needed a specific heat capacity model. Then, the optimization problem was defined and five scenarios corresponding to five steady states data set were used. Finally, the results obtained were evaluated. Figure 1 depicts the main steps of the method.

Two methods were used to solve the SRDEP problem: (i) decoupled resolution, and (ii) coupled resolution. On one hand, simultaneous resolution consists in solving

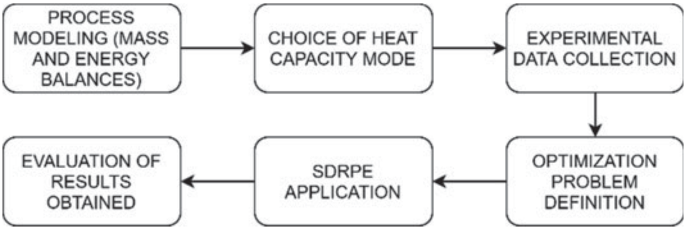


Fig. 1 Steps to apply simultaneous reconciliation in a heat exchange process

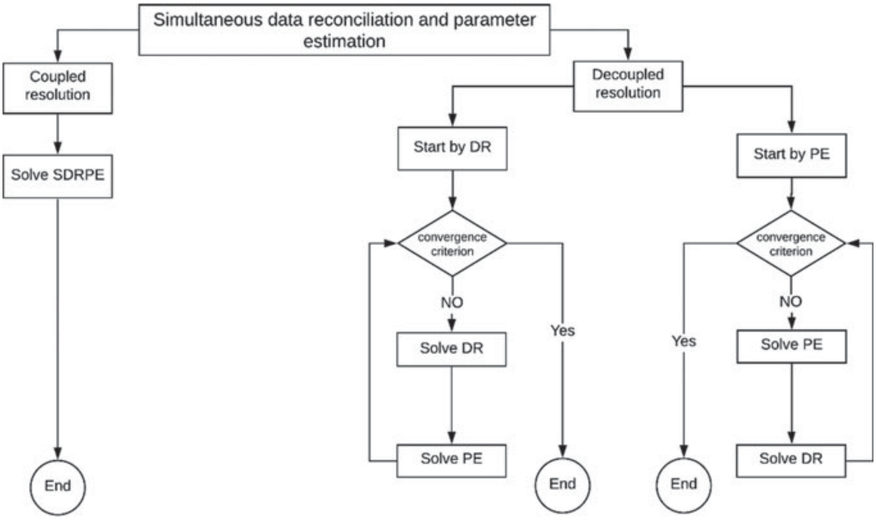


Fig. 2 Diagram for solution methods used to solve the SDRPE problem

the problem with all decision variables in a single objective function, Eqs. (5) and (6). On the other hand, the decoupled resolution consists in an iterative process, in which each problem is separately solved, with DR in an external loop and the EP in an internal loop, or vice versa. Figure 2 shows both solution methods.

3.1 Case Study

The case study assesses a simplified heat exchange process diagram in which water is the only substance involved, which process diagram is presented in Fig. 3. The system consists of six process streams with temperature and flow meters in each. It is considered that the specific heat varies with temperature, so it is obtained through indirect measurement based on model available in [17]. Another observed quantity is the heat provided by the heat exchanger.

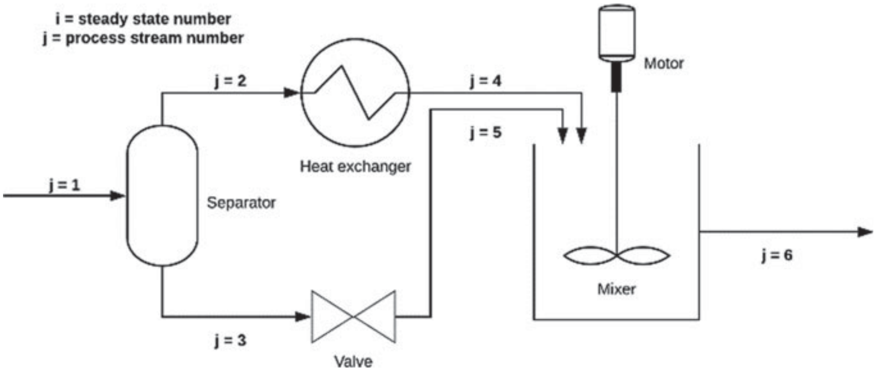


Fig. 3 Heat exchange process diagram (adapted from Narasimhan and Jordache [18])

Table 1 Description of the quantities observed in the process diagram

Quantity	Description
F_{ij}	Observed flow value in scenario *i* at process stream *j*
T_{ij}	Observed temperature value in scenario *i* at process stream *j*
c_{ij}	Observed specific heat value in scenario *i* at process stream *j*
Q_i	Heat provided by heat exchanger in scenario *i*

The observed data set was obtained by trial and error until they were coherent to mass and energy process balances. The uncertainties of temperature, flow, and heat observed were arbitrated. The uncertainties of specific heat were considered equal to 5% of specific heat estimated values. In Table 1 it is possible to see the description of the observed quantities in the process.

The SDRPE optimization problem is described by:

$$\min_{F_R,\, T_R C_R,\, Q_R,\, \theta} \sum_{i=1}^{NC} \left\{ \begin{array}{l} \sum_{j=1}^{NO} \left[\frac{\left(F_{o_{ij}} - F_{R_{ij}}\right)^2}{u^2_{F_{o_{ij}}}} + \frac{\left(T_{o_{ij}} - T_{R_{ij}}\right)^2}{u^2_{T_{o_{ij}}}} + \frac{\left(c_{o_{ij}} - c_{R_{ij}}\right)}{u^2_{c_{o_{ij}}}} \right] \\ \quad + \frac{\left(Q_{o_i} - Q_{R_i}\right)}{u^2_{Q_{o_i}}} + \sum_{k=1}^{NO} \left[\frac{\left(c_{o_{ik}} - c_{R_{ik}}\left(T_{R_i}, \theta\right)\right)^2}{u^2_{c_{o_{ik}}}} \right] \end{array} \right\}, \tag{7}$$

subject to:

$$c_{R_{ij}} = \theta_1 T_{R_{ij}}^{2,5} + \theta_2 T_{R_{ij}}^2 + \theta_3 T_{R_{ij}}^{1,5} + \theta_4 T_{R_{ij}} + \theta_5, \tag{8}$$

$$F_{R_{ij}} = F_{R_{i2}} + F_{R_{i3}}, \tag{9}$$

$$F_{R_{i2}} = F_{R_{i4}}, \tag{10}$$

$$F_{R_{i3}} = F_{R_{i5}}, \tag{11}$$

$$F_{R_{i4}} = F_{R_{i6}} - F_{R_{i5}}, \tag{12}$$

$$T_{R_{i1}} = T_{R_{i2}}, \tag{13}$$

$$c_{R_{i1}} \cdot F_{R_{i1}} \cdot \left(T_{R_{i1}} - T_{ref}\right) = c_{R_{i2}} \cdot F_{R_{i2}} \cdot \left(T_{R_{i2}} - T_{ref}\right) + c_{R_{i3}} \cdot F_{R_{i3}} \cdot \left(T_{R_{i3}} - T_{ref}\right), \tag{14}$$

$$c_{R_{i2}} \cdot F_{R_{i2}} \cdot \left(T_{R_{i2}} - T_{ref}\right) = c_{R_{i4}} \cdot F_{R_{i4}} \cdot \left(T_{R_{i4}} - T_{ref}\right) - Q_{R_i}, \tag{15}$$

$$c_{R_{i3}} \cdot F_{R_{i3}} \cdot \left(T_{R_{i3}} - T_{ref}\right) = c_{R_{i5}} \cdot F_{R_{i5}} \cdot \left(T_{R_{i5}} - T_{ref}\right), \tag{16}$$

$$c_{R_{i4}} \cdot F_{R_{i4}} \cdot \left(T_{R_{i4}} - T_{ref}\right) = c_{R_{i6}} \cdot F_{R_{i6}} \cdot \left(T_{R_{i6}} - T_{ref}\right) - c_{R_{i5}} \cdot F_{R_{i5}} \cdot \left(T_{R_{i5}} - T_{ref}\right), \tag{17}$$

where *NC* is the number of scenarios, *NO* is the number of observations in each scenario, the sub-indices *O* and *R* mean, respectively, observed and reconciled, T_{ref}, is the reference temperature for which thermodynamic data are available in literature, θ_1, θ_2, θ_3, θ_4 and θ_5 are the parameters of the model to be estimated. For this work $T_{ref} = 25$ °C was used.

The calculation procedures were executed using Python with Casadi, Numpy, Pandas, Matplotlib, and Scipy packages [10]. IPOPT was the optimization algorithm, which is based on primal-dual method of the interior point and is indicated for non-linear problems of high dimension [19]. For data organization it was used Excel.

4 Results and Discussion

4.1 Imbalances and Reconciled Data

Table 2 shows that both solution methods are able to satisfy the process constraints, i.e., the imbalances are equal to zero.

Both solution methods presented similar reconciled values, except for the heat specific, as shown in Fig. 4. Concerning the decoupled solution, the results are similar regardless of whether the algorithm of Fig. 2 is initialized by DR or by PE. Table 3 shows the results obtained for scenario 1.

Table 2 Imbalances before and after the SDRPE for the two solution methods considering the standard uncertainty of c_{ij} equal to 5% of its value

Imbalances	Before	After decoupled	After coupled	Unit
Equation (9)	2.9	0.0	0.0	kg/h
Equation (10)	0.2	0.0	0.0	kg/h
Equation (11)	−1.8	0.0	0.0	kg/h
Equation (12)	1.6	0.0	0.0	kg/h
Equation (13)	−2.2	0.0	0.0	°C
Equation (14)	−45.3	0.0	0.0	kJ/h
Equation (15)	0.7	0.0	0.0	kJ/h
Equation (16)	−653.2	0.0	0.0	kJ/h
Equation (17)	477.4	0.0	0.0	kJ/h

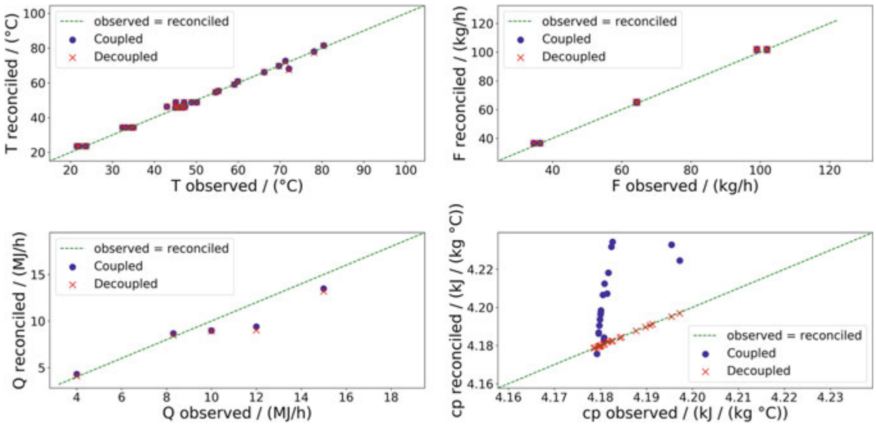


Fig. 4 Dispersion between process observed values and reconciled values obtained by the decoupled and simultaneous solution methods, considering the standard uncertainty of c_{ij} equal to 5% of its value

Thus, the solution method does not significantly impact the results of the reconciled quantities and the imbalances.

4.2 *Estimated Parameters*

The parameters obtained for the model described in Eq. (8) are shown in Table 4.

Table 3 DR results for scenario 1 after applying SDRPE for both solution methods considering the standard uncertainty of c_{ij} equal to 5% of its value

Quantity	Observed	Decoupled reconciled DR → PE	Decoupled reconciled PE → DR	Coupled reconciled	Unit
F_{11}	101.9	101.6	101.6	101.6	kg/h
F_{12}	64.4	65.1	65.1	65.1	kg/h
F_{13}	34.6	36.6	36.6	36.5	kg/h
F_{14}	64.2	65.1	65.1	65.1	kg/h
F_{15}	36.4	36.6	36.6	36.5	kg/h
F_{16}	99	102	102	102	kg/h
T_{11}	45.1	46.3	46.3	46.3	°C
T_{12}	47.3	46.3	46.3	46.3	°C
T_{13}	43.0	46.3	46.3	46.3	°C
T_{14}	78.1	77.3	77.3	77.8	°C
T_{15}	46.4	46.3	46.3	46.3	°C
T_{16}	66.2	66.2	66.2	66.2	°C
c_{11}	4.18	4.18	4.18	4.19	kJ/(kg °C)
c_{12}	4.18	4.18	4.18	4.19	kJ/(kg °C)
c_{13}	4.18	4.18	4.18	4.19	kJ/(kg °C)
c_{14}	4.20	4.19	4.19	4.23	kJ/(kg °C)
c_{15}	4.18	4.18	4.18	4.19	kJ/(kg °C)
c_{16}	4.19	4.19	4.19	4.25	kJ/(kg °C)
Q_1	8.3	8.5	8.5	8.7	MJ/h

Table 4 Estimated parameters for both methods considering the standard uncertainty of c_{ij} equal to 5% of its value

Parameter	Decoupled DR → PE	Decoupled PE → DR	Coupled	Unit
θ_1	1.70×10^{-6}	1.70×10^{-6}	-3.74×10^{-4}	kJ/(kg °C^{3,5})
θ_2	-5.61×10^{-5}	-5.61×10^{-5}	-1.13×10^{-2}	kJ/(kg °C^{3})
θ_3	8.07×10^{-4}	8.07×10^{-4}	1.18×10^{-1}	kJ/(kg °C^{2,5})
θ_4	-4.15×10^{-3}	-4.15×10^{-3}	-4.48×10^{-1}	kJ/(kg °C^{2})
θ_5	4.21×10^{-0}	4.21×10^{-0}	6.49×10^{-0}	kJ/(kg °C)

According to Table 4, the parameters obtained by the decoupled solution are the same regardless of whether the DR or EP is solved first. However, the parameters obtained by the decoupled solution and the coupled solution are different.

It is worth mentioning that in the decoupled solution the uncertainties of T_{ij} are significant only in the DR step because in the PE step they are considered insignificant

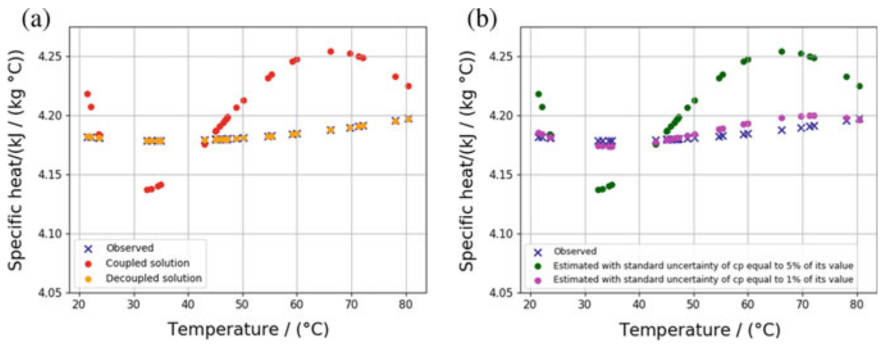


Fig. 5 **a** Comparison of estimated specific heat by experimental temperature for both solution methods, **b** impact of decreasing the temperature uncertainty on the prediction of specific heat by the coupled solution

when compared to the uncertainties of c_{ij}. Thus, as shown in Fig. 5a, the system tends to reach a state in which the estimated specific heat values are compatible with the observed temperatures.

On the other hand, in the coupled solution, the problem is solved through one objective function, thus this solution considers at the same time the uncertainties of the dependent and independent quantities, but, as depicted in Fig. 5a, the estimated specific heat values are not as close to the observed values as in the decoupled solution. So, the temperature uncertainty impacts the performance of the coupled solution.

In fact, if the uncertainty of temperature is decreased, the prediction capability of the specific heat evaluated with the coupled solution improves, as exemplified in Fig. 5b. Then, the quality of data has a greater impact on the simultaneous solution than on the decoupled solution.

Thus, the solution method impacts the parameters obtained and, consequently the model estimates.

4.3 Residuals Analysis

Figure 6a depicts the dispersion residues for the two solution methods after the application of SDRPE. It is possible to see that there are candidate points for gross errors or process outliers. Figure 6b suggests that the residues behavior is different than expected for a normal PDF.

Table 5 presents a statistical test to assess if the residues follow a normal distribution, considering a 95% confidence level. The analysis of p-values suggests that the residues do not behave as a normal distribution, confronting the established premise for developing the objective function.

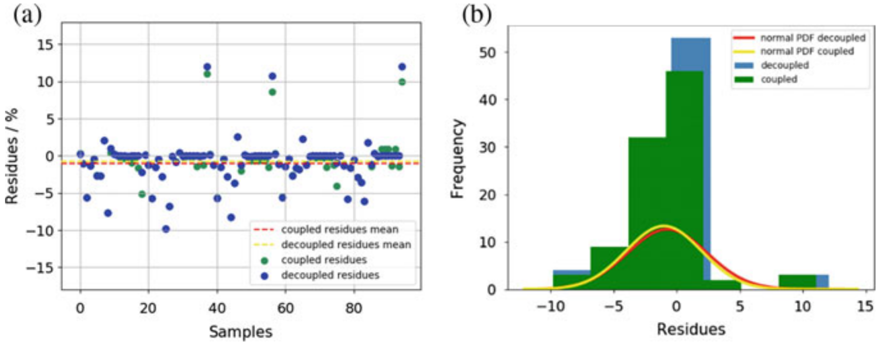


Fig. 6 **a** Relative residue dispersion, *(observed − reconciled)/observed*, for all five evaluated scenarios considering the standard uncertainty of c_{ij} equal to 5% of its value, **b** Histogram for all residues obtained for the five evaluated scenarios considering the standard uncertainty c_{ij} equal to 5% of its value

Table 5 Hypothesis tests for SDRPE residues considering the standard uncertainty of c_{ij} equal to 5% of its value

Statistical test	Null hypothesis	Alternative hypothesis	p-value for decoupled residues	p-value for coupled residues
Lilliefors	Have normal distribution	Don't have normal distribution	2.39×10^{-35}	3.8×10^{-14}

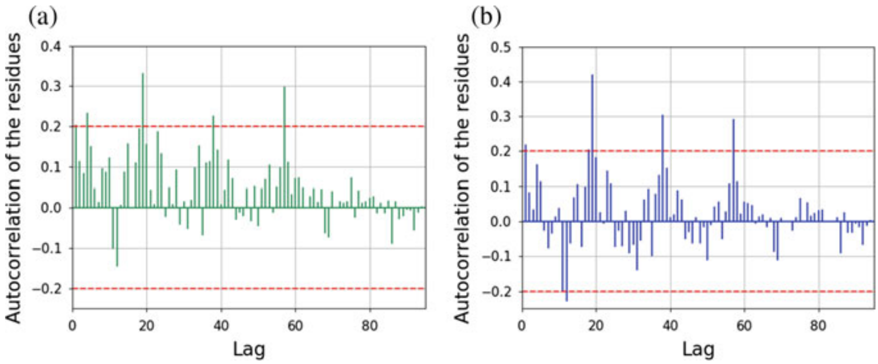


Fig. 7 **a** Autocorrelation of residues obtained after SRDEP with decoupled resolution considering the standard uncertainty of c_{ij} equal to 5% of its value, **b** autocorrelation of residues obtained after SRDEP with coupled resolution considering the standard uncertainty of c_{ij} equal to 5% of its value

Figure 7 shows the autocorrelation of the residues and suggests randomness and low autocorrelation among them. Thus, it can be inferred that the impact of a residue in the others is low.

5 Conclusion

This work investigates the impacts of two methods for simultaneous data reconciliation and parameter estimation. While both methods evaluated similar reconciliated data, satisfying the constraints imposed by the process model, the parameters estimated for each method are different.

In the decoupled solution the parameters allowed a heat capacity prediction closer to observed data, mainly due to uncertainties of the independent quantities not being considered in the parameter estimation step. While, the coupled solution showed greater sensitivity to the quality of the experimental data, and the smaller the uncertainties of the independent quantities the better the prediction. The fact that in the coupled solution all the decision variables are included in the same objective function makes the problem resolution more complex.

For both methods, the residues presented low autocorrelation and did not present normal behavior. However, this information is not sufficient to state the statistical significance of the results.

Comparing both methods, they presented different results for adjusted model parameters and closed results for the reconciled values. It is worth citing that the coupled resolution is more representative than the decoupled solution for the original problem. For future work, a more detailed analysis of the parameters and residues obtained, as well as the assessment of uncertainty after SRDEP are suggested.

References

1. Menezes, D., Sarruf, I., Peixoto, F., Prata, D.: Reconciliação de dados em colunas de destilação utilizando o simulador EMSO. XX Congresso Brasileiro de Engenharia Química. Florianópolis, 2014
2. Valle, E., Kalid, R., Secchi, A., Kiperstok, A.: Collection of benchmark test problems for data reconciliation and gross error detection and identification. Comput. Chem. Eng. v. 111, p. 134–148 (2018)
3. Tjoa, L., Biegler, L.: Reduced Successive Quadratic Programming Strategy for Erros-In-Variables Estimation. Comput. Chem. Eng. 16(6), 523–533 (1992)
4. Câmara, M., Soares, R., Feital, T., Anzai, T., Diehl, F., Thompson, P., Pinto, J.: Numerical Aspects of Data Reconciliation in Industrial Applications. Processes, 5(4), 56 (2017)
5. Romagnoli, J., Sanches, M.: Data Processing and Reconciliation for Chemical Process Operations. Academic Press. 270, 1999. LNCS Homepage, http://www.springer.com/lncs, last accessed 2016/11/21
6. Pages, A., Pingaud, H., Meyer, M., Joulia, X.: A Strategy for Simultaneous Data Reconciliation and Parameter Estimation On Process Flowsheets. Comput. Chem. Eng., 18(S), S223-S227, p. 223–227 (1994)
7. Francken, J., Maquin, D., Ragot, J., Bèle, B.: Simultaneous data reconciliation and parameter estimation. Application to a basic oxygen furnace. IFAC Proceedings Volumes (IFAC – Papers Online), 2 (Part 1) (2009)
8. Raghunathan, A., Pérez-Correa, J., Biegler, L.: Reconciliation and Parameter Estimation in Flux-Balance Analysis. Biotechnology and Bioengineering, 84, 700–709 (2003)

9. Zhang, Z., Chuang, Y., Chen, J.: Pervasive knowledge discovery by just-in-time learning to solve simultaneous data reconciliation and parameter estimation of industrial processes. Industrial and Engineering Chemistry Research. 53, p. 10194–10205 (2014)
10. Rosario, T., Kalid, R., Santana, D.: Python calculation engine to solve simultaneous parameter estimation and data reconciliation problem (2020) https://doi.org/10.5281/zenodo.3866060
11. Morad, K., Young, B., Svrcek, W.: Rectifcation of plant measurements using a statistical framework. Computers & Chemical Engineering, 29(5), pp. 919–940 (2005)
12. Crowe, C.: Data reconciliation – progress and challenges. Journal of Process Control, 6(2), pp. 89–98 (1996)
13. Prata, D., Schwaab, M., Lima, E., Pinto, J.: Simultaneous robust data reconciliation and gross error detection through particle swarm optimization for an industrial polypropylene reactor. Chemical Engineering Science, 65(17), pp. 4943–4954 (2010)
14. Schwaab, M., Pinto, J.: Análise de Dados Experimentais I: Fundamentos da Estatística e Estimação de Parâmetros. Rio de Janeiro: e-papers, p. 462 (2007)
15. Santana, D.: Interpretação da região de abrangência na estimação de parâmetros. 2014. Dissertação (Mestrado em engenharia industrial) – Escola Politécnica, Universidade Federal da Bahia, Salvador
16. Weiss, G., Romagnoli J., Islam, K.: Data reconciliation – An industrial case study. Comput. Chem. Eng. 20, pp. 1441–1449 (1996)
17. Popiel, C., Wojtkowiak, J.: Simple Formulas for Thermophysical Properties of Liquid Water for Heat Transfer Calculations (from 0° C to 150° C). Heat Transfer Engineering 19(3) (1998)
18. Narasimhan, S., Jordache, C. Data Reconciliation & Gross Error Detection. Gulf Publishing Company, p. 14 (2000)
19. Wächter, A.: An Interior Point Algorithm for Large-Scale Nonlinear Optimization with Applications in Process Engineering. 2002. Doctoral thesis, Carnegie Mellon University, Pittsburgh, PA, USA

Analysis of Greenhouse Gases and Atmospheric Pollutants Emissions by Helicopters in the Oil and Gas Industry

Gustavo Valério Mendes, Luiz Antônio Silveira Lopes, Orivalde Soares da Silva Júnior, Flávia Oliveira Perucci, and Filipe Machado Heringer

Abstract This paper seeks to estimate the emission of greenhouse gases (GHG) and air pollutants by a fleet of helicopters that supports offshore exploration and production activities of an oil and gas company in Brazil. GHGs contribute to global warming, while atmospheric pollutants can cause damage to people's health. Considering the lack of studies on the emissions caused by these operations, which are significantly relevant in the Brazilian context of civil aviation, this analysis aims to contribute with more accurate information on these emissions, using Rindlisbacher and International Civil Aviation Organization—ICAO methodologies. In order to understand the representativeness of these emissions, a comparison among the total emissions in the year of 2019 of the two main civil aviation companies and the main oil and gas company in Brazil is presented. Thereafter, it is expected that decision-making regarding helicopter operations can take into account this important environmental and public health aspect.

Keywords Greenhouse gases · Air pollutants · Helicopters · Oil and gas

1 Introduction

The growing concern about global warming has triggered a series of studies from various economic segments around the world. The initiatives, action plans and goals established aim to contribute to the effort of minimizing the negative impacts of this phenomenon associated with an increase in the atmosphere concentration of

G. V. Mendes (✉) · L. A. S. Lopes · O. S. da Silva Júnior
Instituto Militar de Engenharia, Rio de Janeiro, RJ 22290-270, Brazil
e-mail: gustavovmendes@gmail.com

F. O. Perucci
Pontifícia Universidade Católica de Minas Gerais, Belo Horizonte, MG 30535-901, Brazil

F. M. Heringer
Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, RJ 22451-900, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_26

green-house gases (GHG), such as carbon dioxide (CO_2), methane (CH4), nitrogen dioxide (N_2O) and fluorinated gases (HFCs, SF6 and PFCs). CO_2 concentrations, for instance, has risen by 40% since the pre-industrial era and the main source of emissions is represented by fossil fuels combustion [1].

Another relevant subject related to fossil fuels burning is the emission of atmospheric pollutants, such as particulate materials (PM). The suspended particles are capable of absorbing radiation, but the mechanisms and effects concerning climate change have not yet been fully described in the literature [2]. On the other hand, the negative consequences related to human health are already recognized. The main deleterious effects associated with PM inhalation are cancer of the respiratory system, arteriosclerosis, lung inflammation and worsening of asthma symptoms [3]. Other air pollutants that, in high concentrations, can cause respiratory problems are carbon monoxide (CO) and nitrogen oxides (NO_x). Such oxides are responsible for the phenomenon known as photochemical smog.

In recent years, several companies in Brazil have internalized the cost of carbon emissions in order to anticipate to more restrictive regulations in terms of emissions, a trend observed worldwide [4]. An increasing number of countries plan to implement a carbon tax or an emissions trading system (cap and trade) in the coming years. In 2018, there were 51 initiatives implemented or planned. In 2019, the number increased to 57. Brazil fits into the group of countries that are considering the adoption of a pricing mechanism [5].

The aviation segment is responsible for a significant emission of GHG and air pollutants. Air transportation emits substantial amount of gases, such as CO_2, NO_X, SO_X, H_2O and soot [6]. "*If global aviation was a country, it would rank in the top 10 emitters*", since direct emissions from aviation account for about 3% of the EU's total GHG emissions and more than 2% of global emissions [7]. Aviation pollution, including induced cloud cover, accounted in 2005 for up to 4.9% of the total anthropogenic emissions [8]. Around 1,200 deaths per year in North America due to particulate matter inhalation from aviation emissions [9]. Emissions from international civil aviation may represent 22% of global emissions of GHG in 2050 [10]. Concerning helicopter operations, is expected a rise in the environment impacts of civil aviation related to this segment and due to severe conditions, including areas where the air contains salt, sand and dirt in general, the performance of the helicopters engines is affected with a drop in fuel burning efficiency, resulting in higher pollutant emissions [11].

The emissions inventory carried out by the Brazilian aviation authority did not take into account the emissions caused by helicopters. The fleet destined to transport passengers who work in oil and gas maritime units in Brazil is significant, especially in the target company of this study.

Regarding oil and gas industry, 63% of historical CO_2 and methane anthropogenic emissions from 1751 to 2010 are linked to just 90 entities, of which 56 are from this sector [12]. And it is important to remember as early as 1989, just one year after the establishment of the IPCC, a significative number of the largest oil and gas and coal firms came together to launch the Global Climate Coalition (GCC), an advocacy group dedicated to promoting climate skepticism [13]. Fortunately, since 2014, firms have joined initiatives established by international organizations, such as the World Bank's Zero Routing Flaring by 2030 and the UN's Climate and Clean Air Coalition Oil and Gas Methane Partnership. Additionally, they have joined in partnerships with other firms, as in The Oil and Gas Climate Initiative (OGCI), The Energy Transitions Commission and the World Business Council for Sustainable Development's Low Carbon Technology Partnership [14].

Therefore, evaluating the helicopters' emissions of the target company and comparing it to the total emissions of oil and gas industry and with other commercial aviation companies contributes to the literature, to the market and to society in general. Thus, the objective of this paper is to estimate the emission of greenhouse gases (GHG) and air pollutants in 2019 by helicopters that operate offshore flights to an oil and gas company in Brazil, using two methodologies.

This paper is organized as follows. After this introduction, Sect. 2 presents the theoretical framework, Sect. 3 describes the methodological procedures, Sect. 4 details the results and discussion and, finally, Sect. 5 points out the conclusions of this paper.

2 Theoretical Framework

Kyoto Protocol, signed in 1997, aimed to reduce, in a global approach, the emission of gases that contribute to global warming (GHG), in order to promote sustainable development [15]. The protocol did not defined limits on emissions from international aviation, but established, in Article 2, that signatory countries should work through the International Civil Aviation Organization (ICAO). It is a United Nations' entity responsible for the standardization and organization of civil aviation.

The establishment of the Committee on Aircraft Engine Emissions in 1977 by ICAO was one of the precursor initiatives adopted to mitigate global warming in the civil aviation sector. This committee published in 1981 the Volume II (Aircraft Engine Emissions) of the Annex 16 (Standards and Recommended Practices for Environmental Protection) of the International Civil Aviation Convention. This document establishes guidelines to standardize the gas emissions certification by aircraft engines [16].

At its 38th Assembly, held in 2013, ICAO published the Resolution A38-18, which set targets for an annual rise of 2% in the aviation fuel efficiency by 2050. Furthermore, it established that aviation's emissions in any given year post-2020 should be lower than the emissions levels of the baseline year (2020). In order to achieve these goals, ICAO reinforced the request to its member countries to implement action plans aiming to reduce GHG emissions [17].

Brazil, represented by the National Civil Aviation Agency - ANAC and by the Civil Aviation Secretariat, submitted two action plans to ICAO and also elaborated the National Inventory of Atmospheric Emissions from Civil Aviation in 2014. Like in other countries, the direct emissions by helicopter operations were not estimated due to the "unavailability of emission factors for turbine engines typically used in this type of aircraft (turbine shaft)". However, Brazilian authorities pointed out that "the large amount of equipment in the Brazilian fleet should lead to a not insignificant share in the gas emissions and QAv consumption" [18].

In 2016, during the 39th ICAO Assembly, the International Aviation Carbon Reduction and Compensation Scheme (CORSIA) was approved. It consists in a program to reduce and offset the emissions of international aviation. In other words, emissions of the aviation sector are offset by purchasing carbon credits or by investment in projects that reduce GHG emissions in other sectors. There is no cap, but all the emissions have to be compensated [19]. According to ICAO, this is the first market mechanism at a global level with mandatory participation of countries and air-lines companies by 2027, with the exception of some countries, which Brazil is not included [20].

Another CO_2 trade scheme in aviation segment is the EU Emissions Trading Scheme (EU ETS) for aviation, introduced in 2012 in Europe. It is a cap-and-trade system where participating members of the sector have to purchase allowances (emission permits) from other sectors in order to compensate their emissions that exceeds a pre-defined cap. During 2021–2035, the scheme is estimated to offset around 80% of the emissions above 2020 levels [7].

Although nowadays there is not a mandatory CO_2 trade scheme in force in the Brazilian's aviation sector, ANAC published resolution to regulate the monitoring, reporting and verifying of CO_2 emission's data used in international air transport [21]. Subsequently, the agency published the procedures for monitoring and providing CO_2 emissions data by public air operators related to international air transport [22].

Though GHG monitoring and reporting are restricted to international commercial aviation, there is a growing concern about measuring and controlling air transportation emissions in a regional and sectorial scale. Moreover, there is a gap in measurement and analysis of some segments of aviation, such as the helicopters commonly used in offshore transport by oil and gas industry.

Regarding national air pollution legislation, CONAMA [23] establishes the air quality standards and its correspondent limits of emissions. It follows the recommendations proposed by the World Health Organization (WHO). An air emission control plan must be elaborated to guarantee the operation of projects with potential air polluting. The pollutants associated with fuel combustion included are: SO_2, NO_2, CO and particulate matter [24].

3 Methodological Procedures

IPPC [25] recommends two methods to estimate the emissions from use of fuels. Top-down approach considers the GHG emissions of fuels without differentiating how and where they are used. On the other hand, bottom-up approach takes into account the consumption characteristics of each sector, considering energy purposes. Three different tiers can be used in the bottom-up method: Tier 1 is based on standard average emission factors; Tier 2 rely on local specific emission factors; and Tier 3 is based on direct emissions measurements [26].

The methodology choice will depend on the quality of existing local primary data. IPCC encourages specialists to develop local emission factors to be used in GHG inventory, aiming at improving the quality of information [25]. This paper is based in literature data once the target company couldn't afford the measurement of direct emissions in the field.

Helicopter's emissions are not easily accessible, since the data on emissions by turbine engines are not available in public domain and there is no recognized approach of how to estimate helicopter's emissions [27]. However, two methodologies were identified, one proposed by Rindlisbacher [28] and another by ICAO [20]. The first methodology takeover Tier 3, while the second one considers Tier 2. When combined, the methodologies are capable of providing and estimated GHG emissions and atmospheric pollutants for the case studied proposed in this paper.

3.1 Rindlisbacher Methodology

The first methodology adopted was the one described by Rindlisbacher in the second edition of the document Guidance on the Determination of Helicopter Emissions, defined by FOCA. This government agency from Switzerland developed the HELEN program, which had as one of its goals improving the estimation of emissions by helicopters in national inventories. The results of this methodology came from direct measurements observed in the Ruag Aerospace laboratory, in Stans, Switzerland.

This method was adopted by Dutch government to estimate the emission of pollutants by helicopters and this data is reported annually in its national inventory [29]. Rindlisbacher [28] informs that the current version of the Swiss methodology incorporated some improvements proposed by ICAO and included in its database new models of helicopters and calculation of emissions of non-volatile particulate matter, which can be understood as soot.

According to Rindlisbacher [28], it is possible to calculate emissions from information on the number of LTO—Landing and Take-off cycle, that is, landing and take-off cycle, and also from the number of hours flown. The first one is recommended for calculating emissions at airports and helipads and the second one is suggested as a complement to the first, especially for calculating emissions during the cruise flight. The number of LTO is understood as the number of movements divided by two.

3.2 ICAO Methodology

The second methodology adopted was an adaptation of the proposal presented in Annex 16, Volume IV, Carbon Offsetting and Reduction Scheme for International

Aviation (CORSIA), proposed by ICAO in the document called International Standards and Recommended Practices. According to this annex, the formula used to calculate CO_2 emissions is as shown in the Eq. (1).

$$CO_2 = \sum_f M_f * FCF_f \tag{1}$$

where,

CO_2 = total CO_2 emissions, expressed in tons;

M_f = fuel mass "f" used, expressed in tons;

FCF_f = fuel emission factor "f", equal to 3.16 (kg of CO_2/kg of fuel) for fuel of type QAv, Jet-A or equivalent.

ICAO suggests some methods for estimating M_f. However, the adaptation made in this methodology, for this case study, was the use of the fuel consumption values, according to Table 2, referring to the methodology of Rindlisbacher [28]. Thus, for each aircraft model, the sum of the fuel consumption per cycle was multiplied by the number of cycles with the fuel consumption per hour of flight multiplied by the number of hours flown to obtain the adapted M_f value (M_{fa}), according to Eq. (2).

$$M_{fa} = \text{Cons.QAV}_{\text{LTO}} * \text{No.of LTO} + \text{Cons.QAV}_{\text{Hour}} * \text{No. Flight hours} \tag{2}$$

The emission factor $FCF_f = 3.16$ for the QAv Jet A1 fuel was also adopted by Climate Action Reserve, an organization created in 2001 by the California government in the United States, committed to solving climate change through accounting and emission reduction [30].

4 Results and Discussion

The helicopter is the modal most used for carry on people to marine units and is the most efficient means of transport in terms of speed and safety [31]. Nevertheless, to the best of our knowledge there are no published studies that address the estimation of offshore helicopters GHG emissions. The two methodologies, proposed by Rindlisbacher [28] and by ICAO [20], were applied to assess the emissions of a big oil and gas Brazilian company's helicopter fleet. This firm provided the data related to flight hours and Landing and Take-off (LTO) quantities, per aircraft model in 2019. In this case, there are fifty-one helicopters of six different models, with operations carried out in 10 aerodromes serving more than 120 marine units. Regarding to environmental awareness, the highlight is the bidding bonus offered by this company to contracted airlines that provide certified greenhouse inventories, among other excellence criterias, since February 2019.

Tables 1 and 2 presents a summary of the reference values for the emissions for LTO and flight hour of each helicopter model used by the studied company.

In the studied company, the pendulum flight strategy is mainly adopted, that is, flights that departs from an aerodrome towards a single maritime unit and return to the airport. The figures for this company's annual operation can be seen in Table 3.

Considering the parameters presented in Tables 2 and 3 and the number of flight hours and LTO recorded in the operations of this company, presented in Table 4, it is possible to calculate the estimated amount of fuel consumed and the consequent LTO emissions and flight hour emissions, as shown in Tables 4 and 5.

Although the pollutant emission is higher during one hour of flight, the emission during one Landing and Take-off cycle (LTO), with an approximate duration of few seconds, is very significative. In both situations, NOx and CO accounted for the majority of emissions of all the aircraft models.

Analyzing the sum of the values for the six models and the two flight stages, it is possible to observe the total amount of pollutant emissions, as shown in Table 6.

Table 1 LTO emission index by aircraft type

Aircraft	Fuel (kg)	NOx (g)	HC (g)	CO (g)	PM non volatile (g)	PM number
EC35	41.2	206.9	769.1	999.6	7	3.072E + 16
EC55	51.2	329.9	603.6	774.4	10.2	3.416E + 16
S76C+	48.4	292	640.3	822.2	9.2	3.322E + 16
S76C++	50	310.7	624.2	800.7	9.7	3.368E + 16
A139	55	312.8	250.1	689.6	12.7	4.688E + 16
S92	98.8	1066.2	419.1	524.5	28.9	5.506E + 16

Adapted from Rindlisbacher [28]

Table 2 Flight hour emission index by aircraft type

Aircraft	Fuel (kg)	NOx (g)	HC (g)	CO (g)	PM non volatile (g)	PM number
EC35	259.3	1.66	1.49	1.84	51	1.50E + 18
EC55	337.4	2.73	1.26	1.55	79	1.44E + 18
S76C+	313.4	2.38	1.3	1.6	70	1.02E + 18
S76C++	324.5	2.56	1.28	1.56	74	1.08E + 18
A139	360	2.56	0.26	1.98	112	3.68E + 18
S92	735.1	10.59	0.91	1.1	271	3.97E + 18

Adapted from Rindlisbacher [28]

Table 3 Operational data

Aircraft type	Total flight hours	Total LTO
EC35	487	1541
EC55	277	306
S76C+	4326	6994
S76C++	8902	15439
A139	28957	35708
S92	24833	32195

Table 4 LTO emissions by aircraft type

Aircraft	Fuel (t)	NOx (t)	HC (t)	CO (t)	PM non volatile (t)	PM number
EC35	63.49	0.32	1.19	1.54	0.01	4.73E + 19
EC55	15.67	0.10	0.18	0.24	0.00	1.05E + 19
S76C+	338.51	2.04	4.48	5.75	0.06	2.32E + 20
S76C++	771.95	4.80	9.64	12.36	0.15	5.20E + 20
A139	1963.94	11.17	8.93	24.62	0.45	1.67E + 21
S92	3180.87	34.33	13.49	16.89	0.93	1.77E + 21

Table 5 Flight hour emissions by aircraft type

Aircraft	Fuel (t)	NOx (t)	HC (t)	CO (t)	PM non volatile (t)	PM number
EC35	126.28	0.81	0.73	0.90	0.02	7.31E + 20
EC55	93.46	0.76	0.35	0.43	0.02	3.99E + 20
S76C+	1355.77	10.30	5.62	6.92	0.30	4.41E + 21
S76C++	2888.70	22.79	11.39	13.89	0.66	9.61E + 21
A139	10424.52	74.13	7.53	57.33	3.24	1.07E + 23
S92	18254.74	262.98	22.60	27.32	6.73	9.86E + 22

Table 6 Pollutant total emissions

Fuel (t)	Nox (t)	HC (t)	CO (t)	PM non volatile (t)	PM number
39477.9	424.5	86.1	168.2	12.6	2.25E + 23

Considering the consumption of 39,477.9t of QAv in 2019 by the helicopter fleet of the oil and gas industry evaluated in this case study, the air pollutant most emitted was NOx.

According to the adaptation of the methodology proposed by ICAO [20], the total amount of CO_2 emitted by this operation would be 124,750.13 tons, as shown in Table 7.

Table 7 CO_2 emissions

Aicraft type	Mf (t)	FCFf	CO_2 (t)
EC35	189.77	3.16	599.67
EC55	109.13	3.16	344.85
S76C+	1694.28	3.16	5353.92
S76C++	3660.65	3.16	11567.65
A139	12388.46	3.16	39147.53
S92	21435.60	3.16	67736.50
Total	39477.89	3.16	124750.13

Considering that CO_2 emissions may represent a new cost to be taken into account in the company's decision make regarding future policies to reduce GHG emissions, the annual amount to offset emissions would correspond to 3,099,919 euros. This amount was estimated based on the average price per ton of carbon adopted in the financial market between January and December 2019 (24.85 EUR/t) [32].

Figure 1 shows that the fuel consumption (third column) and the emissions of each model (fourth to eighth columns) are not directly proportional to the number of hours flown (first column) or LTO cycles (second column). However, the CO_2 emitted is proportional to fuel consumption, as expected. The S92 model has the highest proportional emission of Nox and PM non volatile. The A139 model is exceeded by the quantities of CO and PM number. The smaller power and size aircraft models,

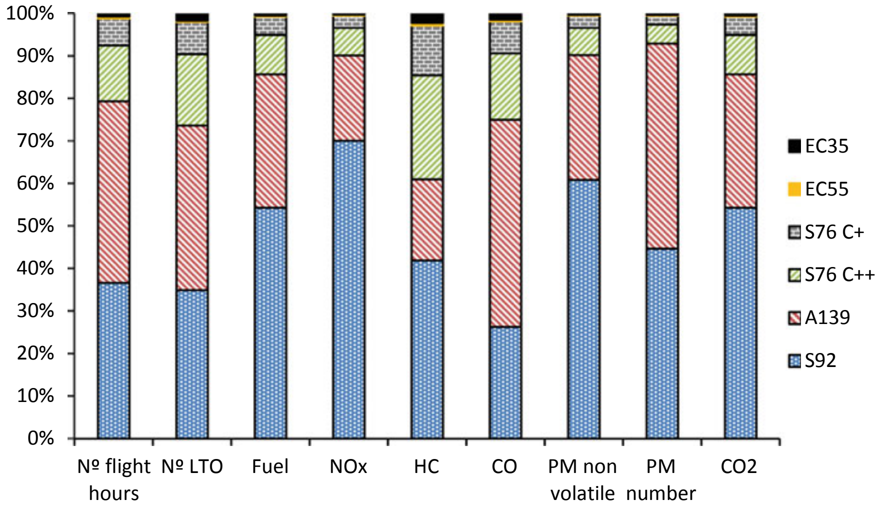


Fig. 1 Emissions distribution

Table 8 Comparison of offshore helicopters and oil and gas company emissions

Scope	CO_2 (t)	NOx (t)
Offshore Helicopters operations (H)	124,750	424.5
All other operations (O)	57,900,000	240,000
H/O	0,22%	0,18%

Table 9 Comparison of offshore helicopters and Brazilian airlines

Operation	CO_2 (t)	Helicopters proportion (%)
Offshore Helicopters	124,750	
LATAM Brasil	5,511,845	2.23
GOL	3,362,743	3.61

S76 C ++, S76 C +, EC55 and EC35, draw attention to HC emissions. Thus, because the glut of PM, it is not recommended to operate S92 and A139 models at aerodromes close to urban centers.

Considering the relevance of the oil and gas industry for global warming, the CO_2 and NOx emissions of the helicopters targeted in this study were compared with the total emissions by the largest oil and gas company in Brazil in 2018 (most recent data available) [33], as described in Table 8.

Likewise, in view of the importance of aviation for pollutants and GHG emissions, a comparison was made for CO_2, scope 1, of the whole year 2018 (most recent data available of two largest airlines companies in Brazil, in number of passengers, Latam [34] and Gol [35], according to Table 9.

It is possible to observe that the contribution of the offshore helicopters targeted in this study is small compared to these two industries, at least in Brazil. However, it must be remembered that they are highly polluting sectors as already demonstrated. Thus, in the face of the global climate emergency, every measurement effort and incentives for offset must be taken into account.

5 Conclusions

Since oil and gas companies have different ownership structures and energy portfolios and face different regulatory and social pressures, it can be expected that their roles will vary in the area of climate change governance [36]. Despite that, the engagement of the oil and gas sector in climate governance heralds the injection of vast and sorely needed resources whether financial, technological or political into efforts to stem climate change [37]. It is necessary to take advantage of the opportunity that this industry is providing to raise awareness among all those involved and stimulate compensation initiatives for all productive segments, in proportion to their responsibility for global warming.

This paper sought in the literature the most appropriate way to quantify greenhouse gases and air pollutants emissions by helicopters in operations of the oil and gas industry when field research data is not available. Albeit the proportion of helicopter emissions are insignificant compared to the oil and gas industry, it is part of a whole responsibility that also need a response. The results obtained provide more precise values for the offshore air transport of the studied company, whose operations are significant in the global context. With that, it becomes possible to recommend better options for fleet allocation related to helicopter models in each base, make comparisons with other transport modals and helicopter models, analyze the evolution of emissions over the years and propose actions to mitigate these emissions. Withal, in relation to helicopter manufactures and their engines, this study propose efforts in the development of less emitting equipment, considering all gases and pollutants analyzed and its potential to cause disease and intensify the global warming.

References

1. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2015.
2. Roorda, N. (2012). Fundamentals of Sustainable Development. London: Routledge.
3. MINISTÉRIO DO MEIO AMBIENTE (MMA) – Ministry of the Environment. Atmospheric Pollutants, https://www.mma.gov.br/cidades-sustentaveis/qualidade-do-ar/poluentes-atmosféricos.html, last accessed 2020/02/10.
4. CONSELHO EMPRESARIAL BRASILEIRO PARA O DESENVOLVIMENTO SUSTENTÁVEL (CEBEDS) - Brazilian Business Council for Sustainable Development. Guia de precificação de carbono, https://cebds.org/publicacoes/guia-de-precificacao-de-carbono/#.XkAFFEBFxjo, last accessed 2020/01/25.
5. WORLD BANK GROUP. State and trends of carbon pricing (2019), http://documents.worldbank.org/curated/en/191801559846379845/pdf/State-and-Trends-of-Carbon-Pricing-2019.pdf, last accessed 2020/02/10.
6. Sausen, R., Isaksen, I., Grewe, V., Hauglustaine, D., Lee, D. S., Myhre, G. & Zerefos, C. Aviation radiative forcing in 2000: An update on IPCC (1999). Meteorologische Zeitschrift, 14(4), 555–561 (2005).
7. EUROPEAN COMISSION (EC). Reducing emissions from aviation (2020), https://ec.europa.eu/clima/policies/transport/aviation_en, last accessed 2020/02/10.
8. Lee, D. S., Fahey, D. W., Forster, P. M., Newton, P. J., Wit, R. C., Lim, L. L., … & Sausen, R. (2009). Aviation and global climate change in the 21st century. Atmospheric Environment, 43(22–23), 3520-3537.
9. Caiazzo, F., Ashok, A., Waitz, I. A., Yim, S. H., & Barrett, S. R. (2013). Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. Atmospheric Environment, 79, 198–208.
10. INSTITUTO DE CONSERVAÇÃO E DESENVOLVIMENTO SUSTENTÁVEL DA AMAZÔNIA – IDESAM. CORSIA/ICAO. Desafios e oportunidades para o Brasil. (2018), https://idesam.org/publicacao/corsia-oportunidades-para-o-brasil-v2.pdf, last accessd 2019/11/30.

11. Ortiz-Carretero, J., Castillo Pardo, A., Pachidis, V., & Goulos, I. (2017, June). Assessment of the effect of environmental conditions on rotorcraft pollutant emissions at mission level. In ASME Turbo Expo 2017: Turbomachinery Technical Conference and Exposition. American Society of Mechanical Engineers Digital Collection.
12. Heede, R. (2014). Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854–2010. Climatic Change, 122(1–2), 229-241.
13. Revkin, A. C. (2009). Industry ignored its scientists on climate. New York Times, 23.
14. Bach, M. S. (2017). Is the oil and gas industry serious about climate action?. Environment: Science and Policy for Sustainable Development, 59(2), 4–15.
15. UNITED NATIONS (UN). 1998. Kyoto protocol to the United Nations framework convention on climate change.
16. INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO). Standards and recommended practices for environmental protection of the International Civil Aviation Convention. Volume II - Annex 16 - Aircraft engine emissions. (1981).
17. INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO). Assembly Resolutions in Force, https://www.icao.int/Meetings/GLADs-2015/Documents/A38-18.pdf, last accessed 2019/11/30.
18. AGÊNCIA NACIONAL DE AVIAÇÃO CIVIL (ANAC). Inventário nacional de emissões atmosféricas da aviação civil 2014: ano base 2013, http://www.anac.gov.br/publicacoes/inventario_nacional_de_emissoes_atmosfericas_da_aviacao_civil.pdf, last accessed 2019/11/30.
19. INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO). What is CORSIA and how does it work? (2020), https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ2.aspx, last accessed 2020/05/03.
20. INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO). First edition to the International Standards and Recommended Practices. Environmental Protection. Annex 16 to the Convention of International Civil Aviation. Volume IV Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). 2018.
21. AGÊNCIA NACIONAL DE AVIAÇÃO CIVIL (ANAC). Resolução nº 496, de 28 de novembro de 2018. Regulamenta o monitoramento, o reporte e a verificação de dados de emissão de CO_2 relativos ao transporte aéreo internacional, https://www.anac.gov.br/participacao-social/audiencias-e-consultaspublicas/audiencias/2018/aud22/ra2018-0496.pdf, last accessed 2019/11/30.
22. AGÊNCIA NACIONAL DE AVIAÇÃO CIVIL (ANAC). Portaria nº 4.005/ASINT, de 26 de dezembro de 2018. Estabelece os procedimentos para monitoramento e fornecimento dos dados de emissão de CO_2 pelos operadores aéreos nacionais relativos ao transporte aéreo internacional, https://www.anac.gov.br/assuntos/legislacao/legislacao-1/portarias/2018/portaria-no-4005-asint-26-12-2018/@@display-file/arquivo_norma/PA2018-4005%20-%20Compilado%20at%C3%A9%20PA2019-1018.pdf, last accessed 2019/11/30.
23. CONSELHO NACIONAL DO MEIO AMBIENTE (CONAMA). Resolution number 491/2018.
24. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). Climate Change 2001: Mitigation. 2006, https://archive.ipcc.ch/ipccreports/tar/vol4/index.php?idp=197, last accessed 2019/11/30.
25. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. 2000, https://www.ipcc-nggip.iges.or.jp/public/gp/gpg-bgp.html, last accessed 2019/11/30.
26. INSTITUTO EKOS BRASIL & GEOLOCK CONSULTORIA E ENGENHARIA AMBIENTAL. Activity 5-C: Sustainable Transport and Air Quality Program (STAQ). 2012, https://www.prefeitura.sp.gov.br/cidade/secretarias/upload/meio_ambiente/INVEMI_P5.pdf, last accessed 2019/11/30.
27. Linares, C., Lawson, C. P., & Smith, H. (2013). Multidisciplinary optimisation framework for minimum rotorcraft fuel and air pollutants at mission level. The Aeronautical Journal, 117(1193), 749–767.
28. Rindlisbacher, T. (2009). Guidance on the determination of helicopter emissions. Federal office of civial aviation FOCA.

29. Klein, J., & Geilenkirchen, G. (2012). Methods for calculating the emissions of transport in the Netherlands. Task Force on Transportation of the Dutch Pollutant Release and Transfer Register.
30. Davis, G. (2002). California Climate Action Registry: General Reporting Protocol.
31. Hermeto, N. D. S. S., Ferreira Filho, V. J. M., & Bahiense, L. (2014). Logistics network planning for offshore air transport of oil rig crews. Computers & Industrial Engineering, 75, 41–54.
32. INVESTING. Crédito de Carbono Futuros Preços. 2019, https://br.investing.com/commodities/carbon-emissions, last accessed 2019/11/30.
33. PETROLEO BRASILEIRO S.A. (Petrobras). Relatório de Sustentabilidade 2018, https://mz-filemanager.s3.amazonaws.com/25fdf098-34f5-4608-b7fa-17d60b2de47d/relatorios-anuais central-de-downloadskit-do-investidor/60ba8f4ec6b0a8b8c0a2419281f5fc5fbdf1822c38a80 0a6ee4ae78e70bd0313/sustentabilidade_2018.pdf, last accessed 2019/11/30.
34. FUNDAÇÃO GETÚLIO VARGAS (FGV). Registro Público de Emissões – Programa Brasileiro GHG Protocol. 2018, https://rpe-gvces.s3.amazonaws.com/tmp/cache/pdf/626355c4/latam-airlines-brasil.pdf, last accessed 2020/03/10.
35. FUNDAÇÃO GETÚLIO VARGAS (FGV). Registro Público de Emissões – Programa Brasileiro GHG Protocol. 2018, https://rpe-gvces.s3.amazonaws.com/tmp/cache/pdf/82098696/gol-linhas-aereas-sa-grupo-gol.pdf, last accessed 2020/03/10.
36. Nasiritousi, N. (2017). Fossil fuel emitters and climate change: unpacking the governance activities of large oil and gas companies. Environmental Politics, 26(4), 621–647.
37. Bach, M. (2019). The oil and gas sector: from climate laggard to climate leader? Environmental Politics, 28(1), 87–103.

Study of the Use of Data Mining in Modeling Non-standard Processes in a Higher Education Institution

Diogo Rocha Ferreira Maia, Renato de Campos, and José de Souza Rodrigues

Abstract Business process management (BPM) is an administration discipline to design, improve and manage processes, and consists of several phases. One of them is the modeling of the current process (as is), during which the process is mapped as it is. One tool that can be used in the process discovery and modeling phase is data mining in information systems. Data mining techniques allow a series of applications in organizations, either as a verification process or as a discovery process. The purpose of this article is to analyze the use of data mining in the modeling stage of complex and not well structured processes when applying BPM to improve processes at a Federal Institute of Higher Education in Brazil. Due to the fact that the nature of the products and services requested in the institute's system is very varied, the processes are not standardized, and the use of the information system is not done in a disciplined way, data mining was not enough to identify the complete processes and the flow of activities in detail. Although it was not enough, data mining facilitated the definition of instance flows and made it possible to detect critical points in the process, such as points with a long duration of time. With data mining, the analysis time, meetings and modeling effort of the analysts and users were reduced.

Keywords Business process management · BPM · Data mining · Non-standard processes · Higher education

1 Introduction

Organizations that operate in the current complex and turbulent environment need to implement changes in their structures and processes. Therefore, new management approaches are necessary to allow organizations to grow and increase their competitiveness [1–3].

D. R. F. Maia (✉)
Federal Institute of Education of Roraima, Boa Vista, RR, Brazil
e-mail: diogo.maia@ifrr.edu.br

R. de Campos · J. de Souza Rodrigues
São Paulo State University, Bauru, SP, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_27

Being part of the management task, it is necessary to describe the structure and implementation of business processes to continually improve them. Business Process Management (BPM) is an approach capable of supporting both the description and the improvement of processes. Both can be performed incrementally or radically [4].

BPM consists of several phases. One of them is the modeling of the current process (as is), during which the process is mapped as it is. Then the process is analyzed and improved, to design the future process (to be) [5].

One tool that can be used in the process discovery and modeling phase is data mining in information systems. Data mining techniques allow a series of applications in public administration or private companies, either as a verification process or as a discovery process [6].

The purpose of this article is to analyze the use of data mining in the modeling stage of complex and not well structured processes, specifically applying BPM to improve processes at a Federal Institute of Higher Education in Brazil.

2 Theoretical Reference

The way the processes are designed and carried out affects both the quality of the service and the efficiency with which the service is delivered. An organization can outperform another that offers similar services if it has better processes and performance. This holds true not only in customer-facing processes, but also in internal processes [7].

In the last decades, there has been a growing interest in BPM due to its ability to help organizations increase productivity by achieving operational excellence and reducing costs [8].

Research in this field originated in computer science, administration and information systems, and has resulted in a multitude of models, methods and tools that support the design, approval, management and analysis of business processes [8]. For Aalst, La Rosa and Santoro [9], "BPM is the discipline that combines approaches to the design, execution, control, measurement and optimization of business processes".

BPM life cycles are steps and activities that must be followed to conduct BPM projects. Theoretical and empirical studies show differences in the number of steps and activities that must be carried out to promote BPM [10].

The BPM discipline can be seen as a continuous cycle that involves a series of phases, such as process identification; process modeling; process analysis; process redesign; process implementation; and process monitoring and control [7].

Business process modeling emerged from the need to explain and communicate business processes in an organization, making them easier for business users to understand. These users range from business analysts, who design the initial drafts of the processes, to the technical developers responsible for implementing them, and even the business team that implement and monitor such processes [11].

According to Aalst [12], creating models is a difficult and error-prone task. He cites some typical modeling errors, such as: the model describes only one version of reality; the model is unable to adequately capture human behavior; and the model is at the wrong level of abstraction.

The practice of process modeling emerged as a key instrument to allow decision making in the context of the analysis and design of information systems with process recognition [13].

Process mining aims to build a process model using an event log and a process discovery algorithm; such a technique has been applied for the discovery, modeling and improvement of processes [14].

Tiwari et al. [15] explain that among the main drivers of increased business process mining is the need for companies to learn more about how their processes operate.

The goal of process mining is to leverage event data to understand how an organization works. With process mining, it is possible to discover the sequence of tasks that are performed in a given business process as well as the interactions that occur between the participants in that process [16].

Business process mining can be used as a tool to discover how people drive processes in the real world. Dustdar, Hoffmann and Aalst [17] distinguish three different perspectives in the mining of business processes:

- Process perspective: focuses on the ordering of activities (the process control flow). The goal is to find an acceptable representation of all possible paths within the process. These paths can be expressed in terms of a process model (for example, Petri net or event-oriented process chain);
- Organizational perspective: focuses on originators within a process, that is, the people and roles that are involved and how they are related. This approach can be used to portray the roles and relationships between individuals in a process in terms of a social network;
- Case perspective: takes into account the properties of the cases, that is, attributes that can differentiate one path through one process (case) from another.

Ferreira [16] explains that the event log can be the real log of an information system or it can be a log file created from historical data recorded in a database, for example. Whatever the source, the data in an event log must have a specific structure and must contain at least the following information:

- a case id, which identifies the instance of the process;
- a task name, which identifies the activity that was performed;
- a user name, which identifies the participant who performed the task;
- a timestamp, indicating the date and time the task was completed.

Process mining starts from event data and uses process models in several ways. For example, process models can be discovered from event data records, as well as serving as reference models, or used to design bottlenecks. In order to treat the information contained in an event's logs it is necessary to develop algorithms. The process mining algorithms for the discovery of processes transform the information from the event's logs into process models [12].

3 Research Method

This research is classified as exploratory and qualitative, and was developed as a case study in a Federal Institute of Higher Education in Brazil. The process analyzed was the Acquisition of Goods and Services. It was considered a critical process because it is extensive and complex and still involves several sectors of the organization. The process uses an information system, but it is not well structured and has a low level of standardization. This complexity is mainly due to the different types of products and services that are requested by the users of the organization.

The research consists of four stages, the first being a literature review, in order to theoretically support the research. The sources of consultation used were Emerald Insight, Scopus, Web of Science, Springer, Google and books, in addition to documentary sources, from which information was obtained from the organization.

The second stage started with the collection of data through the mining of processes in the institute's information system, describing the process of the acquisition of goods and services, which are the related activities and who are the actors involved in the process. The data were extracted in order to create an event log and refer to the sequence of the flow and processing of the goods and services acquisition processes in the period from 2014 to 2017. The data served as a basis for the development of the "as is".

In the third stage, in order to complement the information obtained with data mining and provide more quality in the modeling of the process (as is), it was necessary to hold working meetings with the objective of obtaining more details of the activities and answering questions regarding the results of the mining.

Afterwards, the analysis of the results and the conclusions of the research were carried out.

4 Development and Results

For the modeling of the processes and activity flow of the Goods and Services Acquisition process, SQL language was used to extract data from the institute's information system and to create the event log. The SQL code can be seen in Fig. 1.

After executing the SQL code, the event log generated 138 instances of the process of goods and services acquisition, and more than 3,900 procedures for the acquisition of goods and services processes were found. To facilitate the reading and demonstration of the event log result in the survey, two instances of the goods and services acquisition process were selected. An example of the event log result is described in Table 1.

Each of these participants plays a role in this process by carrying out some of the activities identified. However, when performing these activities, these agents interact with each other in a way that is not fully recorded by the system. Figure 2 shows the flow between the agents in each process activity.

```sql
SELECT protocolo_processo.id,
     origem.nome AS setor_origem,
     protocolo_processo.assunto,
      concat(to_char(tramite.data_encaminhamento, 'DD/MM/YY'),' ',
      to_char(tramite.data_encaminhamento, 'HH24:MI:SS')) as data_encaminhamento,
      recebimento.nome as setor_destino,
      concat(to_char(tramite.data_recebimento, 'DD/MM/YY'),' ',
      to_char(tramite.data_recebimento, 'HH24:MI:SS'))  as data_recebimento


  FROM protocolo_processo,


  INNER JOIN protocolo_tramite tramite ON protocolo_processo.id = tramite.processo_id
  INNER JOIN setor origem ON setor_origem_id = origem.id
  INNER JOIN setor recebimento ON orgao_interno_recebimento_id = recebimento.id

  WHERE
    status=1 AND
    search NOT ILIKE '%MIGRADO%' AND
    (search ILIKE '%compras%' OR
    protocolo_processo.search ILIKE '%aquisição%' OR
    protocolo_processo.search ILIKE '%pbs%');
```

Fig. 1 SQL code for extracting information about the process from the system

Table 1 Example of the result of an SQL system database query (instance 6142)

Id	Source sector	Forwarding date	Sector destination	Receiving date	Total of hours
6022	Protocol Coordination	23/06/2014 11:57	Head of Cabinet	24/06/2014 14:08	26:11:22
		15/08/2014 23:05	Administration and Planning Office	20/04/2017 18:29	23491:24:15
		24/06/2014 14:12	Administration and Planning Office	25/06/2014 15:27	25:15:15
		26/06/2014 22:35	Coordination of Contracts and Agreements	30/06/2014 18:41	92:06:18
		07/08/2014 21:16	Office of Rectory	15/08/2014 13:41	184:24:23
		20/04/2017 18:29	Accounting and Finance Coordination	29/05/2017 14:13	931:43:23

The process was modeled from the mining data of the process and represents the flow of an instance (id = 6022) of the process. It is possible to understand the flow between sectors (actors). However, it was not possible to identify the activities performed by the process participants. The event logs (id = 6022) of the purchasing process (see lines in the Table 1) represent the process procedures between the sectors of the institute. However, it was found that the process instances vary and do not allow

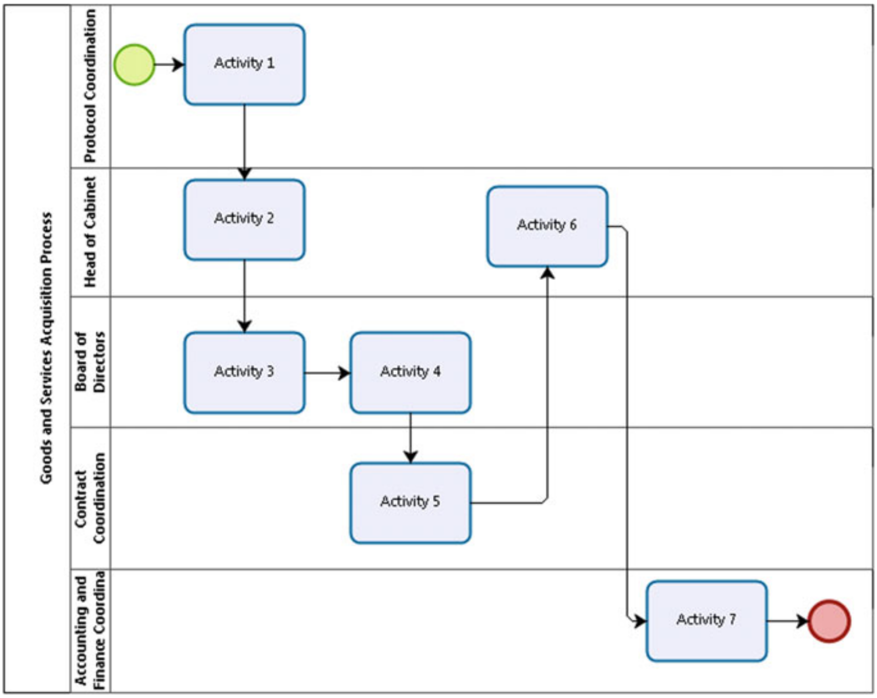


Fig. 2 Modeling process based on mining of instance 6022

a visualization of the complete interaction between all sectors. This can be evidenced by the analysis of other instances, such as that of id 6142 (Table 2).

In order to understand the flow of the process instance described in Table 2, a model was elaborated, illustrated in Fig. 3. The modeling of the instance mentioned allowed for the identification of 19 activities necessary for its completion.

Another fact resulting from process mining was the discovery of the lack of standardization in the process. This can be verified when comparing Tables 1 and 2, or Figs. 2 and 3, both resulting from the mining process. The lack of standardization is evident.

Another major discrepancy was the different interaction times of the activities sectors, recorded in the'total hours' column in Tables 1 and 2. In a meeting with the users of the process and information system, the times of some procedures were questioned (for example, see total hours column in Tables 1 and 2). Users reported that sometimes the processing between sectors occurs only physically, leaving the information system out of date.

It was realized that this is due to the fact that the information system is vulnerable to misuse by the employees of the institute. There are no hard rules for using the system and, therefore, the real processes do not correspond to the digital processing recorded.

Table 2 Example of the result of an SQL system database query (instance 6142)

Id	Source sector	Forwarding date	Sector destination	Receiving date	Total of hours
6142	Protocol Coordination	28/08/2014 21:11	Pro Rectory of Education	02/09/2014 15:11	114:00:42
		09/09/2014 13:35	Board of Directors	15/09/2014 15:05	145:29:45
		05/09/2014 13:04	Price Research Coordination	05/09/2014 15:18	2:13:51
		22/09/2014 13:47	Protocol Coordination	22/09/2014 14:12	0:25:02
		01/10/2014 21:24	Purchasing Coordination	01/10/2014 21:41	0:16:30
		24/07/2014 13:41	Pro Rector of Administration	24/07/2014 21:03	7:21:11
		08/09/2015 14:57	Accounting and Finance Department	15/12/2015 15:20	2352:22:45
		31/10/2014 19:08	Accounting and Finance Department	04/11/2014 19:29	96:21:09
		30/10/2014 21:02	Budget Department	31/10/2014 13:06	16:04:12
		29/10/2014 12:54	Office of Rectory	30/10/2014 18:48	29:54:18
		21/08/2015 13:24	Pro Rector of Administration	25/08/2015 13:20	95:55:34
		22/09/2014 14:12	Office of Rectory	01/10/2014 18:25	220:12:27
		01/10/2014 18:25	Board of Directors	01/10/2014 21:24	2:58:45
		19/09/2/014 19:12	Office of Rectory	22/09/2014 13:45	66:33:21
		24/07/2014 21:03	Price Research Coordination	07/08/2014 15:14	330:10:45
		23/07/2014 15:29	Office—Rectory	24/07/2014 13:32	22:03:23
		05/09/2014 15:18	Budget Department	09/09/2014 13:34	94:15:57
		15/09/2014 15:28	Purchasing Coordination	15/09/2014 19:14	3:45:07

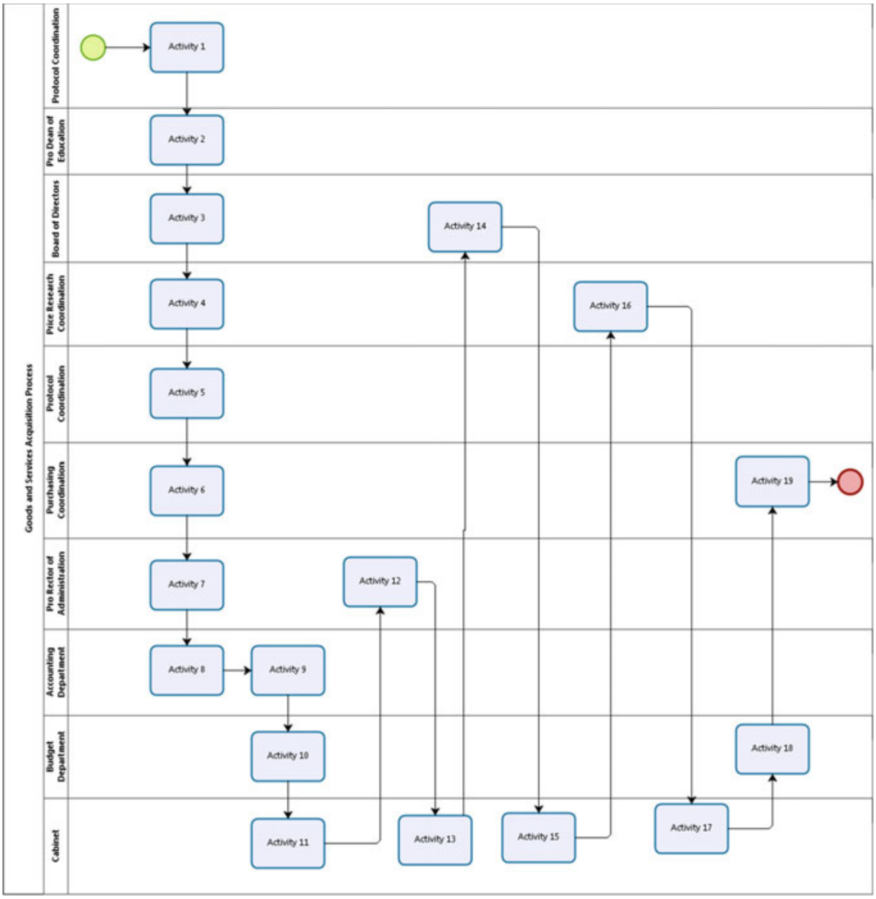


Fig. 3 Modeling process based on the mining of instance 6142

As an example, the seventh row of Table 2 describes the procedure in the Accounting and Finance Department, where the total processing time was 2,352 h and 22 min. It was found that often the processes arrive and are stopped in the sector until they receive the certificate of receipt of the equipment or until the service contracted is fully paid off with the supplier. Some services, such as the service contract for internet supply, take up to two years to finalize the total payment, as in the case of a contract with monthly payments; and after one year it can be extended for another year.

Although the mining process helped to understand the current situation of the goods and services acquisition process, the data collected was insufficient to model the current functioning (as is) of the goods and services acquisition process. For this reason, it was necessary to hold meetings with the users seeking to give more quality in the modeling of the process.

In order to obtain a complete representation and a final'as is' model of the process with all details, it was decided to bring together the users of the departments responsible for each activity of the process, resulting in a report with information on the author, flow activities and description activities. This more detailed analysis allowed the development of an 'as is' model of the process which is closer to reality, with 25 activities being identified in the process. With the current model (as is) defined, it was possible to move on to the next stages of application of BPM at the institute.

5 Final Considerations

This research presented the description and analysis of process modeling using data mining at a Federal Institute of Higher Education in Brazil.

The 'as is' modeling was developed using process mining techniques in the database of the information system of the organization, and through interviews and meetings with the process users.

Due to the fact that the nature of the products and services requested in the institute's system is very varied, the processes are not standardized, and the use of the information system is not managed in a disciplined way, data mining was not sufficient enough to identify the complete processes and the flow of activities in detail.

Despite this, data mining facilitated the definition of instance flows and made it possible to detect critical points in the process, such as points with a long duration of time. With data mining, the analysis time, meetings and modeling effort of the analysts and users were reduced.

In organizations that have a high number of processes, such as the case of the organization analyzed, data mining has been demonstrated to be a tool that facilitates and streamlines the process of identifying, modeling and mapping processes in the application of BPM.

It also showed that the efficiency of data mining depends on how the organization uses its information system. As the processing of the purchasing process does not follow a logical sequence of activities or an event log, it was not sufficient for the modeling of this process, requiring the use of interviews and meetings with users.

As this research presented the results of only one case, its conclusions cannot be generalized, for which an investigation of other institutes and/or other types of organizations would be necessary. Also, it is suggested that future research might reanalyze the process of acquiring goods and services at the organization studied after the implementation of the model 'to be', and verify how the process is behaving.

References

1. Smith, H., Fingar, P.: Business Process Management (BPM): the third wave. Meghan- Kiffer Press (2007).
2. Barretta, A., Busco, C.: Technologies of government in public sector's networks: in search of cooperation through management control innovations. Management Accounting Research, Boston, vol. 22, n. 4, pp. 211–219 (2011).
3. Segatto, M., Pádua, S. I. D., Martinelli, D. P.: Business process management: a systemic approach? Business Process Management Journal, Ribeirão Preto, vol. 19, n. 4, pp. 698–714 (2013).
4. Niehaves, B., Plattfaut, R., Becker, J.: Business process management capabilities in local governments: a multi-method study. Government Information Quarterly, Munster, vol. 30, n. 3, pp. 217–225 (2013).
5. Pourmirza, S. et al.: A systematic literature review on the architecture of business process management systems. Information Systems, Eindhoven, vol. 66, pp. 43–58 (2017).
6. Avelar, C.F.P., Rocha, T.A.H., Cruz, F.J.S.: Data mining: a review of the Administration literature - Mineração de dados: uma revisão da literatura em Administração. Vianna Sapiens: Juiz de Fora, vol. 8, n. 2 (2017). Disponível em: http://www.viannasapiens.com.br/revista/article/view/232/212 last accessed 2020/02/17.
7. Dumas, M. et al. Fundamentals of business process management. Springer Berlin, Tartu, p. 25–100, 2013.
8. Recker, J., Mendling, J.: The state of the art of business process management research as published in the bpm conference. Business and Information Systems Engineering, vol. 58, n. 1, pp. 55–72 (2016).
9. Aalst, W. M. P. V. D., Larosa, M., Santoro, F. M.: Business process management. Business and Information Systems Engineering, vol. 58, n. 1, pp. 1–6 (2016).
10. Morais, R. M. et al.: An analysis of BPM lifecycles: from a literature review to a framework proposal. Business Process Management Journal, vol. 20, n. 3, pp. 412–432 (2014).
11. Milton, S. K., Johnson, L. W.: Service blueprinting and BPMN: a comparison. Managing Service Quality: an international journal, Melbourne, vol. 22, n. 6, pp. 606–621 (2012).
12. Aalst, W. V. D.: Process mining: the missing link. Process Mining, Springer Berlin Heidelberg. Berlin, pp. 25–52 (2016).
13. 13. Recker, J.: Opportunities and constraints: the current struggle with BPMN. Business Process Management Journal, vol. 16, n. 1, pp. 181–201 (2010).
14. Alharbi, A.; Bulpitt, A.; Johnson, O.: Improving pattern detection in healthcare process mining using an interval-based event selection method. Lecture Notes In Business Information Processing, Barcelona, pp. 88–105 (2017).
15. Tiwari, A., Turner, C.J., Majeed, B.: A review of business process mining: state-of-the-art and future trends. Business Process Management Journal, Cranfield, vol. 14, n. 1, pp. 5–22 (2008).
16. Ferreira, D. R.: Event logs: a primer on process mining. Springer International Publishing. Eindhoven, pp. 1–13 (2017).
17. Dustdar, S., Hoffmann, T., AALST, W. V. D.: Mining of ad-hoc business processes with teamlog. Data and Knowledge Engineering, Vienna, vol. 55, n. 2, pp. 129–158 (2005).

Process Mining Classification with a Weightless Neural Network

Rafael Garcia Barbastefano, Diego Moreira de Araujo Carvalho, and Maria Clara Lippi

Abstract Using a weightless neural network architecture WiSARD we propose a straightforward graph to retina codification to represent business process graph flows avoiding kernels, and we present how WiSARD outperforms the classification performance with small training sets in the process mining context.

Keywords Process mining · Weightless neural network · Business process management

1 Introduction

Information systems, as a relevant part of organizations, are strongly linked with business process models and the operations they represent and support [1]. They generate and record data based on event logs, which are especially useful for process mining proposes [2].

Process mining is a research area which merges Business Process Management approaches with data mining tasks and techniques. De Leoni, van der Aalst [3] consider it as “the missing link between model-based process analysis and data-oriented analysis techniques”. Process mining is covered by three types: process discovery, process conformance and process enhancement [4]. Process discovery consists on modeling business processes, as they really occurred, from raw data (majorly system’s event logs). The conformance type of process mining consists of comparisons between an existing process and a model [5]. Conformance checking is essential for business, to find undesirable deviations or to measure efficiency.

The literature has several references on the relevance of neural networks in process mining [6], both in process discovery studies and conformance analysis. Maita et al. [7] conducted a systematic review about techniques employed on process mining

R. G. Barbastefano (✉) · D. M. de Araujo Carvalho · M. C. Lippi
Federal Centre for Engineering Studies and Technological Education—CEFET/RJ, Rio de Janeiro, RJ, Brazil
e-mail: rafael.barbastefano@cefet-rj.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_28

investigations. They evidenced that computational intelligence or machine learning techniques were present in 19% of the cases, whereas traditional data mining ones represent 81%. Their study found there are no studies combining conformance checking with artificial neural networks and the predominant method is the support vector machines (SVM). SVM cases make use of kernel methods introducing a preprocessing phase when working with graphs. Besides, it suggests the use of methods that need the construction of representative kernels of graph data.

Considering the application of neural networks in mining processes, it is always desirable to have both a clear preprocessing step as well as the use of a small subset of training data. Therefore, it is valuable to measure and compare not only the results but also the methods' performance. Learning curves (LC) are renowned for accomplishing this purpose since it enables to measure predictive performance for different learning effort levels [8]. A classic application example of this tool is the predictive efficiency as a function of training sample size [8].

We propose a graph-to-retina's codification to represent graph flows avoiding kernels, and we present how WiSARD performs on graph flow classification with different levels of dataset complexity visualized by LC. The rest of the paper is organized as follows. A short presentation of the WiSARD weightless neural network architecture is described at Sect. 2. The process dataset details are given at Sect. 3 and the experiment design and results in Sect. 4. Section 5 concludes this paper.

2 The WiSARD Weightless Neural Network Architecture

The WiSARD weightless neural network name comes from its authors (Wilkie, Stonham, and Aleksander's Recognition Device) [9] and it was initially created to recognize images as a hardware architecture [10]. Although WiSARD has been previously categorized as a supervised learning method, and new developments reveal its usage as unsupervised learning as well [11].

WiSARD organizes its structure in discriminators (or neurons), sets of X one-bit word RAMs with n inputs. One discriminator often determines just one class of many given as input to the classifier. In the training phase, the classifier receives binary vectors (example instances) and each one depicts an image mapped to a *retina*. A *retina* is a division of the input vector in X tuples of n bits and is frequently rearranged pseudo-randomly. Each n-bit tuple represents an address of RAM of 2^n positions, with the n tuples mapping X memories. Figure 1 illustrates this dynamic and exemplifies how WiSARD operates on the training phase [11].

The network learns from example writing a '1' in all memory addresses, associated to a particular input. Input mapping in the classification phase follow the same process as in the training examples. After that, all discriminators receive the inputs. The counting of the number of memories mapped by the classification example defines the score r_y for a discriminator y. The highest score designates the output class [11].

The standard WiSARD model may present some drawbacks. One of them occurs when it handles very noisy data. Another problem is saturation, which happens when

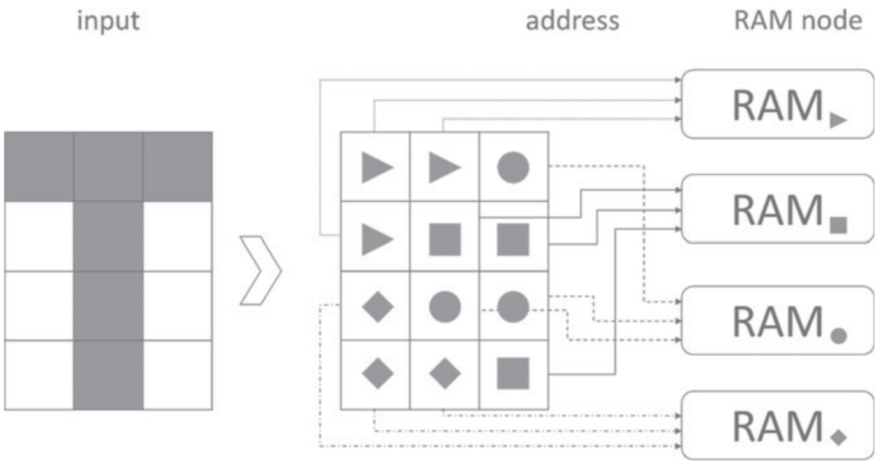


Fig. 1 Example of how WiSARD operates on the training phase [11]

many classes have a high number of responses from the discriminators. In order to tackle the saturation effect, there is a method called "bleaching" [12]. Sparse retinas can also be a problem, and there is another WiSARD extension to deal with it [13].

3 The Process Dataset

This study analyzed process data from a Brazilian public sector higher education institution specialized in engineering studies. As a public company, it shall keep records of its administrative activities respecting preestablished government rules and laws, which stipulates logged information. As a transaction system, the information system records every time a process moves between organizational units or departments, resulting in a sequence of organizational units visited by each process. Besides, upon creation, information about the kind or processes class, and owner (process metadata) are also recorded.

We dumped the information system database that comprises the logged process data from 2013 to 2017, and it got filtered to remove any inconsistencies. Every resulting process represents a process matrix that describes the process flow through all corresponding organizational units. Figure 2 shows the process matrix where every row represents an organizational unit and the columns represent the sequence in the process life.

The database, summarized in Table 1, exhibits eight different classes and the table displays the process quantity in each class and the amount of unique process matrix or symbols. For example, class A has 1,575 instances, but only 95 distinct ones, showing many repetitions. Conversely, class H shows 467 different processes with 383 distinct symbols. The Shannon entropy [14] and normalized entropy quantify

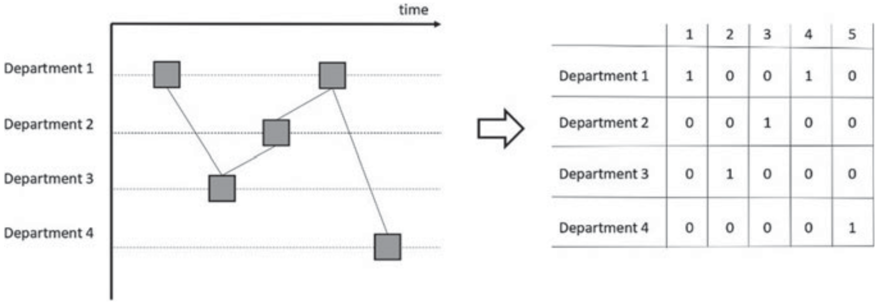


Fig. 2 Creation of a retina from process time flow, where each row represents an organizational unit and columns depict the sequence. The final dataset comprises 5,372 administrative processes and each one composed by 173 organizational units versus 78 sequence positions (matrix size of 13,494 elements), and every process was classified accordingly with its kind using the metadata

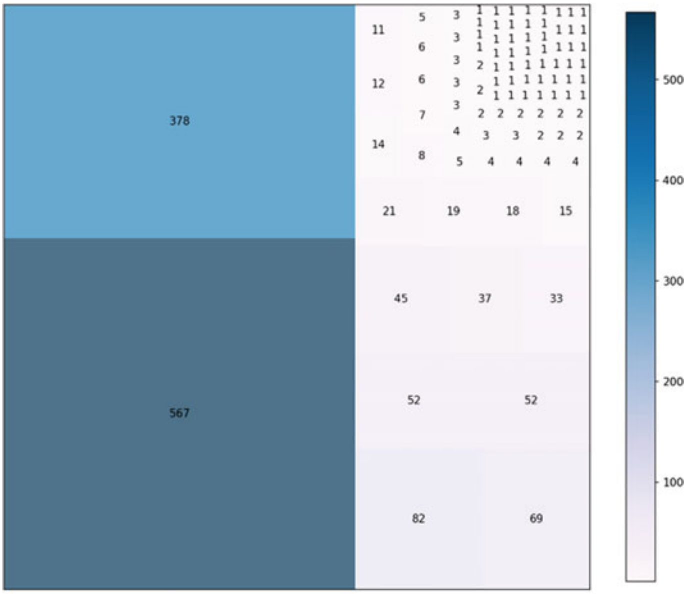
Table 1 Dataset summary

Class	Process set name	Total	Sym	Entropy	Norm. Ent.	Max Pxs	Density
A	Internship agreement	1575	95	351056	0.53434	86	0.0064
B	Prof. perf assessment	318	25	287673	0.61947	28	0.0021
C	Prof. promotion	349	119	534360	0.77502	97	0.0072
D	Prof. qualification	627	244	676195	0.85263	135	0.0100
E	Staff perf. assessment	670	353	732065	0.86497	214	0.0159
F	Procurement	983	696	858400	0.90901	847	0.0628
G	Staff promotion	383	245	751830	0.94729	129	0.0096
H	Staff qualification	467	383	842781	0.98212	251	0.0186
	Total	5372	2160	–	–	–	–
	Min value	318	25	2877	0.534	28	0.0021
	Average value	671.9	270	6293	0.811	223.4	0.0166
	Max value	1575	696	8584	0.982	847	0.0628

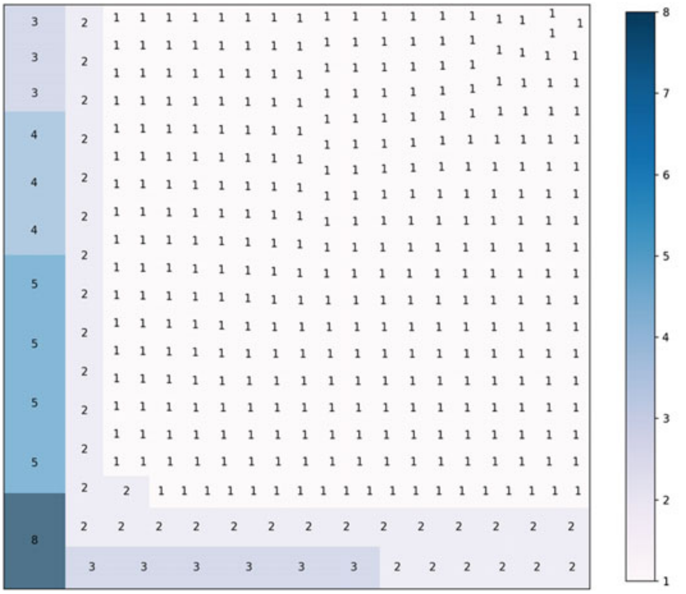
the different inner structure among classes. The both measures are also presented in Table 1, where the Shannon entropy varies from 2.877 to 8.584, and the normalized entropy varies from 0.53434 to 0.98212.

The lack of proper routine documentation hindered the use of some classes, so we select class A and H in order to determine their process conformance status based on available proper documentation. This subset represents 38% of the initial set and represents the lowest and the highest normalized entropy classes, which provides an idea about the classification performance. Each process on both classes received a tag meaning a conform process (SP—standard process) or non-compliant one (NP—non-conform process).

Classes A and H are depicted on Fig. 3, and every square designates a symbol (distinct process matrix), and the number of repetitions appears as a figure in the



(a) Process class A - Internship agreement



(b) Process class H - Staff qualification

Fig. 3 Process classes A (Internship agreement) and H (Staff qualification). Every square designates a symbol (distinct process matrix), and the number of repetitions appears as a figure in the middle of the representing square middle of the representing square. Class A has two important classes where the biggest is an SP type, and the second is an NP. Furthermore, class A has 45% of SP process that are composed by only four symbols. As the entropy shows, class H is more diverse and showcases a greater symbol diversity.

The internship agreement processes (process class A) operationalize Internship Programs for undergraduate students. Since it is mandatory by law, the education institution must examine if enterprises comply with these legal requirements in order to formalize the Agreement. The Agreement allows the enterprise to hire students as interns.

On the other hand, staff qualification processes (process class H) regard the analysis and decision on administrative requests for statutory professional qualification leave petitioned by staff employees.

4 The Experiment Design and Results

We compared the WiSARD performance with SVM using 36 LCs, among them, 32 (16 for class A and 16 for class H) were drawn varying the WiSARD's RAM size (2, 4, 8, and 16 bits), the bleaching state (activated or not), and the ignore full-zero patterns (switch on or not). The remaining four curves represent two experiments with SVM for each class, where we tried out two different kernels: a standard linear and a graph kernel (a Weisfeiler-Lehman Graph Kernels) [15]. In addition, we used a public available WiSARD implementation (https://github.com/IAZero/wisardpkg) and SVM from SciKitLearn (https://scikit-learn.org/stable/). Figure 4 shows de resulted curves.

On each LC, we stepped the training size from 2 up to the minimum of the size of SP and NP in each specific class, and then we randomly select each half of the

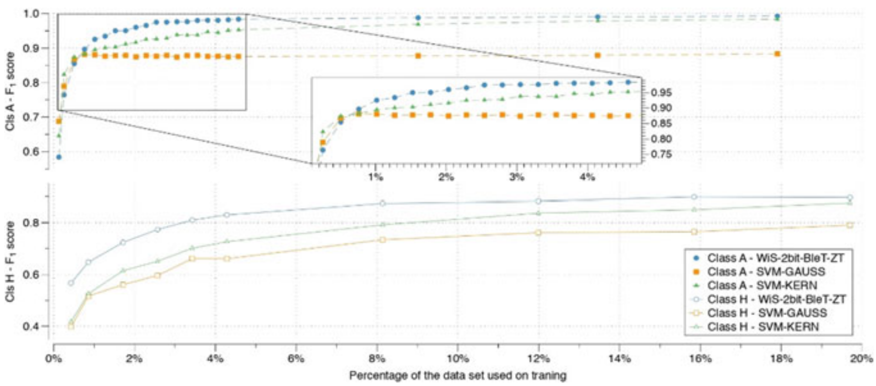


Fig. 4 Class A and H F_1-Score performance comparison of selected WiSARD configurations (blue lines) with SVM (green and orange lines)

training set respectively from SP and NP subsets. Each point on every LC is the average of the F_1-Score of 50 samples.

The comparison of all WiSARD's configurations shows that there is a small improvement with the use of the ignore full-zero pattern flag in this specific context. Although every class has sparse retinas as presented in Table 1, where density varies from 0.0021 to 0.0628 pixels lit per retina on average showing sparseness, improvement is only present within class H (highest density). This effect shows that the lack of bright pixels (meaning that the process has not visited that organizational unit) is so crucial as a lit one. Besides, bleaching increases the F_1-Score in 0.0991 on best-case average on every experimented class.

Thus, to choose the best configuration among all 36 WiSARD experiments, we decide to take the configuration: RAM size, bleaching and the ignore full-zero flag that reaches a F_1-Score of 0.9 first for each class. Class A got a tie on RAM size equals 2, 4 or 8, and with bleaching equals true and the ignore full-zero flag as false. This tie happens with a sample size of 12 (6 SP and 6 NC). On the other hand, class H fits better with the WiSARD configured with bleaching, the ignore full-zero flag as true and RAM size of 8 bits at a sample size of 92 (46SP and 46NC).

The only shortcoming presented by the data is that the figure reveals a fluctuation until 0.5% on class A (lower entropy). This abscissa corresponds to a training set composed of 4 SP and 4 NC of 1575 process, and it is due to the unbalanced data in the subset of SP in class A which has cardinality 705, and it comprises only four distinct symbols with the following frequencies: 567, 35, 45, and 52. However, the WiSARD's performance is tantamount with the reference methods.

5 Conclusion

In this work, we presented a straightforward graph to retina codification that precludes the kernel construction preprocessing. This representation is more palatable to the process management practitioner, and it avoids any issue related to intermediary representations. Besides, we show that WiSARD generalizes faster and learns with small training sets that help the practitioners since they do not need to further advance on the manual process-dataset classification.

References

1. Dumas, M., La Rosa, M., Mendling, J., Reijers, H.A.: Introduction to business process management. In: Fundamentals of Business Process Management. 1–33. Springer, 2018.
2. Kalenkova, A., Burattin, A., de Leoni, M., van der Aalst, W., Sperduti, A.: Discovering high-level BPMN process models from event data. Business Process Management Journal. 25(5):995–1019, 2019.
3. Leoni, M., van der Aalst, W. A general process mining framework for correlating, predicting and clustering dynamic behavior based on event logs. Information Systems, 56:235–257, 2016.

4. van der Aalst, W. Process mining: Data science in action. Springer-Verlag Berlin Heidelberg, 2016.
5. Rozinat, A., van der Aalst, W.M.P.: Conformance checking of processes based on monitoring real behavior. Inf. Syst. 33(1): 64–95, 2008.
6. Maita, A. Martins, L.C., López Paz, C.R., Peres, S.M., Fantinato, M. Process mining through artificial neural networks and support vector machines. Business Process Management Journal, 21(6):1391–1415, November 2015.
7. Maita, A., Martins, L., Paz, C. A systematic mapping study of process mining. Enterprise Information Systems, 12:505–549, 2018.
8. Perlich, C. Learning Curves in Machine Learning. In: Sammut, C. and Webb, G.I. (eds.) Encyclopedia of Machine Learning. pp. 577–580. Springer US, Boston, MA, 2010.
9. Aleksander, I. Thomas, W. and Bowden, P. WiSARD a radical step forward in image recognition. Sensor review, 4(3):120–124, 1984.
10. Franca, F. Gregorio, M. Lima, P. and Oliveira, W. Advances in weightless neural systems. In: European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning, pages 497–504, 2014.
11. Barbosa, R., Cardoso, D., Carvalho, D., and França, F. Weightless neuro-symbolic GPS trajectory classification. Neurocomputing. 298: 100–108, 2018.
12. Grieco, B., Lima, P., Gregorio, M., and França, F. Producing pattern examples from "mental" images. Neurocomputing, 73(7):1057–1064, 2010.
13. Rangel, F., Faria, F., Lima, P. and Oliveira, J. Semi-supervised classification of social textual data using WiSARD. In 24th European Symposium on Artificial Neural Networks, ESANN 2016, Bruges, Belgium, April 27–29, 2016, 2016.
14. Shannon, C. A mathematical theory of communication. Bell System Technical Journal,27(3):379–423, 1948.
15. Shervashidze, N., Schweitzer, P., van Leeuwen, E.J., Mehlhorn, K., Borgwardt, K.M. Weisfeiler-Lehman Graph Kernels. Journal of Machine Learning Research, 12(77):2539–2561, 2011.

Quantitative Approaches for Identification of Indicators and Their Relationships in Performance Measurement Systems: A Literature Review

Anderson da Silva Ramos, Fernando Luiz Cyrino Oliveira, and Cristina Márcia Barros de Castro

Abstract The deployment of strategic objectives into indicators that portray organizational performance to the operational level is the main focus of performance measurement systems. The selection of indicators and the mapping of relationships between them and the objectives using quantitative methods are an important research aspect, given that several initiatives for the implementation of performance measurement systems have been limited in their ability to assist decision-making processes, especially due to the subjectivity in some methods. In this sense, this paper presents a review with the main approaches already available in the literature about the use of quantitative tools for the identification of performance indicators and their relationships. It is observed an opportunity to expand studies about the application of business analytics techniques, in order to exploit their potential for information extraction from historical data and their applicability in strategic processes.

Keywords Performance measurement system · Selection of indicators · Quantitative approaches · Business analytics

---

A. da S. Ramos (✉) · F. L. Cyrino Oliveira
Industrial Engineering Department, Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: anderson.ramos@engenharia.ufjf.br

F. L. Cyrino Oliveira
e-mail: cyrino@puc-rio.br

C. M. B. de Castro
Production and Mechanical Engineering Department, Federal University of Juiz de Fora, Juiz de Fora, Brazil
e-mail: cristina.castro@ufjf.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_29

1 Introduction

Performance measurement systems (PMSs) seek to define objectives from organizational strategy and to break them down into a set of key performance indicators (KPIs) to be tracked and whose results should indicate whether the intended objectives are being achieved [1]. These systems have aroused great interest from academics and practitioners over the last decades, generating different studies about models for their application. However, several implementation initiatives have been limited in their potential to support decision-making processes [2]. Often, there is a great debate whether the selected indicators are actually suitable for providing the information needed to map the relationships between corporate objectives [3].

The Balanced Scorecard (BSC) model, proposed by Kaplan and Norton [4], is a classic approach to design a PMS, with attention to unfolding of corporate objectives in performance indicators covering not only the financial perspective, but also other organization's performance horizons (customers, internal processes and learning and growth). Although widely known and used, this model is significantly dependent on subjectivity arising from expert opinion and lacking in quantitative methods for selecting KPIs, identifying relationships between them and strategic objectives and projecting future scenarios [5]. Subjectivity contributes to ineffective indicators and relationships to organizational strategy being monitored, undermining the expected effectiveness of PMS [6]. On the other hand, many interdependent relationships between KPIs and objectives are hidden and could provide relevant information for decision making in the context of performance management [1].

Given the need for quantitative methods that support the implementation of PMSs, especially regarding the objectivity in the deployment of strategic objectives, this paper presents a review of the literature on approaches that address the definition of indicators and the mapping of relationships in the unfolding of corporate objectives, highlighting opportunities for future research in this area. Section 2 presents the main works found in the literature, with their segregation into two major groups based on the quantitative methods used, and the description of the tools and phases considered in each approach. Section 3 presents an observed opportunity for advancement in the literature on quantitative methods of supporting PMSs, while Sect. 4 presents final considerations.

2 Literature Review

The literature review was conducted through the analysis of publications available in the Scopus database, with a search performed on filters related to title, abstract and keywords by combining two groups of terms, having a need that, at least, one term from each group was present in the publications. The first group was composed by the terms "performance measurement system", "performance management system" and "key performance indicator", while the second group by "quantitative model", "operational research", "business analytics" and "big data". The resulting materials were initially evaluated by title and/or abstract, with those considered the most representatives for the scope of this work analyzed in full by the authors. We also used search from citations made between publications to identify other works relevant to the proposed scope.

Considering more quantitative approaches to the structuring of PMSs, the literature can be divided into two broad strands, one encompassing operational research and management methods and the other related to business analytics. The first covers publications that extend from the early works on selection of performance indicators and identification of relationships in a quantitative manner to current applications. The business analytics strand is newer, with works have been published especially in the last decade.

2.1 Operational Research and Management

For operational research and management methods, Santos et al. [2] presented a brief review of the main models already published, segregating them into two major groups. The first is composed by methods not originally designed for the context of PMS, but which combined can be applied for this purpose. The other group includes performance analysis techniques, such as Data Envelopment Analysis (DEA), in conjunction with other operational research methods. Given the scope of the review presented by Santos et al. [2], the exposition of works within the operational research and management strand, provided in the following two paragraphs, is based on this review. In addition, considering that approaches employing the DEA technique focus more on the Decision Making Units (DMUs) comparative analysis, which exceeds the initial scope of this paper related to the evaluation of proposals for selection of indicators and identification of relationships between them, it is restricted to discussing only works of the first group described by Santos et al. [2]. Table 1 presents the references of the "Operational research and management" strand.

One of the first approaches using operational research and management techniques for PMS was presented by Suwignjo et al. [7], based on the combination of cognitive maps, cause and effect diagrams and tree diagrams with the Analytic Hierarchy Process (AHP) method. This approach was titled Quantitative Model for Performance Measurement System (QMPMS). The maps and diagrams are directed to the identification of performance factors and the hierarchical organization of their relationships, while the AHP method allows quantification of the effects of each factor on the final performance. Bititci et al. [8] presented the application of this approach considering scenario analysis for strategic positioning. Sarkis [9] proposed a model adjusted by replacing the AHP method with ANP (Analytic Network Process), as it is less susceptible to classification reversals and allows combined calculation of the effect of factors on final performance.

Table 1 References of the "Operational research and management" strand

Reference	Journal	Approaches/techniques
Suwignjo et al. [7]	International Journal of Production Economics	QMPMS (AHP, Cognitive Map, Cause and Effect Diagram and Tree Diagram)
Bititci et al. [8]	International Journal of Production Economics	QMPMS and Scenario Analysis
Sarkis [9]	International Journal of Production Economics	QMPMS (ANP, Cognitive Map, Cause and Effect Diagram and Tree Diagram)
Santos et al. [10]	International Journal of Operations & Production Management	CLP, Oval Mapping and Multicriteria Decision Analysis
Santos et al. [11]	Journal of the Operational Research Society	
Santos et al. [2]	Technological Forecasting & Social Change	
Ferreira et al. [12]	Journal of the Operational Research Society	Cognitive Map and MACBETH
Joshi et al. [13]	Expert Systems with Applications	Delphi

Note QMPMS—Quantitative Model for Performance Measurement System; AHP—Analytic Hierarchy Process; ANP—Analytic Network Process; CLP—Causal Loop Diagram; MACBETH—Measuring Attractiveness by a Categorical-Based Evaluation Technique

Santos et al. [2], Santos et al. [10] and Santos et al. [11], in turn, dealt with the application of techniques such as CLP (Causal Loop Diagram), oval mapping and multicriteria decision analysis in selection of relevant indicators and measurement of dependency relationships. Ferreira et al. [12] employed cognitive mapping with the Measuring Attractiveness by a Categorical-Based Evaluation Technique (MACBETH), which is used to quantify relationships between factors. Joshi et al. [13], among other aspects, presented the application of the Delphi method for the indicator definition process, based on convergence of expert opinions.

2.2 Business Analytics

Although operational research methods already contribute to the implementation of PMSs, as they better target the choice of indicators and the visualization of relationships, most models are dependent on subjective considerations at some stage, mentioning, for example, the weights given in relevance analysis between factors within the AHP method. The potential for extracting information directly from historical data of indicators provided by business analytics techniques has been an important factor for carrying out work in this area. The following are the main references within this strand of quantitative methods for PMS. Table 2 presents the references of the "Business analytics" strand.

Table 2 References of the "Business analytics" strand

Reference	Journal	Approaches/techniques
Schläfke et al. [6]	International Journal of Productivity and Performance Management	Performance Management Analytics
Raffoni et al. [14]	Production Planning & Control	Business Performance Analytics
Rodriguez-Rodriguez et al. [1]	Computers in Industry	QRPMS (PCA/SEM and PLS)
Rodriguez-Rodriguez et al. [15]	Technological Forecasting & Social Change	PCA and Scenario Analysis
Wang and Chien [16]	International Journal of Production Research	Correlation Test, VIF, Decision Tree Rules and Logistic Regression
Peral et al. [3]	Computer Standards & Interfaces	ARIMA, SVM, Random Forest and MLP
Wang et al. [5]	Computers & Industrial Engineering	Random Forest, Bayesian Belief Network and ARIMA

Note QRPMS—Quantitative Relationships at the Performance Measurement System; PCA—Principal Component Analysis; SEM—Structural Equation Model; PLS—Partial Least Squares; VIF—Variance Inflation Factor; ARIMA—Autoregressive Integrated Moving Average; SVM—Support Vector Machines; MLP—Multilayer Perceptron

Schläfke et al. [6] presented an approach called Performance Management Analytics (PMA), characterized by data-intensive and analytical tools to understand organizational dynamics, select KPIs and increase operational performance. Although not specify techniques for implementing PMSs, this approach underscores the relevance of business analytics as a potential success factor that can bridge the gap between structuring these systems and their effective implementation.

Also more conceptually, Raffoni et al. [14] highlighted a framework called Business Performance Analytics (BPA) that is composed of five steps and emphasizes the use of data and performance management analysis techniques. The first two steps relate to evaluating organizational strategy and objectives and defining key questions that translate the strategic issues into more specific aspects. In the third step, it is conducted an identification of what data are needed for answering the key questions, followed by the collection of them from the available sources. Then, the more suitable analytical methods and tools are chosen and applied in order to transform data into valuable information, considering the four perspectives of business analytics approaches (description, diagnosis, prediction and prescription). Lastly, actions are taken based on the results observed in a performance management cycle. The authors highlighted the potential of the structure for supporting the identification of the most relevant variables to be controlled, as well as the links between them.

Rodriguez-Rodriguez et al. [1] proposed a model called Quantitative Relationships at the Performance Measurement System (QRPMS), aimed at selecting KPIs, eliciting relationships between them and projecting impacts on strategic objectives. The model consists of four stages, starting with a structuring/analysis of the PMS focused on the conceptual link between pre-established indicators and objectives. Then, the historical data is preprocessed, considering, for example, filtering of abnormal values, time frequency homogenization, normalization and centralization of data. After these treatments, relationships between indicators are identified using Principal Component Analysis (PCA) or Structural Equation Model (SEM), depending on the ratio between number of indicators and sample size. The Partial Least Squares (PLS) technique is applied in order to quantify the existing relationships. Finally, these are projected on the level of the objectives, considering the conceptual links evaluated in the first stage. Rodriguez-Rodriguez et al. [15] presented a scenario analysis model using the historical evolution of the business aspects (components) extracted from the PCA.

Wang and Chien [16] described another approach considering business analytics by employing techniques for initial indicator selection, followed by the application of classifiers that indicate significant relationships for performance prediction. The authors presented the use of supervised correlation testing and unsupervised Variance Inflation Factor (VIF) to remove redundant indicators within a pre-existing list. Then, they dealt with the calibration of two classifiers derived from decision tree rules and logistic regression, making comparisons in terms of accuracy, sensitivity and specificity.

Peral et al. [3] highlighted how a data mining-oriented structure can contribute to achievement of strategic objectives by using information technology tools. In this context, it is necessary to properly select indicators based on the relationships between them and the objectives. Therefore, the authors presented an approach in which the definition of KPIs is done in five steps: preprocessing, detection of potential anomalies, calculation of difference series, analysis of pair-wise relationships and analysis of compound relationships (between various indicators). In terms of techniques, the authors showed Autoregressive Integrated Moving Average (ARIMA) models as an alternative to verify the interactions between the variables from the calculated difference series. Moreover, Support Vector Machines (SVM), Random Forest and Multilayer Perceptron (MLP) methods were evaluated within a case study in the compound analysis step.

Finally, Wang et al. [5] described the combination of the Random Forest, Bayesian Belief Network and ARIMA methods to respectively select KPIs, identify relationships for the construction of strategic maps and simulations, and conduct performance forecasting considering the temporal impact of the indicators on the results. The authors pointed out that these procedures make it possible to meet the four perspectives of business analytics approaches. The selection of indicators is part of the description and diagnosis, performance forecasting is associated with the nature of prediction and simulations based on strategic maps contribute within the prescription aspect.

3 Discussion

In the literature, the quantitative approaches to performance measurement systems address three main topics: identification of KPIs and their relationships with strategic objectives, comparison between performance units, and projection and analysis of future scenarios based on interdependent historical results. Operational research and management tools and business analytics are the main alternatives found in PMS implementations.

Approaches considering the use of operational research and management techniques have been proposed as a way to improve, in terms of application, the conceptual framework presented in the BSC model [2]. However, many models still require subjective considerations in some steps and are unable to extract information directly from historical indicator data [16]. Thus, new works concerning selection of KPIs and identification of their interdependent relationships are relevant, especially in the current context of big data, where organizations have access to an increasing volume of data, which has enormous potential for generating business value when applied in performance measurement systems [3, 17].

Despite the potential of business analytics techniques to fill the gaps in the PMS implementation process, their use is still considered unexplored for this purpose [6, 14, 17]. In this sense, there is an opportunity to expand the use of these methods, which tend to broaden the capacity of analysis in an objective way and, consequently, improve the use of performance measurement systems [17].

With the application of these techniques, the relationships of dependence and support between indicators and objectives are no longer considered primarily based on the experience of experts and are now expressed from facts portrayed in historical results [6, 15]. Redundant indicators, for example, tend to be identified and eliminated as they negatively impact the quality of analysis techniques, increase computational complexity and lead to inefficiencies in the use of organizational resources [1, 3, 5].

In addition, business analytics techniques can provide a better understanding of organizational dynamics by supporting data-driven decision-making processes that can promote competitive gains not seen in other PMS approaches. Due to the knowledge of the existing dynamics between several factors, it is possible to broaden the usual focus of the PMSs, directed to the control of the strategy execution, in order to contribute also in the definition phase of the same [6]. It is also noteworthy that business analytics can be suitable for more and more dynamic environments and its application can fill the gap observed in the research on PMS in such environments [18].

Another important point to highlight is the potential of business analytics tools to provide a more proactive character to actions arising from monitoring the content present in PMSs, by predicting future performance from the historical results of the indicators. Thus, one can effectively explore the mapping of relationships between indicators and objectives, allowing process managers to anticipate the development of measures that lead to the achievement of organizational strategy. Interpreting the temporal effect of indicators on future results is a major business challenge that can be faced with business analytics techniques [5].

It is also relevant that the application of business analytics in the context of performance measurement systems tends to contribute to their strategic aspect, which needs to be further explored in order to broaden their scope that is still problem-oriented to an operational level [19].

4 Conclusion

This paper presents a review of the literature on the use of quantitative methods in performance measurement systems, mainly aimed at identifying key indicators and their interdependent and supportive relationships with strategic objectives. Works in this area can be divided into two broad strands, one encompassing operational research and management methods and the other business analytics. Although studies of the first group have contributed to improve the PMS implementation process, subjectivity in some steps of the methods is still seen as an important challenge to be addressed.

Given the potential of business analytics techniques to extract information directly from historical data, which is now increasing in volume, there is an opportunity to broaden their application in the process of selecting KPIs from relationships with corporate objectives, as well as projecting future performance based on the results already observed. It is suggested that new works address, via practical studies, the application of these methods in different organizational contexts, using the approaches to PMS already presented in the literature or also other business analytics tools. It is believed that these works will contribute to fill the gap regarding the lack of objectivity in the deployment of organizational objectives in PMSs and the consequent limitation experienced in the implementation of these systems to support decision-making processes, also helping to explore the potential for use of business analytics methods in strategic activities.

Acknowledgments This study was financed by Carlos Chagas Filho Foundation for Research Support in the State of Rio de Janeiro (FAPERJ), Grant/Award Number: E-26/202.824/2018 and 211.086/2019; Brazilian National Council for Scientific and Technological Development (CNPq), Grant/Award Number: 307403/2019-0 and Brazilian Coordination of Improvement of Higher-Level Personnel (CAPES), Grant/Award Number: 001.

References

1. Rodriguez-Rodriguez, R., Saiz, J. J. A., Bas, A. O.: Quantitative relationships between key performance indicators for supporting decision-making processes. Computers in Industry 60(2), 104–113 (2009).
2. Santos, S. P., Belton, V., Howick, S., Pilkington, M.: Measuring organisational performance using a mix of OR methods. Technological Forecasting & Social Change 131, 18–30 (2018).

3. Peral, J., Maté, A., Marco, M.: Application of Data Mining techniques to identify relevant Key Performance Indicators. Computer Standards & Interfaces 50, 55–64 (2017).
4. Kaplan, R. S., Norton, D. P.: The balanced scorecard – measures that drive performance. Harvard Business Review, Janeiro-Fevereiro 71–79 (1992).
5. Wang, C.-H., Cheng, H.-Y., Deng, Y.-T.: Using Bayesian belief network and time-series model to conduct prescriptive and predictive analytics for computer industries. Computers & Industrial Engineering 115, 486–494 (2018).
6. Schläfke, M., Silvi, R., Möller, K.: A framework for business analytics in performance management. International Journal of Productivity and Performance Management 62(1), 110–122 (2013).
7. Suwignjo, P., Bititci, U. S., Carrie, A. S.: Quantitative models for performance measurement system. International Journal of Production Economics 64(1), 231–241 (2000).
8. Bititci, U. S., Suwignjo, P., Carrie, A. S.: Strategy management through quantitative modelling of performance measurement systems. International Journal of Production Economics 69(1), 15–22 (2001).
9. Sarkis, J.: Quantitative models for performance measurement systems - alternate considerations. International Journal of Production Economics 86(1), 81–90 (2003).
10. Santos, S. P., Belton, V., Howick, S., Pilkington, M.: Adding value to performance measurement by using system dynamics and multicriteria analysis. International Journal of Operations & Production Management 22(11), 1246–1272 (2002).
11. Santos, S. P., Belton, V., Howick, S.: Enhanced performance measuring using OR: a case study. Journal of the Operational Research Society 59(6), 762–775 (2008).
12. Ferreira, F. A. F., Santos, S. P., Rodrigues, P. M. M.: Adding value to bank branch performance evaluation using cognitive maps and MCDA: a case study. Journal of the Operational Research Society 62(7), 1320–1333 (2011).
13. Joshi, R., Banwet, D. K., Shankar, R.: A Delphi-AHP-TOPSIS based benchmarking framework for performance improvement of a cold chain. Expert Systems with Applications 38(8), 10170–10182 (2011).
14. Raffoni, A., Visani, F., Bartolini, M., Silvi, R.: Business Performance Analytics: exploring the potential for Performance Management Systems. Production Planning & Control 29(1), 51-67 (2018).
15. Rodriguez-Rodriguez, R., Saiz, J. J. A., Bas, A. O., Carot, J. M., Jabaloyes, J. M.: Building internal business scenarios based on real data from a performance measurement system. Technological Forecasting & Social Change 77(1), 50–62 (2010).
16. Wang, C.-H., Chien, Y.-W.: Combining balanced scorecard with data envelopment analysis to conduct performance diagnosis for Taiwanese LED manufacturers. International Journal of Production Research 54(17), 5169–5181 (2016).
17. Mello, R., Martins, R. A.: Can Big Data Analytics Enhance Performance Measurement Systems?. IEEE Engineering Management Review 47(1), 52–57 (2019).
18. Sahlin, J., Angelis, J.: Performance management systems: reviewing the rise of dynamics and digitalization. Cogent Business & Management 6(1), 1–21 (2019).
19. Kunc, M., O'Brien F. A.: The role of business analytics in supporting strategy processes: Opportunities and limitations. Journal of the Operational Research Society 70(6), 974-985 (2019).

Use of DMAIC and Lean Six Sigma to Reduce Body Defects in an Automotive Factory

Sílvio Sérgio Silveira de Siqueira

Abstract The automotive industry is an important sector for the economy of Brazil. In times of financial crisis, investments are scarce and companies must find cheap alternatives to solve problems. Lean six sigma and DMAIC are tools that use statistics and allow for quick problem detection and help engineers find inexpensive solutions to the problem. The following research shows the use of these tools to reduce daily defects in an automotive industry, following the methodology from the selection of the problem to the confirmation of the effectiveness of the actions taken. The study confirmed the effectiveness of the methodology because the number of defects was reduced and no major financial investments were made to achieve the objective, and reduced the rework cost.

Keywords DMAIC · Lean six sigma · Automotive

1 Introduction

The status of automobile industry in Brazil is a thermometer for measuring the condition of economy. In 2016 Brazilian GDP had the biggest drop in 20 years [1] at the same time in 2016. The volume of new vehicles sold in Brazil, reached its lowest level in ten years [2]. In order to remain competitive, companies choose to reduce costs in periods when the economy is shrinking. The defect ratio reduction is important especially during times of economic crisis, when the automakers focuses on economical production reducing losses due quality issues [3]. Also, the Lean Manufacturing, and quality improvement [3] put up together evolves as Six Sigma, this enables the improvement of performance towards, achieving quality standards of product and process. The South of Rio de Janeiro state in Brazil, has 3 automakers companies, this study seeks to reduce quality issues in an automaker in the body shop area. At the same way, costs will be reduced by reducing rework due to improved

S. S. S. de Siqueira (✉)
Universidade Federal Fluminense (UFF), Volta Redonda, RJ, Brazil
e-mail: silviosiqueira91@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_30

quality. To active this goal the company will apply Six Sigma and DMAIC tool to gain the most reducing body defects per unit. This study will check, step by step, the DMAIC tool applied on Body Shop plant in a South of Rio de Janeiro state.

2 Objectives

- Improve body quality per units in, automotive vehicles in plant.
- Use DMAIC methodology to identify the main issue, measure current condition, analyze current condition, advise engineers to take the best action and avoid reoccurrence.
- Reduce the cost of rework by improving quality.

3 Methods

3.1 Six Sigma

Six sigma is an improvement methodology developed by Motorola in the 1980s, focusing on the costumer. One advantages of six sigma, is that it allows to solve problems accurately using statistical tools [4], as capability analysis, correlation analysis and others. To achieve Six Sigma quality, a process produce no more than 3.4 defects per million of units [5, 6] define six sigma as an equitable management strategy, which aims to increase companies profitability by improving the quality of products and processes, then six sigma must be adopted with managerial support. General electric adopted and endorsed six sigma from the legendary CEO Jack Welch. The GE capital's 1998 performance over than $300,000 million were generated in net income from six sigma quality improvements.

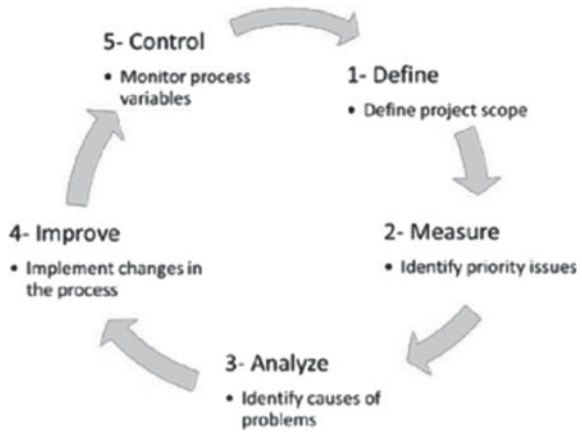
3.2 DMAIC

DMAIC is a methodology that has a set of steps, namely, define (D), Measure (M), Analyze (A), Improve (I), Control (C) [7, 8] (see Fig. 1).

Using the DMAIC tool, based on the six sigma methodology aims to outline the improvement points in the operation [8, 9]:

Define—Who are the costumers, what is the problem?
Measure—How is the maintenance function measured and how is it performing?
Analyze—What is the root or the main cause of the problem?
Improve—How can we remove the cause of defects?
Control—How can we avoid the reoccurrence?

Fig. 1 DMAIC cycle. *Source* Adptation of Souza Pinto et al. [8]



Using these concepts, it's possible to find and solve the mains problems of process, for different companies and business.

3.3 Capability Analysis

Even the process has a normal distribution and is under statistical control, it's possible to find defective items. therefore, it is essential to assess whether the process is capable of meeting the specifications established from the needs of the customers; this evaluation is done by analyzing the capacity of the process, which is measured by measuring the natural variability in relation to the established tolerances.

Cp index. The cp index, potential capacity of the process, considers that the process is centered on the nominal specification. The Cp index could be seen on Eq. (1):

$$Cp = \frac{USL - LSL}{6\sigma} \tag{1}$$

USL: Upper specified limit

LSL: Lower specified limit

σ: Process standard

This index relates the natural variability of the process in relation to the specifications, the higher the Cp the more likely the process to meet the specifications [10]; A rule to evaluate the index is the table of intervals with values of Table 1.

The Cp however does not consider the centralization of the process, being based on the amplitude of the samples, and the amplitude of the specification intervals [10].

Table 1 Reference intervals for Cp analysis

Cp	Items out of spec (PPM)	Interpretation
Cp < 1.0	Over than 2700	Unable process
$1.0 \leq$ Cp < 1.33	64–2700	Acceptable process
Cp $\geq$ 1.33	<64	Capable process

Cpk index. As mentioned in this section, Cp just consider the amplitude of the samples and amplitude of the tolerances, but not considers the centralization, it's means that if only the Cp is considered for analysis, wrong conclusions can be made. A process can be stable but outside the specified limits. To avoid this type of error proposed the Cpk index, that takes into account the distance from the process average in relation to the specification [11]. This index could be seen on Eq. 2:

$$Cpk = \left(\frac{USL - \mu}{6\sigma}\right); \left(\frac{USL - \mu}{6\sigma}\right) \tag{2}$$

USL: Upper specified limit

LSL: Lower specified limit

μ: Process average

σ: Process standard deviation

The correct Cpk is the smallest value between the two presented equations if the process is correct centralized Cp = Cpk or a similar value. In capability analysis is usual use Cp index together the Cpk index, and the interpretation of Cpk is the same as Cp, which is seen in Table 1.

4 Results

4.1 Define

The company has a KPI to monitor body quality in defects per unit (dpu). As a defining step, the pareto diagram is used to identify the item with the greatest impact on total defects (see Fig. 2).

As can be seen in Fig. 2, the main issue is Kicks Hood Gap. It's concluded, using the DMAIC methodology, that the problem to be solve is the hood gap, also this kind of concern is classified as an assembly concern. In the company's definition, this item is considered an assembly concern.

Hood gap. Hood gap is a problem of body geometry, this is a type of problem that a costumer detects when looking at the vehicle without a technical knowledge, it's noticed that vehicle outside of geometry has an "ugly" aspect. In this study, gap

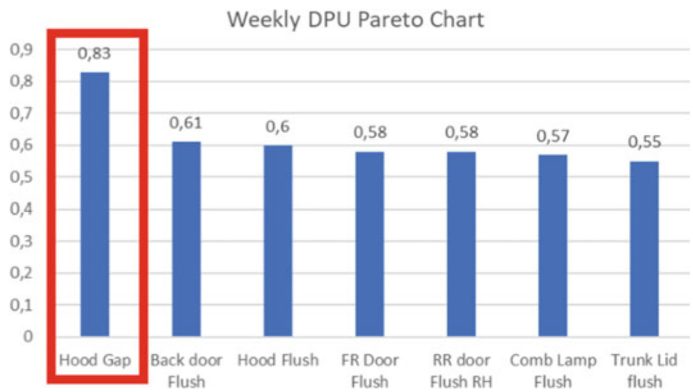


Fig. 2 DPU pareto chart. *Source* Author's own

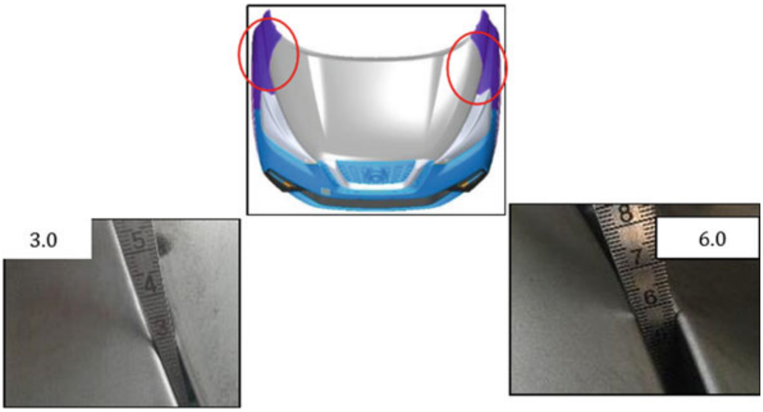


Fig. 3 Hood gap. *Source* Author's own

concern is the difference in distances between the hood x left fender and hood x right fender, the description can be seen using a body with problem as example (see Fig. 3).

In this example, the distance between the hood against left fender is 6.0 mm, the distance between hood and right fender is 3.0 mm. The nominal value is 3.5 mm, a gap greater than 4.5 mm or less than 2.5 mm is considered a defect.

4.2 Measure

Quality inspectors on the production line judge vehicles as ok or not ok, using a go no go gauge. This means that there is no measurement record for the vehicles. In order to know the condition of the vehicles using Lean Six Sigma, measurements of 100 vehicle samples were collected on the final line. The results of the statistical analysis of sample capacity (see Fig. 4).

The assembly of hood and fenders are manual process, with many variables, and have no impact on vehicle safety, so for this process the company has an acceptable capability greater than 1.0. In the graphs it's possible to see a lot of variations in the process. The Cp for gap in both sides was less than 1.0. However, this values are for vehicle condition, to confirm if this is a problem caused by the body or caused by another shop (assembly or paint), it is necessary to measure body condition before delivery to Paint Shop. The results could be seen (Fig. 5).

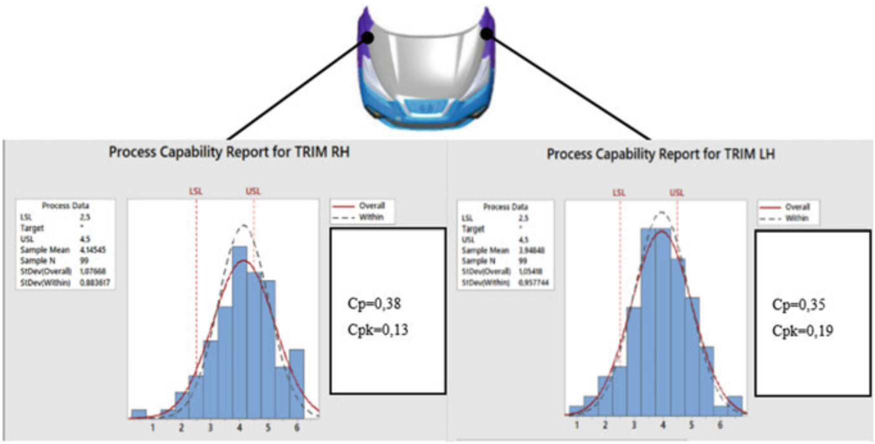


Fig. 4 Capability analysis gap hood x right/left fender on vehicle. *Source* Author's own

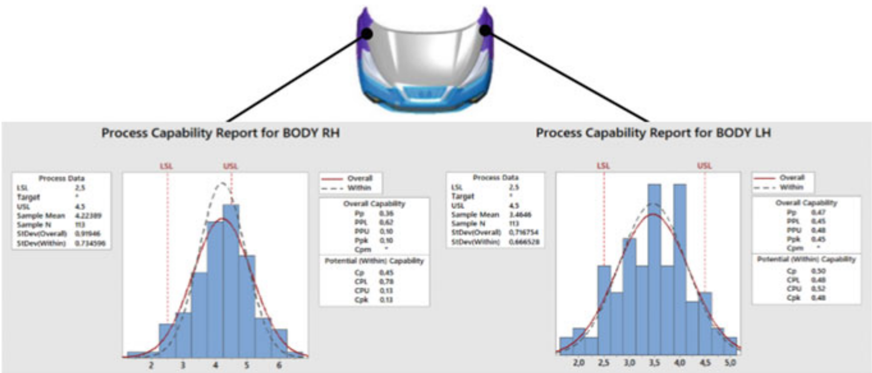


Fig. 5 Capability analysis gap hood x fender right/left side on body. *Source* Author's own

4.3 Analyze

In the analyze step, the Ishikawa diagram was applied to evaluate all process variables (see Fig. 6).

The cause and effect diagram show the main factors that can generate gap in hood and fenders. The items that have borders in red are the potential items that should be analyzed. In material there is the hinge hood (dobradiça) the articulated part that supports and opens the hood, in manpower has the execution of the activity by the operator (Seguimento de padrão), the machine factor has the hood assembly device (jig de montagem do capot), and method has the quality check (check de qualidade), that is not cause of concern, but it's cause of outflow. After confirm the hood, fender and body geometry using a laser measurement system (VTS system) the result was ok. As next step was measure hood position during body assembly using VTS system. This equipment uses a laser technology that can confirm the position of vehicle parts on a three-dimensional plane compared to design condition. The analysis continues for hood assembly measurement in four points ten times, the points could be seen in Fig. 5. The average of measurement could be seen on (Figs. 7, 8, 9, 10 and 11).

The points 1, 2, 3 and 4 are the measurement points by VTS. The graphics show the position of the hood, in millimeters. Each point has its own graph, the blue line shows the position on the x coordinate and the orange line the y coordinate, the first position shows hood position in assembly device, the second position shows hood position after tight hood and disassembly hood device. It's possible to see no variation, it's means that the device is correctly calibrated. In the second position it's possible see in all points that hood move some millimeters. The study concludes

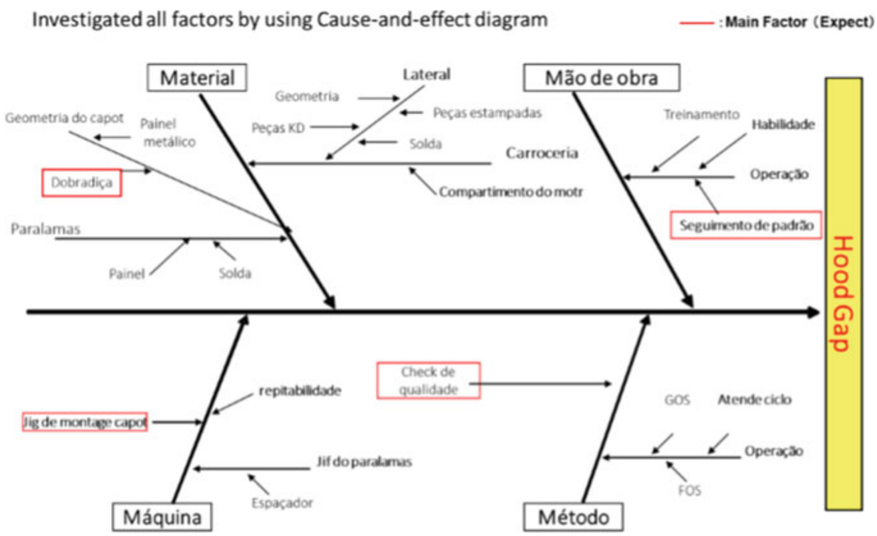


Fig. 6 Ishikawa diagram. *Source* Author's own

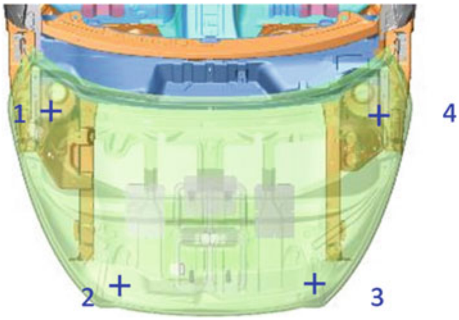


Fig. 7 Hood measurement points. *Source* Author's own

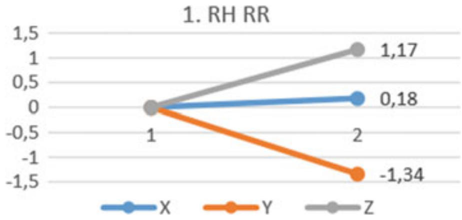


Fig. 8 POINT 1. *Source* Author's own

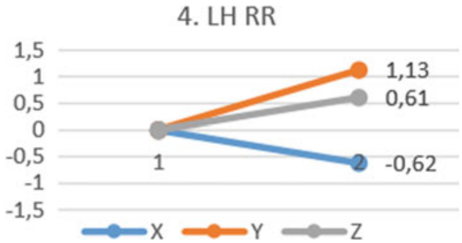


Fig. 9 POINT 4. *Source* Author's own

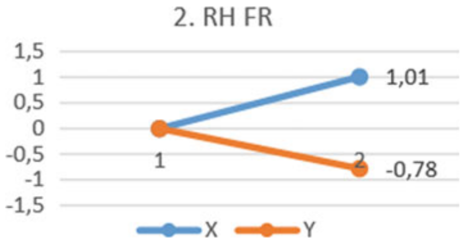


Fig. 10 POINT 2. *Source* Author's own

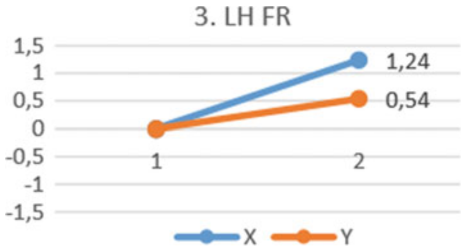


Fig. 11 POINT 3. *Source* Author's own

that hood is moving after tight. This is the main point of the concern, after found the main issue the study to evaluate the root cause of this concern. Analyzing the situation, the hood hinge could not support hood weight. The hinge was so far from device's attachment, causing hinge and hole misalignment (see Fig. 12).

Figure 12 shows the fixing hole obstructed by hinge, the study detect that operators always push hinge during bolt tight, this movement cause a tension in hinge, and after disassembly hood device, the hood could move for any direction, causing misalignment.

4.4 Improve

Analyzing the situation, the hood hinge could not support hood weight because all device attachments are so far from hinge fixing point, and the hinge support bend by hood weight causing hole misalignment during assembly, is possible to see the assembly device drawing (see Fig. 13).

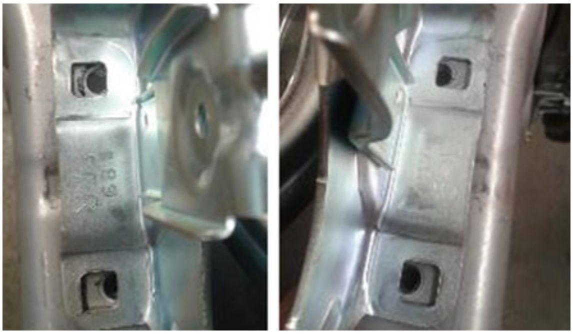


Fig. 12 Hinge bending. *Source* Author's own

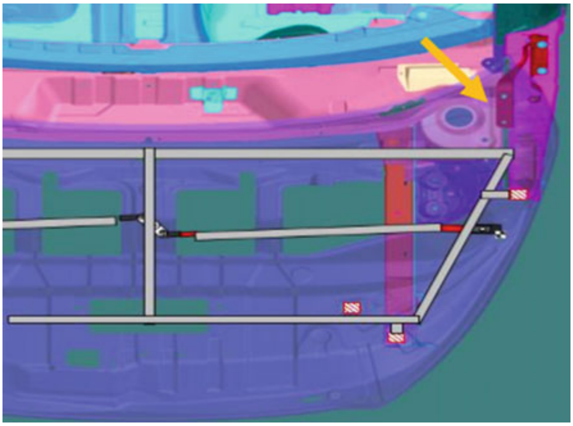


Fig. 13 Hood assembly device. *Source* Author's own

The yellow arrow on (Fig. 13) shows hinge contact point with hood and body, the squares represent the attachments that should support hood weight, is possible to see all attachments so far from hinge, the best solution at low cost is to put an attachment touching hinge to support the weight of hood and do not let the hinge twist, that drawing could be seen on (Fig. 14) and the device modified could be seen on (Fig. 15).

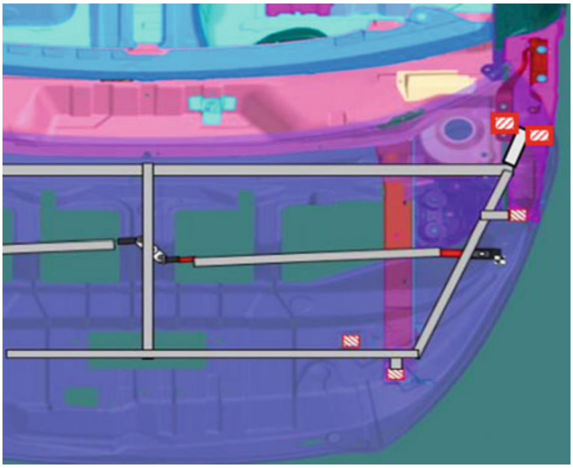


Fig. 14 Device drawing after modification. *Source* Author's own

Fig. 15 Hood device after modification. *Source* Author's own

4.5 Control

After adopt the counter measure, the next step is to control the DPU and monitoring assembly condition to avoid the recurrence. It was adopted a control chart to operator always check the hood assembly device every beginning of shift, the operator must put device in a measurement table and confirm there is no bends or broken parts. The results of countermeasure were confirmed by a capability analysis, using same methodology as the step "Measure", the results for vehicle could be seen on (Fig. 16) and for Body could be seen on (Fig. 17).

It's possible to see in the Figs. 16 and 17, Cp and Cpk is over than 1,0 in all graphs, except for the Body right side gap. Perhaps, the cp is equal 1,22, a small adjustment in fender assembly device could centralize hood. The reason of a better Cpk for vehicle is the adjust operation, when operator at vehicle line easy can fix hood or fender if Cp has a good condition and Cpk it's near than a good condition. After adopt all countermeasure and daily check for devices, the Hood gap x fender dpu was checked over 10 weeks (see Fig. 18).

In the first week the dpu reduce from 0,83 to 0,064, some vehicles that body was produce before countermeasure still in the process and this impact a the dpu in the first week, it's possible to see through the week the dpu for hood gap tending to zero,

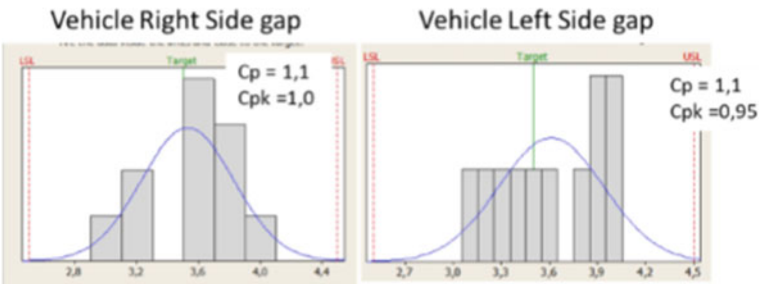


Fig. 16 Vehicle hood gap x fender left and right side. *Source* Author's own

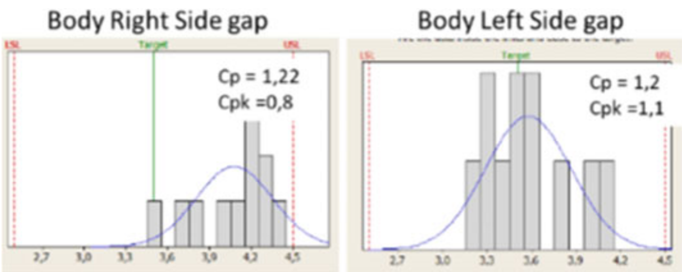


Fig. 17 Body hood gap x fender Left and right side. *Source* Author's own

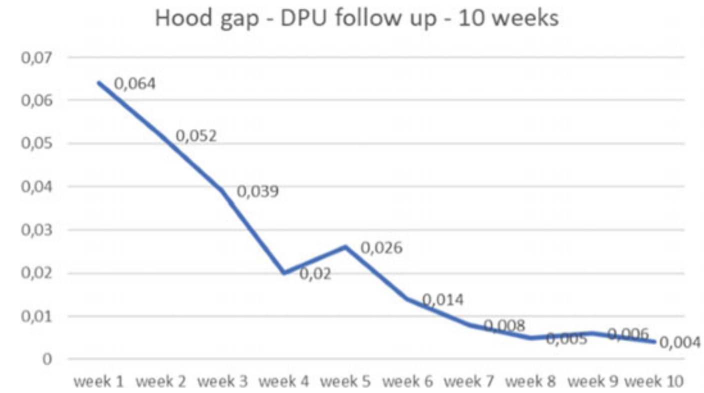


Fig. 18 Hood gap dpu in 10 weeks. *Source* Author's own

the value only did not reach zero, as this defect can be generated by other causes besides the twisting of the hinge, perhaps with a low impact on the total of the dphu.

5 Conclusion

After applied the DMAIC tools, the DPU result decrease, and the rework on hood gap stopped, only new activity that was created was the jigs daily check before start shift. Company's directors assessment of the use of DMAIC was positive. The capability analysis allows to know the stability of the process and indicated in which area the studies should focus. The company saves costs by analyzing and adopting actions in process that are already stable. After the actions the capability analysis allows to measure the effectiveness of the actions and if the process will be stable during this period Compared with other methods for solving process issues, DMAIC proved to be more effective, as it is a method of linear analysis so that problem is identified, measured, analyzed and treated. Other methods used previously, skipped steps measure and analyzing, going directly to the countermeasure, not solving the problem definitively and with high cost, or solving with several actions but without now being sure what the definitive action really was. As could be seen the dpu index for hood gap decreased from 0.83 to 0.004 in ten weeks, the expected savings generated by the reduction of rework on the hood and fenders is 44,815 Brazilian reais. The Lean Six Sigma and the DMAIC if correct applied, can generate big savings for companies in the automotive area.

References

1. IBGE – Instituto Brasileiro de Geografia e Estatística.: Panorâma 2019, Brazil (2019).
2. FENABRAVE.: Anuário do setor de distribuição de veículos automotores no Brasi/2019. Milxtor Arte, (2019).
3. Priya, S. K., Jayakumar, V. and Kumar, S. S.: Materials Today: Proceedings Defect analysis and lean six sigma implementation experience in an automotive assembly line, Materials Today: Proceedings. Elsevier Ltd., (2019).
4. Mantilla Celis, O. L., García, J. M. S.: 'Modelo tecnológico para el desarrollo de proyectos logísticos usando Lean Six Sigma', Estudios Gerenciales, 28(124), 23–43 (2012).
5. Pophaley, M. and Vyas, R. K.: Fortification of Plant Maintenance Management Practices: Role of Six Sigma Approach, Brazilian Journal of Operations & Production Management, 12(1), 56 (2015).
6. Werkema, C.: Criando a Cultura Seis Sigma, Werkema Editora (2013)
7. Morais, V. R., Sousa, S. D., Lopes, I.: Implementation of a Lean Six Sigma Project in a Production Line, Proceedings of the World Congress on Engineering, London (2015).
8. Pinto, J. S., Schuwarten, L. A., Oliveira Júnior, G. C., Novaski, O.: Proposal the application of DMAIC tools and value stream mapping under the perspective of the lean philosophy for process improvement: a case study, Brazilian Journal of Operations & Production Management, 14(4), 556 (2017).
9. Thomas, A., Lewis, G.: Developing an SME-based integrated TPM–Six Sigma strategy. International Journal of Six Sigma and Competitive Advantage, Vol. 3, No. 3, 228–247 (2007).
10. Gonçalez, P. U. and Werner, L.: Comparação dos índices de capacidade do processo para distribuições não-normais', Gestão & Produção (UFSCAR. Impresso), 121–132 (2009).
11. Kane, V. E. Process capability indices. Journal of Quality Technology, v. 18, n. 1, p. 41–52, 1986.

PROMETHEE-SAPEVO-M1 a Hybrid Modeling Proposal: Multicriteria Evaluation of Drones for Use in Naval Warfare

Miguel Ângelo Lellis Moreira, Carlos Francisco Simões Gomes, Marcos dos Santos, Marcela do Carmo Silva, and Jonathas Vinícius Gonzaga Alves Araujo

Abstract Regarding the theme of naval warfare and its needs when addressing the use of tools and instruments for its enhancement, this study aims to present a case based on the need of the Brazilian Navy to carry out a possible acquisition of a Remotely Piloted Aircraft System for use in naval warfare. It was proposed the new hybrid modeling PROMETHEE-SAPEVO-M1, based in Multicriteria Decision Methods, as a methodology and for the decision analysis of this case, which allows a detailed assessment with not only qualitative data, but also quantitative data in the case, a structured format for evaluating and obtaining weights for the criteria, and three integrated models of results analysis. In addition to the proposed method, a computational tool developed in the Python language was used to assist the decision-making agent in the process of analyzing and evaluating the aircraft regarding the required criteria. The proposed method proves to be effective and legitimate because through it is possible to evaluate data of different natures in an equivalent evaluation format, generate weights and have three models of results analysis, providing to the Brazilian Navy a complete, robust and integral analysis with attention to details of the most favorable remotely piloted aircraft in the naval warfare.

Keywords Drones · Remotely piloted aircraft system · Multicriteria decision aiding

M. Â. L. Moreira (✉) · J. V. G. A. Araujo
Military Institute of Engineering (IME), Urca, RJ 22290-270, Brazil
e-mail: miguellellis@hotmail.com

C. F. S. Gomes · M. dos Santos · M. do Carmo Silva
Fluminense Federal University (UFF), Niterói, RJ 24210-346, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_31

1 Introduction

The Remotely Piloted Aircraft (RPA), also known as a 'drone', has been arousing interest for its numerous and varied applications. Initially considered only as a flying device with limited resources, currently the RPAs present in their systems more elaborate resources and technologies, enabling their use in civil and military scope, as in naval warfare operations [1].

The technological advance of the last years allowed the improvement of these types of equipment. The inclusions of technological devices, such as sensors, radars, cameras, and armament, have expanded their applications. In the naval warfare operations, the RPAs are employed in logistics, surveillance, sensing, reconnaissance and combat support operations [1].

Numerous are the equipment models developed by companies of technological renown, with the most varied system specification [2]. The RPA application must consider a system of equipment, so a RPAS (Remotely Piloted Aircraft System) consists of the integration of four subsystems, they are: the aircraft, payload (sensors and armament), control station and communication devices [3].

For the employment of the RPAs in naval warfare, we must consider a set of criteria and some variables that influence the choice of the most favorable system, as an example: velocity, range, weight, autonomy, devices, etc. By the application of methods and algorithms presented in the Operational Research (OR), it is possible to solve real problems present in different areas of human activity [4]. Regarding this case, the application of Multiple Criteria Decision Methods (MCDM) in the structuring problem, would enable the Brazilian Navy a robust analysis regarding which is the most favorable RPA for using in the naval operations [1].

The multicriteria methods can be understood as techniques that enable the structuring and analysis of complex evaluation problems in a transparent manner, with the introduction of quantitative and qualitative criteria, in specific cases, with trade-offs between them [5]. In a MCDM it is necessary that the modeling allows the subjectivity of the evaluation, where the fundamental problem of multicriteria analysis is the association of preference relations (subjectivity) between the criteria in the decision process [6].

These methods support a decision making process, considering various aspects of evaluation, such as technical, socioeconomic, and environmental at operational and strategic levels for decision making [7]. It is noteworthy that the methods present in the MCDM do not aim to present a definitive solution and solve all kinds of problems, but to support the decision process meeting the requested constraints, within an analyzed context [8].

Related for quantitative decision analysis, the method of French School PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations), proposed by Brans et al. [9], is related to the hierarchical relation models, where the preferential order of the variable of each criterion analyzed is normalized by a preference function. The decision maker should indicate the information between each criterion, as which one must be maximized or minimized, and which preference function needs to be applied in each criterion [10].

Enabling an analysis with qualitative and quantitative data allowing by ordinal inputs, the method SAPEVO-M (Simple Aggregation of Preferences Expressed by Ordinal Vectors—Multi Decision Makers), evolution of original SAPEVO [11], designed to problematics that aim to clarify the decision by the grouping of actions in equivalents classes, ordering to the preferences of the decision maker.

1.1 Questions and Objectives

This paper aims to present a hybrid modeling composed of the PROMETHEE and SAPEVO-M methods, enabling a decision analysis composed of data with different natures. A model of result with three different analysis formats is also implemented, providing a methodology that allows the decision maker a sensitivity analysis, comparing the results, bringing gains for a robust analysis.

To enable effective implementation of the method to the study in analysis, a computational tool was developed, supporting the evaluation of the data in the given case, serving as a basis for the Brazilian Navy in the evaluation of the RPAs to the naval warfare operations.

After the paper introduction, Section 2 will present the axiomatic structure of the new modeling, named PROMETHEE-SAPEVO-M1. Section 3 will present an implementation of the modeling in a case study intended to a multicriteria evaluation based on the analysis of drones for use in naval warfare by the Brazilian Navy. Section 4 concludes the work, presenting the gains of the new method, and proposal for future works.

2 PROMETHEE-SAPEVO-M1

The modeling is based on a basic structure of the PROMETHEE method, with the insertion of technics present in the SAPEVO-M method, which enables an evaluation with qualitative and quantitative data. Considering a mono decision maker method will be added a new way of weight set to the evaluation criteria.

The method works in steps, being the first used to structuring problems, defining the number of alternatives, qualitative and quantitative criteria of evaluation. Following the process, the alternatives firstly will be evaluated in the qualitative criteria and then in the quantitative criteria. The quantitative analysis will be worked as the basic structure of the PROMETHEE method, the following steps are the weights set to the respective criteria and the obtaining of outranking flows to results analysis.

The evaluation process is structured in a matrix (Criterion x Alternative), considering a set of alternatives *A*, where a_i *A*, $i = 1, \ldots, n$, evaluating in a set of qualitative criteria *h*, $h = 1, \ldots L$, and a set of quantitative criteria *j*, $j = 1, \ldots k$.

Alternatives						
Criteria		$\boldsymbol{a_1}$	$\boldsymbol{a_2}$	$\boldsymbol{a_3}$	**…**	$\boldsymbol{a_n}$
	$\boldsymbol{h_1}$	a_{11}	a_{21}	a_{31}	…	a_{n1}
	$\boldsymbol{h_L}$	a_{1L}	a_{2L}	a_{3L}	…	a_{nL}
	$\boldsymbol{j_1}$	a_{11}	a_{21}	a_{31}	…	a_{n1}
	$\boldsymbol{j_k}$	a_{1k}	a_{2k}	a_{3k}	…	a_{nK}

2.1 Qualitative Evaluation

The evaluation will be performed concerning qualitative criteria *h*, $h = 1, \ldots L$. The process is characterized by a comparative analysis between the alternatives from set A to each criterion from set h. The analysis is based on the preference evaluation present on an importance scale, Table 1.

For each qualitative criterion evaluated, it is obtained a comparison matrix between the elements belonging to the set *A*. By the equations, the values are normalized (1), obtaining an importance degree of that alternative in a specific criterion.

$$\upsilon = \frac{a_{ij} - \text{min} a_{ij}}{max a_{ij} - \text{min} a_{ij}} \tag{1}$$

Obtained the importance values of alternatives, they are submitted to a maximization evaluation $P_j(a_1, a_2) = P(x) = P[f(a_1) - f(a_2)]$. With a new matrix, the values are normalized by a function with linear variation (2), then is obtained a normalized matrix for each criterion from set h.

$$P(x) = \begin{cases} x/r & x \leq r \\ 1 & x > r \end{cases} \tag{2}$$

Table 1 Importance scale

Absolutely worse	−3
Much worse	−2
Worst	−1
Equivalent	0
Best	1
Much better	2
Absolutely better	3

Table 2 Preference functions

Type	$P(x)$	Parameters	Type	$P(x)$	Parameters
Usual	$P(x) = \begin{cases} 0 & x = 0 \\ 1 & x > 0 \end{cases}$	–	Level	$P(x)\begin{cases} 0 & x \leq q \\ 1/2 & q < x < p \\ 1 & x > p \end{cases}$	q, p
U-shape	$P(x) = \begin{cases} 0 & x \leq q \\ 1 & x > q \end{cases}$	q	V-shape I	$P(x) = \begin{cases} 0 & x \leq q \\ \frac{x-q}{p-q} & q < x \leq p \\ 1 & x > p \end{cases}$	q, p
V-shape	$P(x) = \begin{cases} x/p & x \leq q \\ 1 & x > p \end{cases}$	p	Gaussian	$P(x) = \begin{cases} 0 & x \leq 0 \\ 1 - e^{-x^2/2s^2} & x \geq 0 \end{cases}$	s

Adapted from [12]

2.2 *Quantitative Evaluation*

Evaluation of alternatives regarding the quantitative criteria *j*, $j = 1, \ldots k$. In this step, the analysis structure from the PROMETHEE method maintained in its basic modeling. For each quantitative criterion, it is necessary to specify a general preference function (P_j: $A \; x \; A \rightarrow [0,1]$).

Comparing the alternatives a_1 and a_2 of set *A*, the function $P_j(a_1, a_2) = P(x) = P[f(a_1) - f(a_2)]$ represents the preference degree of a_1 in relation to a_2 according to the criterion *j*. When the criterion needs to be maximized, uses $x = f(a_1) - f(a_2)$ to define a preference function. If it is necessary to minimize the criterion, $x = f(a_2) - f(a_1)$ is used as preference function.

Six types of preference functions (Table 2) have been proposed to normalize the values obtained from the differences between the alternatives [12]. The functions have parameters strict preference (p) and indifference (q).

2.3 *Weights*

Considering a mono decision maker analysis, the evaluation SAPEVO-M1 will consider the qualitative and quantitative criteria in one set j, $j = 1, \ldots, L + k$. Using the importance scale, Table 1, it will be obtained how important a certain criterion is in relation to the other from the set. In SAPEVO-M1 a maximum and minimum possible sum value is considered within criteria set j.

The *maximum sum* is obtained by $x = (n - 1).\,3$, representing the highest possible sum value within that assessment. As closer a criterion is to *maximum sum*, greater will be its dominance in the set.

The *minimum sum* is obtained by $x = (n - 1).\,-3$, representing the lowest possible sum value within that assessment. As lower be the value and its closer to the *minimum sum*, the criterion will represent a little importance in the set.

The values obtained in the evaluation will be normalized by Eq. (3). After the normalization, the sum of degrees obtained will be equivalent to 1 and the points will be weighted according to their respective criteria.

$$\upsilon = \frac{a_{ij} - (\max_{\text{sum}})}{(\max_{\text{sum}}) - (\min_{\text{sum}})} \tag{3}$$

Obtained the normalization matrices and weights, the global preference index π (a_1, a_2) will be calculated for each pair compared, indicating the preference degree of alternative a_1 over a_2, considering the weights assigned to each criterion, where (4):

$$\pi(a_1, a_2) = \sum_{j=1}^{n} a_j P_j(a_1, a_2) \tag{4}$$

2.4 Partial Pre-ordering

Using the positive outranking flows (5), characterized by the dominance level of a_1 over all other alternatives from the set, and the negative outranking flows (6), representing the dominance level of all alternatives over a_1, it is possible to obtain a partial pre-ordering evaluation, where:

$$\Phi^+(a_1) = \frac{1}{n-1}.\sum_{x \in A}^{n} \pi(a_1, x) \tag{5}$$

$$\Phi^-(a_1) = \frac{1}{n-1}.\sum_{x \in A}^{n} \pi(x, a_1) \tag{6}$$

- a_1 is preferable to a_2 ($a_1 P a_2$) if $\begin{cases} \Phi^+(a_1) > \Phi^+(a_2) and \Phi^-(a_1) < \Phi^-(a_2) \\ \Phi^+(a_1) = \Phi^+(a_2) and \Phi^-(a_1) < \Phi^-(a_2) \\ \Phi^+(a_1) > \Phi^+(a_2) and \Phi^-(a_1) = \Phi^-(a_2) \end{cases}$
- a_1 is indifferent to a_2 ($a_1 I a_2$) if $\Phi^+(a_1) = \Phi^+(a_2) and \Phi^-(a_1) = \Phi^-(a_2)$
- a_1 is incompatible to a_2 ($a_1 R a_2$) if $\begin{cases} \Phi^+(a_1) > \Phi^+(a_2) and \Phi^-(a_1) > \Phi^-(a_2) \\ \Phi^+(a_1) < \Phi^+(a_2) and \Phi^-(a_1) < \Phi^-(a_2) \end{cases}$

2.5 Total Pre-ordering

The evaluation consists of the using of preference (p) and indifference (i) relations, utilizing the net outranking flows obtained by the Eq. (7), enabling a total pre-ordering evaluation.

$$\Phi(a_1) = \Phi^+(a_1) - \Phi^-(a_1) \tag{7}$$

- a_1 is preferable to a_2 ($a_1 P a_2$) if $\Phi(a_1) > \Phi(a_2)$
- a_1 is indifferent to a_2 ($a_1 I a_2$) if $\Phi(a_1) = \Phi(a_2)$

2.6 Pre-ordering by Intervals

For each alternative a_1, by a standard error value, an interval $[x(a_1), y(a_1)]$ is generated (8), defining a total pre-ordering of intervals, where:

$$\begin{cases} x_{a_1} = \bar{\Phi}(a_1) - \alpha\sigma_{a_1} \\ y_{a_1} = \bar{\Phi}(a_1) + \alpha\sigma_{a_1} \end{cases} \tag{8}$$

- a_1 is preferable to a_2 ($a_1 P a_2$) if $x_{a_1} > y_{a_2}$
- a_1 is indifferent to a_2 ($a_1 I a_2$) if $x_{a_1} \leq y_{a_2} and x_{a_2} \leq y_{a_1}$

Simplifying, $\left[x_{a_1}, y_{a_1}\right]$ is an interval where the center is the net flow average and the proportional length to the standard error obtained by the distribution of the numbers $\pi(a_1, a_2) - \pi(a_2, a_1)$.

3 Case Study

For the application of the proposed modeling in the case study, six RPAS (Table 3) are evaluated. For the study was analyzed a set of critical variables that directly influence the application of aircraft in operations of surveillance, sensing, logistics, reconnaissance, and combat.

Considering the presence of criteria with different natures, the PROMETHEE-SAPEVO-M1 hybrid modeling will enable a decision analysis with data of qualitative and quantitative origin. The method will also allow the Brazilian Navy to obtain, in a structured way, the respective weights and amounts for each criterion. As presented in Table 4, were evaluated, under a set of 14 criteria, five qualitative and nine quantitative.

The software developed follows the axiomatic structure of the PROMETHEE-SAPEVO-M1 method, step by step. As exposed in Fig. 1, firstly is defined and named the alternatives and criteria. Starting the qualitative evaluation, the alternatives are

Table 3 RPA to evaluation

RPA	Company	Figure
Hermes 900	Ael	
Skeldar V-200 M	Saab	
Camcopter S-100	Schiebel	
Tanan 300	Cassidian	
Pelicano	Indra	
Scan Eagle	Insitu	

Table 4 RPA evaluation matrix

	Hermes 900	Skeldar V-200 M	Camcopter S-100	Tanan 300	Pelicano	Scan Eagle
Wing type	Fixed	Rotary	Rotary	Rotary	Rotary	Fixed
Takeoff model	Runway	Base	Base	Base	Base	Catapult
Sensor integration	Yes	Yes	Yes	Yes	Yes	Yes
Weapon integration	No	No	Yes	yes	Yes	No
Autonomous flight function	Yes	Yes	Yes	No	Yes	No
Maximum speed (Km/h)	220	150	222	150	185	148
Cruising speed (Km/h)	112	100	102	100	90	110
Range (Km)	Unlimited	200	200	180	100	100
Autonomy (h)	36	5	6	8	6	24
Altitude (ft)	30,000	9,842	18,000	13,000	11,800	19,500
Maximum takeoff weight (Kg)	1180	235	200	350	200	22
Propeller/wing extension (m)	15	4.6	3.4	6.3	3.3	3.11
Length (m)	8.3	4	3.11	5.2	4	1.71
Payload capacity (kg)	350	40	50	80	30	3.4

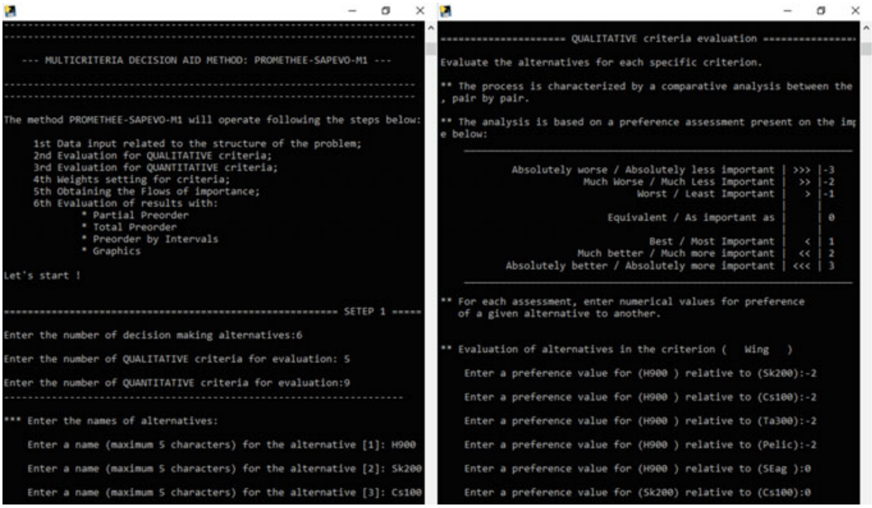


Fig. 1 Entry data and qualitative evaluation (Software PROMETHEE-SAPEVO-M1)

evaluated pairwise, at the end of the evaluation, it is generated a normalized matrix with the preference degrees for each alternative in a specific qualitative criterion.

As stated in Sect. 2.2, the method performs a quantitative evaluation, it is requested to the decision maker the numeric values respective to each alternative in the criterion. With the data entered, the software prompts specify which quantitative criterion must be maximized or minimized and indicate which function will be used for normalization along with its parameters, Table 5 exposes this information.

The next step is intended to the obtaining of weights, representing the importance of each criterion in the given case. According to Sect. 2.3, it is realized a pairwise evaluation, the matrix obtained is exposed to Table 6, representing the relation of importance between the criteria of the case study.

Table 5 Functions for quantitative evaluation

	Function	Function type	Indifference (q)	Preference (p)
Maximum speed (Km/h)	Maximize	V-shape	–	30
Cruising speed (Km/h)	Maximize	V-shape	–	20
Range (Km)	Maximize	V-shape	–	50
Autonomy (h)	Maximize	V-shape I	1	2
Altitude (ft)	Maximize	V-shape I	1000	3000
Maximum takeoff weight (Kg)	Minimize	V-shape	–	50
Propeller/wing extension (m)	Minimize	V-shape I	0.5	1
Length (m)	Minimize	V-shape I	1	2
Payload capacity (kg)	Maximize	V-shape	–	30

Table 6 Criteria comparison evaluation

Importance Scale	
Absolutely worse	**-3**
Much worse	**-2**
Worst	**-1**
Equivalent	**0**
Best	**1**
Much better	**2**
Absolutely better	**3**

	Wing type	Takeoff model	Sensor integration	Weapon integration	Autonomous f. func.	Maximum speed	Cruising speed	Range	Autonomy	Altitude	Maximum takeoff w.	Propeller / wing ext.	Length	Payload Capacity
Wing type	0	-3	-3	-3	-3	-2	-2	-3	-3	-3	-1	0	0	-3
Takeoff model	3	0	1	1	0	1	1	0	2	0	3	3	3	1
Sensor integration	3	-1	0	1	1	3	3	3	3	3	3	3	3	2
Weapon integration	3	-1	-1	0	-2	1	1	-1	1	1	2	3	3	2
Autonomous flight function	3	0	-1	2	0	3	3	3	3	3	3	3	3	2
Maximum speed	2	-1	-3	-1	-3	0	-2	-1	-1	-1	0	2	2	-2
Cruising speed	2	-1	-3	-1	-3	2	0	1	0	1	2	3	3	0
Range	3	0	-3	1	-3	1	-1	0	0	0	3	3	3	1
Autonomy	3	-2	-3	-1	-3	1	0	0	0	0	1	2	2	-1
Altitude	3	0	-3	-1	-3	1	-1	0	0	0	1	2	2	-1
Maximum takeoff weight	1	-3	-3	-2	-3	0	-2	-3	-1	-1	0	0	0	-2
Propeller / wing extension	0	-3	-3	-3	-3	-2	-3	-3	-2	-2	0	0	0	-3
Length	0	-3	-3	-3	-3	-2	-3	-3	-2	-2	0	0	0	-3
Payload Capacity	3	-1	-2	-2	-2	2	0	1	1	1	2	3	3	0

Table 7 Criteria weights

Criteria	Weight	Criteria	Weight
Wing type	0.018	Range	0.086
Takeoff model	0.106	Autonomy	0.070
Sensor integration	0.126	Altitude	0.071
Weapon integration	0.093	Maximum takeoff weight	0.037
Autonomous flight function	0.126	Propeller/wing extension	0.022
Maximum speed	0.055	Length	0.022
Cruising speed	0.082	Payload capacity	0.084

The next step is intended to the obtaining of weights, representing the importance of each criterion in the given case. According to Sect. 2.3, it is realized a pairwise evaluation, the matrix obtained is exposed to Table 6, representing the relation of importance between the criteria of the case study (Table 7).

With the weights obtained, it is calculated the global preference index and by the positive, negative, and net outranking flows, it is possible to analyze the dominance degree of each RPA to the other in the set. In Table 8 is presented the values of flows, respective to each alternative.

With the flows, it is possible to obtain the partial and total pre-ordering, along with the evaluation by intervals. In Fig. 2 is exposed to three charts, generated by the computational tool, showing the results in three different ways of analysis.

In the partial pre-ordering chart, the alternative most favorable is the RPA Camcopter S-100 and Hermes 900, where they obtained an incomparability relation among themselves, however, concerning the others, both are preferable. In the graphic, the preference relation is characterized by the cross of the lines, generated by the positive and negative flows.

The second analysis, total pre-ordering evaluation, it is presented a preference ordering from the most favorable alternative to the least favorable. The analysis is generated by the net outranking flows, how higher it is the value obtained, more favorable is the alternative. In the case study, the RPA Camcopter S-100 and Hermes

Table 8 Preference flows

RPA	Positive	Negative	Net
Hermes 900	0.162	0.088	0.074
Skeldar V-200 M	0.068	0.106	−0.038
Camcopter S-100	0.129	0.048	0.081
Tanan 300	0.101	0.117	−0.016
Pelicano	0.084	0.107	−0.023
Scan Eagle	0.078	0.156	−0.078

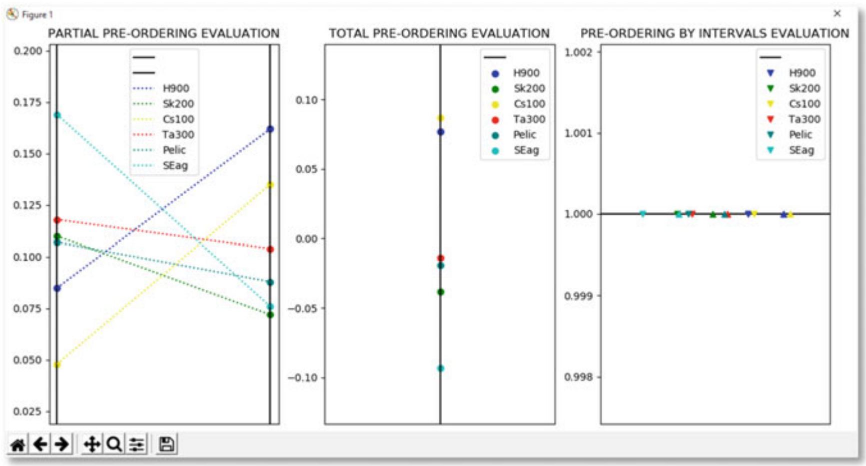


Fig. 2 Evaluations charts (Software PROMETHEE-SAPEVO-M1)

900 obtained the best degrees, however, the alternative Camcopter presented a small advantage concerning Hermes, thus being classified as the most favorable RPA on evaluation.

In the third analysis format, it was obtained a standard error of 0.026, this value enables the creation of an interval by the values of upper and lower limits. In this evaluation, the alternatives with the best ratings, Camcopter S-100 and Hermes 900 become indifferent to each other and both are preferable over the other in the set. A greater advantage of this analysis model is to know if one alternative is really superior to another.

Considering all evaluations exposed, it is clear to understand which aircraft it is more favorable for applying, however, it is also possible to recognize an option that was not favorable in any evaluation model. The three analysis models bring gains for decision making, enabling a sensitivity analysis, and providing security for the final decision.

4 Conclusion

The proposed study aimed to present a real case where the application of a multi-criteria method enabled a high impact evaluation for the Brazilian Navy. The hybrid method presented, PROMETHEE-SAPEVO-M1, proves to be efficient and effective at the moment that enables evaluate data with different natures in an equivalent analysis.

The proposed modeling presents it robust handing a weight set in a structured form, enabling the decision maker to exposes his preference between the criteria in a transparent manner. The inclusion of three models of results analysis based on different models of preference ordering, provides to the decision maker a sensitivity analysis comparing the obtained results in a given case, enabling recognize the most favorable alternative with security in the decision.

The tool developed for implementation of the method, offers a significant gain regarding the model application, guiding the user during the process of entering data and the evaluation of alternatives in the criteria set. The software presented can be applied in different contexts of decision analysis with multiple criteria evaluations, enabling a robust analysis by scripts and graphic models of results.

Regarding the Brazilian Navy, this paper is expected to support the military organization in a decision analysis related to which are the most favorable RPA for application in the naval warfare operations.

As a proposal for future works, it is intended to be applying the PROMETHEE-SAPEVO-M1 method in other cases of multicriteria decision analysis, in a search of identifying points of improvement in the modeling or new technics to integrate, gaining more robust in the new multicriteria decision method.

References

1. Braga, C. C.: A Ação de Drones na Guerra Naval. Revista Marítima Brasileira, v. 139. Rio de Janeiro (2019).
2. Giones, F., Brem, A.: From toys to tools: The co-evolution of technological and entrepre-neurial developments in the drone industry. Business Horizons, v. 60, n. 6, pp. 875–884 (2017).
3. Pecharromán, J. M. P., Veiga, R.: Estudo Sobre a Indústria Brasileira e Europeia de Veículos Aéreos Não Tripulados. [S. l.] (2016).
4. Santos, Marcos; Quintal, R.S.; Paixão, A.C.; Gomes, C.F.S. Simulation of operation of an integrated information for emergency pre-hospital care in Rio de Janeiro municipality. Procedia Computer Science, v. 55, p. 931–938, 2015.
5. Gomes, L. F. A. M., Gomes, C. F. S.: Princípios e métodos para a tomada de decisão: Enfo-que multicritério (6a ed.). São Paulo: Atlas (2019).
6. Cardoso, R. S., Xavier, L. H., Gomes, C. F. S., Adissi, P. J.: Uso de SAD no apoio à decisão na destinação de resíduos plásticos e gestão de materiais. Pesquisa Operacional, 29(1), pp. 67–95 (2009).
7. Greco, S., Figueira, J., Ehrgott, M.: Multiple criteria decision analysis. New York: Springer (2016).
8. Almeida, A. T., Cavalcante, C.A.V., Alencar, M. H., Ferreira, R. J. P., Almeida-Filho, A. T., Garcez, T. V. Multicriteria and multiobjective models for risk, reliability and mainte-nance deci-sion analysis. International Series in Operations Research and Management Sci-ence. 2015.
9. Brans, J. P., Vincke, P. H., Mareschal, B.: PROMETHEE: A new family of outranking meth-ods in multicriteria analysis. Universite Libre de Bruxelles (ULB) (1984).
10. Brans, J. P., Smet, Y.: PROMETHEE methods. In: Multiple criteria decision analysis. Springer, New York, NY, pp. 187–219 (2016).
11. Gomes, L. F. A. M., Mury, A. R., Gomes, C. F. S.: Multicriteria ranking with ordinal data. Systems Analysis Modelling Simulation, v. 27, pp. 139–146 (1997).
12. Brans, J. P., Vincke, P. H., Mareschal, B.: How to select and how to rank projects: The PROMETHEE method. European journal of operational research, v. 24, n. 2, pp. 228–238 (1986).

Application of Statistical Process Control in Painting Office Supplies

Eduardo da Silva Fernandes, Gabriela Belotti, Gustavo Henrique Ceni, Carla Schwengber ten Caten, and Verônica Maurer Tabim

Abstract In recent years, many areas of the industrial sector have experienced fast technological advances and, therefore, have required even more specific tools to control and evaluate their production processes. Statistical Process Control (SPC) is one of the most powerful tools developed to help in effective quality control. Through the control charts, deviations of representative parameters of the process can be detected, reducing the amount of products out of specifications and thereby production costs. This paper aims to use SPC to analyze the variability and stability of a painting process in an office supplies industry. The tools used were the mean and range control charts and the capability analysis. The data were collected taking into account the sequences that make up the paint application process, seeking to offer an improvement in the quality levels of this process to reduce production costs. The results found are of great importance for the company, as control limits that have been established and will allow the process monitoring. In cases where the analysis diagnosed the process remaining out of control, it was necessary to study its causes of variability.

Keywords Statistical process control · Control charts · Production process

E. da Silva Fernandes (✉) · G. Belotti · G. H. Ceni · C. S. Caten · V. M. Tabim
Department of Industrial Engineering, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil
e-mail: edu.silva.fernandes@gmail.com

G. Belotti
e-mail: gbkfestofados@gmail.com

G. H. Ceni
e-mail: Ghceni@gmail.com

C. S. Caten
e-mail: carlacaten@gmail.com

V. M. Tabim
e-mail: veronicatabim@hotmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_32

1 Introduction

The intense competitiveness and the trade barriers reduction with the creation of large economic blocks are the main reasons for changes in the quality and productivity sectors of the organizations [1]. In the face of this increasingly competitive market, companies have been looking for different alternatives to reduce production costs, increase the quality of processes, eliminate waste and reduce the variability of their processes [2].

In this way, statistical tools have come to be valued as extremely important means in the development of organizations and for their strategic alignment [3]. One of these statistical tools is Six Sigma, originated in the 1980s at Motorola, aiming to use real data in solving complex problems in organizations and identifying the root cause, the solution and its statistical control [4]. Six Sigma is also one of the main tools of Statistical Process Control (SPC).

Thus, this paper aims to analyze the variability and stability of a painting process in an office supplies industry. For this purpose, Statistical Process Control was used, more specifically the mean and range control charts and the capability analysis.

The theoretical background related to this work is presented in Sect. 2. Next, the methodological procedures are presented. The empirical results are presented in Sect. 4. Finally, the final conclusions are presented in Sect. 5.

2 Six Sigma

According to Allen [5], Six Sigma is a tool that aims to eliminate defects arising from the production processes. There are two approaches to applying Six Sigma: (i) strategic, and (ii) statistics. The strategic approach is related to a comprehensive perception of the process by which a respective strategy is being implemented, seeking continuous improvement of business performance, boosting the competitive potential of organizations due to improvements in the quality of processes and products [6].

If the statistical approach is the focus, the quantification of variation is prioritized, which is done in quantities of standard deviations associated with a random variable of interest in the study of a critical process [6]. This statistical approach not only improves quality, but also enables an increase in organizational performance as a whole.

Six Sigma also uses a set of tools that are applied within a simple improvement model known as DMAIC, which means Define-Measure-Analyze-Increase-Control [7]. These steps can be characterized as follows:

Define: Improvement goals are defined, which will be the organization's strategies, such as reaching a larger market share or returns on investments

Measure: the results of the existing system are measured, that is, it is necessary to create valid and reliable metrics to help control improvements before a starting point. In this case, it is interesting to use an exploratory and descriptive analysis to better understand the data;

Analyze: the means of how to reach the set goals is analyzed using statistical tools to guide the analysis;

Incremental: in this step, improvements are made to the system, incrementing new techniques and seeking to optimize processes in order to become cheaper and more effective;

Control: after all the others have already been applied, it is necessary to control the new system and be aware of new improvements with the possibility of application.

3 Methodology

This research can be classified according to the approach as being quantitative. According to the objectives, this research can be classified as being descriptive. Finally, based on the technical procedures used, it is possible to classify this research as a research-action, as it consists of action to solve a problem [8].

The present work aims to analyze the variability and stability of the painting process in an office supplies industry. Other information about the company cannot be provided for reasons of confidentiality. Like several other companies in the current market, it seeks to optimize its processes in order to reduce costs and improve the products quality. As the company has a Quality Management System, the application of the Six Sigma methodology as an improvement technique can be a viable instrument. In this way, the company seeks to update itself in quality control strategies by applying Statistical Process Control in the painting parts area.

Currently, the painting process is carried out in a continuous powder painting line and takes place in six steps: initially the parts are placed on an overhead conveyor, undergo a preparation bath for painting in a spray wash booth. After that, its moisture is removed in the drying oven, the paint is applied to the parts in the powder painting booth with spray, the curing of the paint applied to the parts in the polymerization oven occurs, and finally, the parts are removed by hand from the air carrier.

3.1 Problem Description

After the painting process, it was detected through a routine inspection that parts painted with the black micro-textured paint of the Interpon 600 line were outside the thickness standard for such surface finish as specified by the manufacturer. Until the present study, no part was rejected when using such a measurement, only visual finishing criteria were used. Taking into account the importance of painting the parts for their durability and for the company's reputation, it was deemed essential by the company's factory management to assess the stability of the process.

3.2 Experiment Description

The present experiment aims to characterize the stability of the painting process with the microtextured black ink of the Interpon 600 line. According to the operators involved in the painting process, the variation described in the present work was due to the variation in the thickness of the steel sheets. The process is believed to be optimized for thicker carbon steel sheets.

In this way, it was selected the part of less thickness currently painted with the paint in question, internal code 15497, whose base material is 1.2 mm thick SAE 1010 carbon steel and the thickest part currently painted with paint, internal code 15494 whose base material is 6.35 mm thick 1010 carbon steel. With this, we seek to evaluate the stability of the process itself.

3.3 Data Collect

Together with the company's quality sector, six points of interest were defined in the parts to be evaluated. For part code 15497, the points are shown in Fig. 1, while for part code 15494, the points are shown in Fig. 2.

For the measurement of the paint layer at the specified points, a layer thickness meter from the manufacturer Mitutoyo, model Digi-Derm, was used. The data were

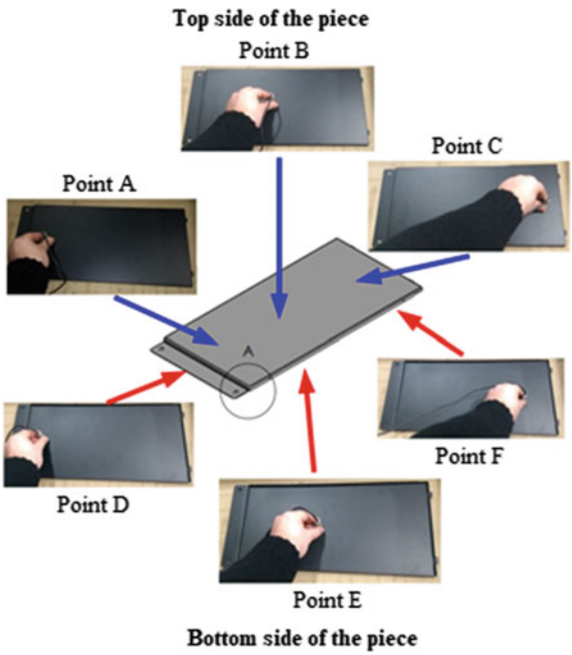
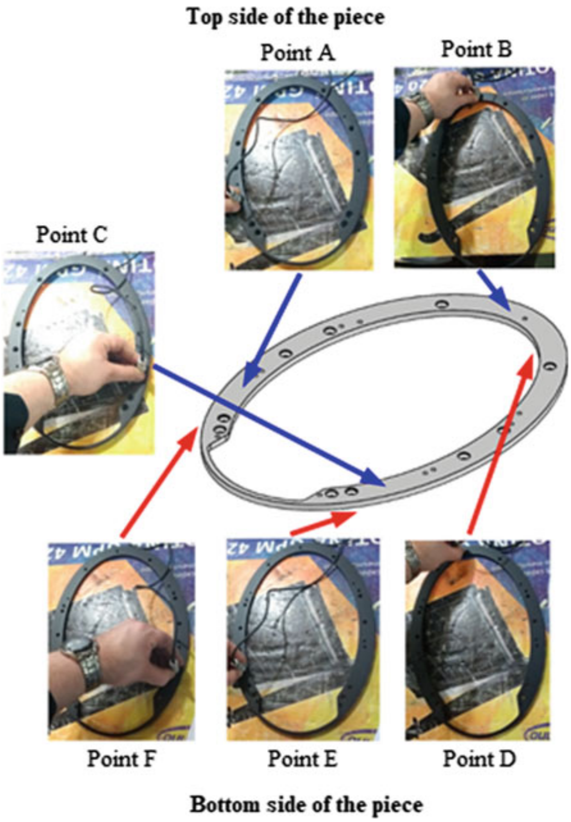


Fig. 1 View of part 15497 checkpoints

Fig. 2 View from the sides of part 15494



collected on May 21, 2018, in the morning, with an ambient temperature of 7 °C. The thickness data for the determined points were collected for 30 parts for part code 15497 and 30 parts for part code 15494, see Tables 1 and 2.

For data analysis, mean and range control chart and capability analysis were used. Minitab software was used to plot these and to calculate the control limits.

4 Results

For part code 15497, the control chart was plotted for the mean and amplitude, shown in Fig. 3.

For the part code 15494, the control chart for mean and range was plotted and is shown in the Fig. 4.

By analyzing the charts shown in Figs. 3 and 4, it can be seen that the data collected are within the control limits, which in turn are less than the value of 0.060 mm

Table 1 Thickness data collected on parts of code 15497

Sample	Paint layer thickness (mm)					
	Point A	Point B	Point C	Point D	Point E	Point F
1	0.073	0.043	0.043	0.072	0.073	0.069
2	0.056	0.043	0.054	0.045	0.073	0.075
3	0.049	0.050	0.056	0.051	0.067	0.080
4	0.078	0.051	0.053	0.046	0.046	0.053
5	0.054	0.047	0.052	0.044	0.049	0.048
6	0.049	0.038	0.039	0.057	0.080	0.054
7	0.050	0.051	0.077	0.055	0.075	0.070
8	0.050	0.054	0.068	0.065	0.079	0.072
9	0.048	0.046	0.048	0.046	0.056	0.072
10	0.054	0.045	0.037	0.055	0.055	0.050
11	0.055	0.047	0.072	0.042	0.043	0.038
12	0.042	0.037	0.040	0.051	0.067	0.049
13	0.044	0.041	0.044	0.070	0.074	0.056
14	0.056	0.046	0.043	0.054	0.069	0.058
15	0.056	0.052	0.071	0.051	0.042	0.038
16	0.044	0.050	0.046	0.075	0.082	0.077
17	0.043	0.038	0.049	0.046	0.068	0.074
18	0.074	0.071	0.083	0.046	0.043	0.042
19	0.050	0.055	0.057	0.072	0.087	0.081
20	0.045	0.040	0.042	0.069	0.080	0.055
21	0.070	0.042	0.066	0.075	0.076	0.073
22	0.050	0.043	0.051	0.052	0.057	0.079
23	0.090	0.071	0.072	0.047	0.038	0.042
24	0.056	0.039	0.043	0.072	0.068	0.083
25	0.047	0.041	0.049	0.066	0.069	0.067
26	0.037	0.038	0.045	0.069	0.072	0.051
27	0.046	0.047	0.044	0.071	0.069	0.066
28	0.046	0.045	0.046	0.050	0.055	0.055
29	0.079	0.052	0.050	0.048	0.039	0.043
30	0.049	0.039	0.042	0.070	0.069	0.073

established by the manufacturer. Figures 5 and 6 show the capability analysis for parts 15497 and 15494, respectively.

By analyzing the data shown in Fig. 4, it can be seen that the process of painting with microtextured black paint for part 15497 is not capable ($Cp < 1$), and is also not centered, which suggests that the machine needs adjustment. Also, it is worth noting the low performance of the process, with more than 69% of the parts out of specification.

Table 2 Thickness data collected on pieces of code 15494

Sample	Paint layer thickness (mm)					
	Point A	Point B	Point C	Point D	Point E	Point F
1	0.068	0.066	0.048	0.066	0.048	0.048
2	0.052	0.075	0.043	0.049	0.069	0.071
3	0.077	0.080	0.070	0.067	0.073	0.052
4	0.043	0.052	0.057	0.065	0.069	0.053
5	0.078	0.070	0.052	0.082	0.075	0.074
6	0.078	0.070	0.083	0.094	0.077	0.053
7	0.053	0.074	0.064	0.054	0.053	0.074
8	0.086	0.070	0.084	0.083	0.076	0.053
9	0.056	0.068	0.053	0.049	0.056	0.075
10	0.081	0.073	0.080	0.074	0.057	0.069
11	0.094	0.056	0.073	0.084	0.066	0.066
12	0.069	0.091	0.063	0.073	0.067	0.089
13	0.086	0.075	0.084	0.087	0.087	0.068
14	0.090	0.054	0.082	0.077	0.069	0.055
15	0.054	0.080	0.075	0.052	0.051	0.077
16	0.080	0.069	0.078	0.071	0.082	0.080
17	0.073	0.075	0.067	0.078	0.077	0.050
18	0.057	0.066	0.072	0.054	0.068	0.054
19	0.066	0.066	0.057	0.053	0.074	0.082
20	0.085	0.055	0.068	0.065	0.077	0.077
21	0.054	0.084	0.053	0.057	0.071	0.075
22	0.057	0.076	0.057	0.065	0.072	0.056
23	0.073	0.066	0.052	0.068	0.065	0.090
24	0.081	0.065	0.075	0.065	0.065	0.068
25	0.052	0.053	0.050	0.068	0.078	0.049
26	0.075	0.072	0.069	0.071	0.080	0.071
27	0.077	0.072	0.071	0.087	0.079	0.081
28	0.080	0.073	0.055	0.054	0.077	0.074
29	0.069	0.057	0.071	0.056	0.083	0.098
30	0.068	0.066	0.072	0.070	0.057	0.053

By analyzing the data in Fig. 6, it can be seen that the process of painting with black microtextured paint is also not configured as capable ($Cp < 1$), but it is more centered compared to the painting process of part 15497 ($Cp = 0.31$ and $Pbk = 0.26$).

Finally, it was observed that more than 43% of the parts were out of specification. Through the analysis of such data, the company's top management chose to start a

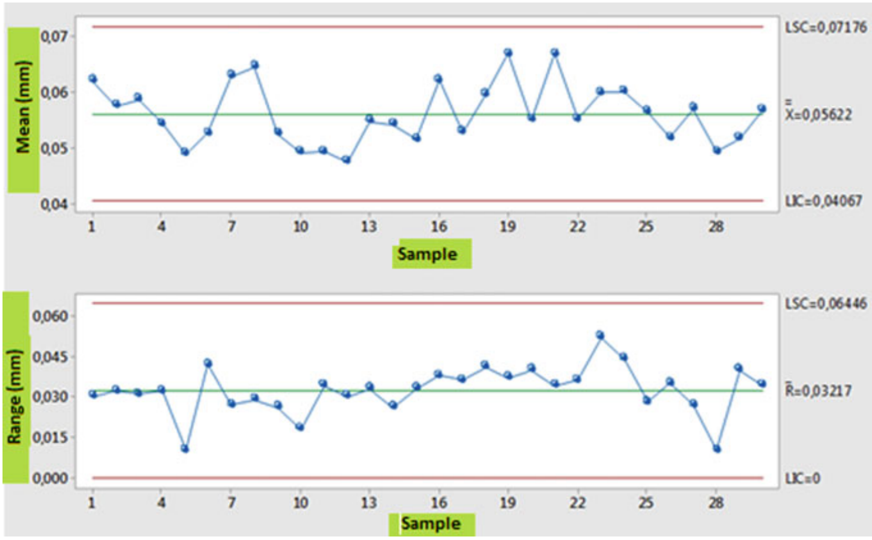


Fig. 3 Control chart for mean and range for part 15497

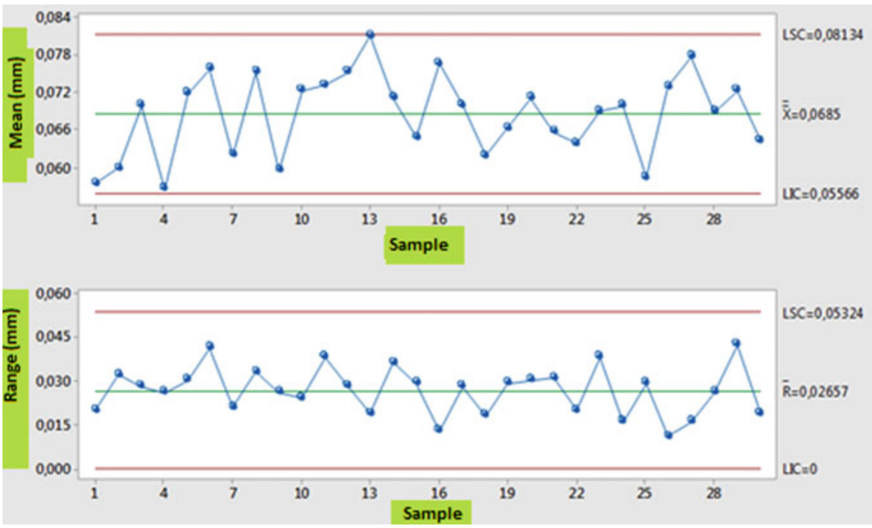


Fig. 4 Control chart for mean and range for part 15494

more detailed study of the painting process, aiming to identify possible improvements to the process through the implementation of statistical process control.

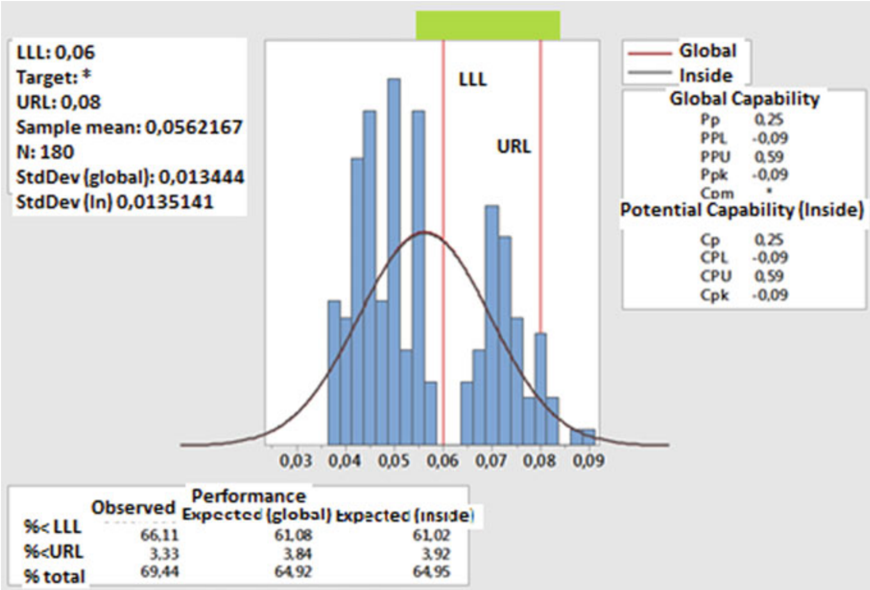


Fig. 5 Capability analysis of the painting process for part 15497

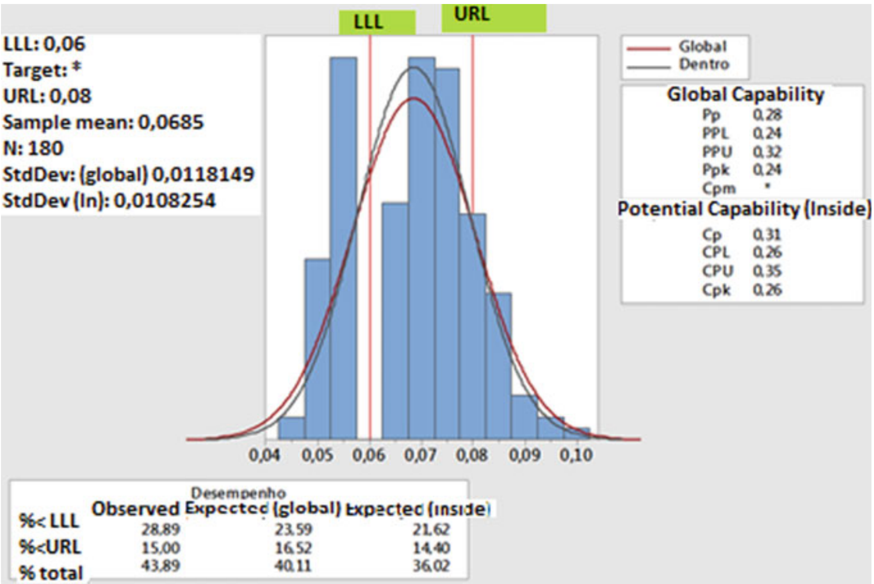


Fig. 6 Capability analysis of the paint process for part 15494

5 Conclusion

Statistical methods are proven to be effective for improving any productive process. Therefore, the implementation of CEP in the industrial painting sector is an ally in the effort to minimize losses and an excellent tool for competitiveness. In this work, we sought to show a global view of the issue of quality and the use of SPC as an analysis tool.

Therefore, after applying SPC to the painting of parts in an office supplies industry, it was concluded that the company's painting sector did not gain the necessary attention to guarantee the specification determined by the paint supplier, generating risks for product quality.

Based on the results described, the company's management decided to immediately implement a statistical control of the painting process, aiming initially to centralize the process for the different parts produced and, after that, make improvements that make the process capable of meeting market demands. Finally, the results obtained in this research show a good opportunity for managers to increase the company's competitiveness, through SPC.

The results are expected to be of great importance for the company, since the present work highlighted the need for improvements and monitoring of machines, processes and parts to eliminate losses due to lack of quality, as well as to provide a better service by the company.

References

1. Andrade, A.: Controle Estatístico de Processo para análise de não conformidades nos setores de produção da empresa Minusa Industrias Mecânicas S/A. Repositórios de Relatórios - Engenharia de Produção, 2, (2019).
2. Santana, N. et al. Controle estatístico da qualidade: uma aplicação em uma indústria têxtil. Revista Latino-Americana de Inovação e Engenharia de Produção 7(12), 47–56 (2019).
3. Cohen, A. et al.: A statistical analysis of critical quality tools and companies performance. Journal of Cleaner Production (255) 120221–120229 (2020).
4. Pacheco, J.: Teoria das Restrições, Lean Manufacturing e Seis Sigma: limites e possibilidades de integração. Production, 24(4), 940–956 (2014).
5. Allen, T.: Introduction to Engineering Statistics and Lean Six Sigma. 2nd edn. Springer-Verlag, London (2019).
6. Santos A., Martins,M.: Modelo de referência para estruturar o Seis Sigma nas organizações. Gestão & Produção 15(1), 43–56 (2008).
7. Pyzdek, T.: Uma ferramenta em busca do defeito zero. HSM Management 38(3), 1–7 (2003).
8. Gil, A.: Como Elaborar Projetos de Pesquisa. 4nd edn. Atlas, São Paulo (2002).

The Influence of Economic Context on the Relationship Between Manufacturing Strategy, Practices and Performance

Lillian do Nascimento Gambi, Harry Boer, Henrike Engele Elisabeth Boer, and Mateus Cecílio Gerolamo

Abstract The aim of this study is to investigate the relationships between manufacturing strategy, practices and performance, and the role of economic context in these relationships. Based on international data collected in 840 firms from 21 countries, a theoretical model with those relationships was tested using Structural Equation Modeling. The results demonstrate that economic context has no effect on strategy, and a negative effect on manufacturing practices and performance. The findings also show that strategy positively affects performance directly and indirectly through the adoption of manufacturing practices. This study contributes for theory and provides managerial insight, showing that for manufacturing firms to be successful in improving their performance it is important to achieve consistency between strategy and the manufacturing practices adopted by the firms. Besides, the study also shows that companies not only have to develop an appropriate strategy to improve performance, but also need to understand how context affects their strategic decisions on manufacturing practices.

Keywords Economic context · Strategy · Manufacturing practices · Performance

1 Introduction

Over the last decades, several studies have been published highlighting that strategy influences organizational performance [1–4]. Other studies focus on manufacturing practices and assert that a company's strategy affects its practices and, consequently,

L. do N. Gambi (✉)
Federal University of Viçosa, Campus Rio Paranaíba, Rio Paranaíba 38810-000, Brazil
e-mail: lillian.gambi@ufv.br

H. Boer · H. E. E. Boer
Center for Industrial Production, Aalborg University, 9220 Aalborg, Denmark

M. C. Gerolamo
Engineering School of São Carlos, University of São Paulo, São Carlos 13563-120, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_33

its performance. In other words, manufacturing practices mediate the association between manufacturing strategy and performance. Amoako-Gyampah and Acquaah [5] for instance suggest that decisions in manufacturing should be aligned with the company's competitive strategy to accomplish competitive goals. Many studies have shown a direct effect of manufacturing practices on performance [6–8].

In parallel, recent studies show that the relationship between manufacturing strategy and performance is different in developed and emerging countries [3, 9]. According to Lee et al. [8], all the activities that help increase process efficiency, including investment in manufacturing practices such as advanced systems and equipment, must be well defined and designed to maximize operational performance in the economic context of the country where a company is located.

There are surprisingly few papers investigating the influence of the external context of a company on its operations strategy. One of the first studies is Swamidass and Newel [10]. Using a sample of 35 companies predominantly from the Pacific Northwest of the USA, they find that environmental uncertainty affects manufacturing strategy, in particular the "*business unit's goals relevant to flexibility*" (p. 518). However, their operationalization suggests that they actually measured flexibility performance. Based on a study of Singapore manufacturers, Ward et al. [11, p. 99] "*identify strong relationships between environmental factors such as labor availability, competitive hostility, and market dynamism and the operations strategy choices encompassed by competitive priorities*". Building on these authors, Badri et al. [12] extend the set of environmental factors with government laws and regulations, and political concerns, and report strong relationships between company context and strategic priorities, too, in a sample of United Arab Emirates manufacturers. It is important to note that all these authors measure the respondents' *perception* of the environmental factors investigated. The side-benefit is that this allows them to do single-country analyses.

Several studies show that nation-specific factors (e.g. economic context and culture) have influence on the relationship between manufacturing practices and performance [8, 13, 14]. The studies of Schoenherr et al. [14] suggest that competitive capabilities (quality, delivery, flexibility, and cost) tend to influence each other to a greater degree in companies in developing countries compared to those located in developed countries.

In spite of the literature presenting evidence that context affects strategy, and strategy has an effect on performance, studies are still missing that *simultaneously* address the effect of (1) strategy on manufacturing practices and, through that, performance, (2) the role of economic context, in (3) a multitude of countries and, thus, allowing for using objective rather than perceptual country data. This study aims to investigate the relationships between strategy, manufacturing practices and performance, and the role of economic context in these relationships, using data from a multitude of countries.

2 Objectives

The main purpose of this paper is to investigate the relationships between strategy, manufacturing practices and manufacturing performance and the role of economic context in these relationships. The following hypotheses are investigated:

H1 *Economic context affects (a) strategy, (b) manufacturing practices, and (c) manufacturing performance.*

H2 *Strategy does not affect manufacturing performance directly. Instead, (b) strategy affects the adoption of manufacturing practices, and (c) manufacturing practices affect manufacturing performance.*

H2 Implies that we expect the adoption of manufacturing practices to mediate the relationships between strategy and manufacturing performance.

3 Methods

3.1 Method

For economic context, secondary data obtained from the Global Competitiveness Report 2014–2015 [15] was used, while for strategy, practices and performance, data were collected electronically using a 5-point Likert scale, in 2013/2014 through the International Manufacturing Strategy Survey (IMSS VI), which includes 22 countries (Belgium, Brazil, Canada, China, Denmark, Finland, Germany, Hungary, India, Italy, Japan, Malaysia, Netherlands, Norway, Portugal, Romania, Slovenia, Spain, Sweden, Switzerland, Taiwan, United States) and a total of 931 responses. In this study we dropped 91 responses belonging to India because the pillars considered in this study have a weight of 35% for India, and 50% for the other countries studies (Schwab, 2014). Thus, the final data set includes 840 responses. The unit of analysis was the manufacturing plant.

First, the survey scales were assessed for reliability using Cronbach's alpha (performed in IBM® SPSS® Statistics 24). Second, a confirmatory factor analysis was performed in IBM® SPSS® Amos 24 to assess the measurement model for each construct, the validity of the scales as well as overall fit indexes. Third, Structural Equation Modeling was used to investigate the relationships between the constructs.

3.2 Operationalization of the Constructs

The constructs are operationalized as follows.

Economic context was operationalized using the Global Competitiveness Report 2014–2015 [15]. This report computes the value of the Global Competitive Index (GCI) which is based on the weighted average of static and dynamic components (such as quality of the education system, intensity of local competition, and availability of latest technologies—measured on a seven-point scale) grouped into 12 pillars of competitiveness. In this study five pillars from the Global Competitiveness Index were used: Higher education and training, Goods market efficiency, Labor market efficiency, Financial market development, and Technological readiness. These pillars were chosen because they have the same weight (50%) for all countries studied.

For strategy, the items were operationalized following Cagliano et al.'s [16] approach, which identified four manufacturing strategy configurations: market, product, capability and price-based strategies, highlighting competitive priorities in each strategy such as quality, service, flexibility, price and product variety. Six items related to the importance of each competitive strategy for the company were measured on a five-point Likert scale ranging from 1 = "Not important" to 5 = "Very important". In the preliminary statistical tests the item "Lower selling prices" was deleted due to lack of reliability, so that five items remained to measure strategy. These items largely cover two performance areas, namely quality (better product design and quality, better conformance to customer specification, and superior product assistance/support), and product innovation (offer more product customization and offer new products more frequently).

Manufacturing practices can be defined as established activities and processes adopted to achieve goals [17]. According to Lee et al. [8, p. 46], manufacturing practices have generally been categorized into plant and equipment, manufacturing systems, quality management, and new product development. Consistent with the two focal performance areas (quality, product innovation), we considered the level of implementation of quality management practices (i.e. quality improvement and control, improving equipment availability, and benchmarking/self-assessment), and of processes and equipment (use of advanced processes, development towards a "factory for the future", and engaging in process automation programs) that provide the flexibility for the factory to absorb and produce effectively the customized and new products developed by the company.

Finally and, again, consistent with the strategy and practices operationalizations, six items were used to measure operational performance in the areas of quality (conformance quality, and product quality and reliability), flexibility (volume flexibility and mix flexibility), and innovation (product customization ability and new product introduction ability). The items measured the companies' performance relative to their main competitors on a five point Likert scale ranging from 1 = "much lower" to 5 = "much higher".

All dimensions and variables measured are presented in Appendix A.

3.3 Research Model

In attempting to investigate the research hypotheses, the structural research model depicted in Fig. 1 was devised. Reflecting the hypotheses, this model shows the interplay between strategy, manufacturing practices, and performance; and the role of economic context in these relationships.

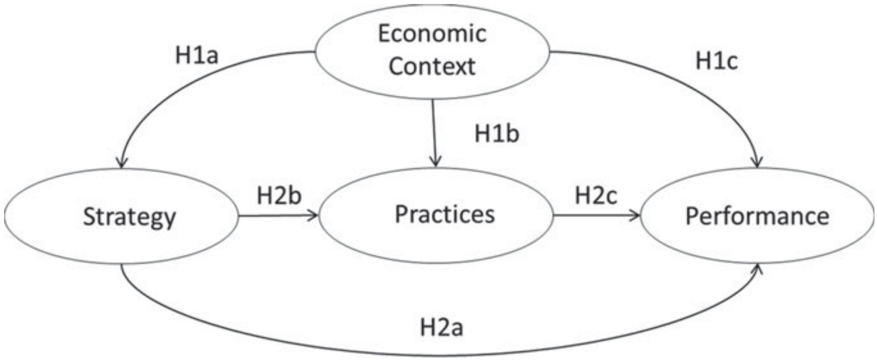


Fig. 1 The relationships between economic context, strategy, manufacturing practices, and operational performance

4 Results

4.1 Preliminary Statistics

Preliminary tests were performed in PASW Statistics 24. Reliability is broadly defined as the degree to which scales are free from error and therefore consistent [18]. Communality and explained variance were also tested, as established bellow.

Economic context—Cronbach's alpha was calculated to evaluate the reliability of the measurement scales. The value was 0.889, above the threshold of 0.70 [19], which demonstrates adequate levels of internal consistency. Construct validity was assessed by analyzing the factor loadings of the items based on sample size. All the variables presented values above 0.81 (threshold of 0.35, $p < 0.05$, according to Hair et al. [19], demonstrating construct validity. Communality (i.e. the extent to which a variable correlates with all other variables) was above 0.65 for all items, which shows that they are able to explain the factor to which they load. Furthermore, the total variance explained was 75%. Thus, the measurement factors are suitable for explaining the data.

Strategy—All variable loadings were above 0.59, and Cronbach's alpha was 0.71, which shows that the measurement scales are reliable. Moreover, the communality (>0.35) of the items and the percentage of total explained variance (47%) indicates that the items and the obtained factors are satisfactory for explaining the data.

Manufacturing practices—Cronbach's alpha was 0.84, which demonstrates an acceptable level of internal consistency of the measures. The factor loading was 0.65 representing around 53% explained variance, which indicates that the items and the obtained factor are thus adequate for using the performance data in testing the research model.

Performance—All variable loadings were above 0.67, and Cronbach's alpha was 0.82, which shows that the measurement scales are reliable. Moreover, the communality of the items was above 0.44 and the percentage of total explained variance (53%) indicates that the items and the obtained factors are satisfactory for explaining the data.

The variables used and the results of the preliminary statistical tests are presented in Appendix A.

4.2 Structural Model

The research questions were tested using Structural Equation Modeling (SEM) in AMOS v. 24. Many indicators are used to indicate the fit of the data to the model (RMSEA, $\chi 2$/df, GFI, CFI). As a guideline, RMSEA <0.07 and $\chi 2$ ($\chi 2$/df) smaller than 5.0 are considered good model fit [19], while CFI and GFI close to 1.0 represent a perfect fit [19]. The overall fit statistics for the model tested are $\chi 2/\text{df} = 2.770$, CFI = 0.964, GFI = 0.948 and RMSEA = 0.046, which suggest satisfactory model fit.

The results of the structural model for testing the research questions are presented in Table 1.

Table 1 The relationship between economic context, strategy, manufacturing practices and manufacturing performance

H1 *Economic context affects (a) strategy, (b) manufacturing practices, and (c) manufacturing performance*	
Effects	
(H1a) Economic Context → Strategy	-0.075^{ns}
(H1b) Economic Context → Manufacturing Practices	−0.134**
(H1c) Economic Context → Performance	−0.203**
H2 *Strategy does not affect manufacturing performance directly. Instead, (b) strategy affects the adoption of manufacturing practices, and (c) manufacturing practices affect manufacturing performance.*	
Effects	
(H2a) Strategy → Performance	0.314**
(H2b) Strategy → Manufacturing Practices	0.200**
(H2c) Manufacturing Practices → Performance	0.314**

ns (not significant; p > 0.05), ** p < 0.001

5 Discussion

The analysis of the empirical data demonstrates that: (1) economic context has no effect on strategy (-0.075, $p = 0.057$), and a negative effect on manufacturing practices and performance (-0.134 and $-0,203$, respectively, $p < 0.001$). Furthermore, (2) strategy has a positive effect on manufacturing practices and performance (0.200 and 0.314, respectively, $p < 0.001$), and manufacturing practices has a positive effect on performance (0.314, $p < 0.001$).

H1 *Economic context affects (a) strategy, (b) manufacturing practices, and (c) manufacturing performance.*

The results show an insignificant effect of economic context on strategy, and a negative effect on manufacturing practices and performance. Specifically for the effect of economic context on strategy, this finding goes against the few other studies that investigated the association between a company's context and its manufacturing strategy [10–12]. One major difference between these studies and ours is that we do not measure the companies' perceptions of their environment, but use objective World Economic Forum measurements [15]. People, and company managers are not different, do not act on fact but on perception—some people may find a temperature of 21 °C comfortable, others put on an extra sweater. So, finding that manufacturing strategy reflects managerial perceptions is rather obvious. However, it remains unclear why companies apparently do not use objective data in their manufacturing strategy decision-making process—further research is needed.

The effects of economic context on manufacturing practices and performance are significant, but negative. This means that higher the development level of a country's economy, the lower the level of adoption of the practices considered in our analyses and the lower the manufacturing performance of companies in these countries, relative to their main competitors. The latter is not far from Naor et al. [20], who study the impact of developmental indices taken from the World Bank [21] "Key development data & statistics" database on manufacturing performance, and do not find any association between country developmental level and manufacturing performance. One reason may be differences in operationalization and analytical method; more importantly, though, their sample includes 189 companies from six highly developed countries; our sample includes several developing countries. Overall, we argue that the developmental level of a country defines a considerable part of the context in which companies compete, and the less developed this environment, the lesser the possibilities for companies to adopt and successfully deploy advanced manufacturing practices, with obvious consequences for their manufacturing performance. According to Schoenherr et al. [14], more developed nations are often more sophisticated in their approaches, which are facilitated by better access to resources and knowledge. Additionally, they state that plants in emerging countries are at a lower maturity level of competitive capabilities and therefore have more opportunities to advance them. Recall that we operationalized economic context as higher education and training, goods market efficiency, labor market efficiency, financial market development, and technological readiness, and manufacturing practices as quality management practices (i.e. quality improvement and control, improving equipment availability, and benchmarking/self-assessment), and of processes and equipment (use of advanced processes, development towards a “factory for the future”, and engaging in process automation programs). We suggest that these contextual factors, lower financial market development and technological readiness affect the adoption of advanced manufacturing practices, while lower education, training and labor market efficiency reduce the effective deployment of these practices. Further research and analysis is needed to investigate these tentative explanations.

H2 *Strategy does not affect manufacturing performance directly. Instead, (b) strategy affects the adoption of manufacturing practices, and (c) manufacturing practices affect manufacturing performance.*

The results show that strategy directly and positively affects performance. Part of these findings are supported by the studies of Amoako-Gympah and Acquaa [5], who state that it is expected that the manufacturing function implements structural and infrastructural decisions that are embedded in the strategy. In this direction, the findings also show that manufacturing performance is affected indirectly by strategy through manufacturing practices. Christiansen et al. [7] conclude that strategy can contribute to the understanding of operational performance and the bundles of manufacturing practices needed to achieve this. Therefore, for manufacturing companies to be successful in improving their performance there must be a consistency between strategy and the manufacturing practices adopted.

Interestingly, it was also found that the impact of strategy on performance is partially mediated by the company’s manufacturing practices. This goes against H2a. It does not make much logical sense to assume that any manufacturing strategy has direct impact on manufacturing performance—this would be like saying that the intention to take a penalty in a football match leads to a goal being scored; many things have to fall into place before the intention (strategy) leads to the intended results (performance). Thus, it is suggested that further research is needed to find out what happens between intent and result, The most obvious approach is to include more manufacturing practices in our analyses and, also, to investigate their interaction, as per Christiansen et al.’s [7] suggestion.

6 Conclusion

Increased (global) competition requires that companies not only have to develop an appropriate strategy to improve performance, but also need to understand how context affects their strategic decisions on manufacturing practices. This study shows that the economic context has no effect on the strategy definition of the company, and a negative effect on the level of adoption of the manufacturing practices considered here and on manufacturing performance. This means that the lower the country’s level of development, the lower the level of adoption and effective deployment of advanced manufacturing practices and their performance effects. We suggest that our operationalization economic context, in particular lower financial market development and technological readiness, affect the adoption of advanced manufacturing practices, while lower education, training and labor market efficiency reduce the effective deployment of these practices. Further research and analysis is needed to investigate these tentative explanations.

Additionally, the results confirm the important role of strategy in the manufacturing performance. The unexpected direct effect of strategy on performance needs further investigation. In particular, we suggest extending the set of manufacturing practices considered and also analyzing their interaction by investigating them as bundles

The study has certain limitations, which are mainly related to the research method applied. It is recommended that further research be undertaken using different methodologies including interviews, field studies or longitudinal case studies to develop a comprehensive understanding of the findings reported here.

Acknowledgments The authors thank the financial support provided by National Council for Scientific and Technological Development (CNPq), Brazil; and State of Minas Gerais Research Foundation (FAPEMIG), Brazil.

Appendix A—Variables and Preliminary Statistics

Variables	Factor loading	Communality	Reliability
Economic context			
Higher education and training	0.893	0.798	0.889
Goods market efficiency	0.927	0.859	
Labor market efficiency	0.805	0.648	
Financial market development	0.844	0.712	
Technological readiness	0.842	0.708	
Strategy			
Better product design and quality	0.747	0.558	0.706
Better conformance to customer specification	0.730	0.533	
Superior product assistance/support	0.678	0.459	
Offer more product customization	0.664	0.441	
Offer new products more frequently	0.587	0.354	
Manufacturing practices			
Quality improvement and control	0.751	0.564	0.835
Improving equipment availability	0.808	0.652	
Benchmarking/self-assessment	0.755	0.571	
Use of advanced processes	0.649	0.421	

(continued)

(continued)

Variables	Factor loading	Communality	Reliability
Development towards a "factory for the future"	0.756	0.572	
Engaging in process automation programs	0.737	0.544	
Performance			
Conformance quality	0.745	0.555	0.817
Product quality and reliability	0.782	0.611	
Volume flexibility	0.723	0.523	
Mix flexibility	0.722	0.521	
Product customization ability	0.666	0.444	
New product introduction ability	0.703	0.494	

References

1. Ward, P.T. and Duray, R. Manufacturing strategy in context: environment, competitive strategy and manufacturing strategy. Journal of Operations Management, 18(2), pp. 123–138 (2000).
2. Prajogo, D.I. and Sohal, A.S. The relationship between organization strategy, total quality management (TQM), and organizational performance—the mediating role of TQM. European Journal of Operational Research, 168(1), pp. 35–50 (2006).
3. Ang, J.S.K., Shimada, T., Quek, S-A and Lim, E. Manufacturing strategy and competitive performance, International Journal of Production Economics, 169 (11), pp. 240–252 (2015).
4. Sardana, D., Terziovski, M. and Gupta, N. The impact of strategic alignment and responsiveness to market on manufacturing firm's performance. International Journal of Production Economics, 77(3), pp. 131–138 (2016).
5. Amoako-Gyampah, K. and Acquaah, M. Manufacturing strategy, competitive strategy and firm performance: An empirical study in a developing economy environment. International Journal of Production Economics, 111(2), pp. 575–592 (2008).
6. Cua, K.O., McKone, K.E. and Schroeder, R.G. Relationships between implementation of TQM, JIT, and TPM and manufacturing performance, Journal of Operations Management, Vol. 19 (6), pp. 675–94 (2001).
7. Christiansen, T., Berry, W.L., Bruun, P. and Ward, P. A mapping of competitive priorities, manufacturing practices, and operational performance in group of Danish manufacturing companies. International Journal of Operations and Production Management, 23 (10), pp. 1163–1183 (2003).
8. Lee, D.H. Rho, B-H. and Yon, S.N. Effect of investments in manufacturing practices on process efficiency and organizational performance, International Journal of Production Economics, 162 (4), pp. 45–54 (2015).
9. Arana-Solares, I.A., Ortega-Jiménez C.H., Alfalla-Luque, R. and De Los Rios, J. L. P-D. Contextual factors intervening in the manufacturing strategy and technology management-performance relationship. International Journal of Production Economics, 207(1), pp. 81–95 (2019).
10. Swamidass, P.M. and Newell, W.T. Manufacturing strategy, environmental uncertainty and performance: A path analytic model. Management Science, 33(4), pp. 509–524 (1987).
11. Ward, P.T., Duray, R, Leong, G. and Sum, C. Business environment, operations strategy and performance: An empirical study of Singapore manufacturers. Journal of Operations Management, 13(2), pp. 99–115 (1995).

12. Badri, M.A., Davis. D. and Davis, D. Operations strategy, environmental uncertainty and performance: a path analytic model of industries in developing countries. Omega, 28(2), pp. 155–173 (2000).
13. Power, D.J., Schoenherr, T. and Samson, D. The cultural characteristic of individualism/collectivism: a comparative study of implications for investment in operations between emerging Asian and industrialized Western countries. Journal of Operations Management. 28(3), pp. 206–222 (2010).
14. Schoenherr, T., Power, D., Narasimhan, R. and Samson, D. Competitive capabilities among manufacturing plants in developing, emerging, and industrialized countries: a comparative analysis. Decision Sciences Journal, 43(1), pp. 37–72 (2012).
15. Schwab, K.. The Global Competitiveness Report 2014–2015. WEF - World Country Forum, Geneva (2012).
16. Cagliano, R., Acur, N. and Boer, H. Patterns of change in manufacturing strategy configurations, International Journal of Operations and Production Management, 25 (7), pp. 701–718 (2005).
17. Voss, C., Blackmon, K., Hanson, P. and Oak, B. The competitiveness of European manufacturing-a four country study. Business Strategy Review, 6(1), pp. 1–25 (1995).
18. Nunnally, J. C. Psychometric theory (1st ed.). New York: McGraw-Hill (1967).
19. Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E., Multivariate Data Analysis, Prentice Hall, Upper Saddle River, NJ, (2009).
20. Naor, M., Linderman, K. and Schroeder, R. The globalization of operations in Eastern and Western countries: Unpacking the relationship between national and organizational culture and its impact on manufacturing performance. Journal of Operations Management, 28(3), pp. 194–205 (2010).
21. World Bank. Key Development Data & Statistics (2005), http://www.worldbank.org, last accessed 2020/02/20.

A System Thinking Approach for Social and Environmental Risks in Supply Chains

Fabíola Negreiros de Oliveira, Luiza Ribeiro Alves Cunha, Tharcisio Cotta Fontainha, Adriana Leiras, and Paula Santos Ceryno

Abstract The discussion of risks in the supply chains is no longer restricted to the financial perspective and also considers social and environmental dimensions in the research on Supply Chain Risk Management (SCRM). Nevertheless, the relationship between the social and environmental dimensions remains scarce in SCRM studies. Thus, this research aims to explore such relationships by discussing hypotheses about the SCRM according to elements already addressed in the academic literature. The methodology follows the system thinking approach by developing a Causal Loop Diagrams (CLD) to present the complex relationship among the variables involved in the social and environmental dimensions. The results highlight two reinforcing loops and six balancing loops, which in turn leads to the definition of 10 hypotheses regarding the SCRM. These loops and hypotheses stress (i) the inner relationships among social and environmental risks (both endogenous and exogenous) and also (ii) their similar relationship with the variables "Consequences" for the companies and "Implementation of strategies" by the company due to fundamental structure of the SCRM. Moreover, the results provide relevant insights for decision-makers interested in an extended approach for SCRM that considers social and environmental dimensions.

F. N. de Oliveira (✉) · L. R. A. Cunha · A. Leiras
Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: negreirosfabiola@gmail.com

L. R. A. Cunha
e-mail: luizarac@gmail.com

A. Leiras
e-mail: adrianaleiras@puc-rio.br

T. C. Fontainha
Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: fontainha@pep.ufrj.br

P. S. Ceryno
Federal University of the State of Rio de Janeiro, Rio de Janeiro, Brazil
e-mail: paulaceryno@hotmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_34

Keywords Risk management · Supply chain management · System thinking

1 Introduction

Supply Chain Risk Management (SCRM) focuses on risks related to interruptions of materials, funds, or information flows between the supply chain links [1, 2]. Recently, companies have given more attention to disruptions by incorporating SCRM to avoid, mitigate or monitor the supply chain risks [3]. Despite the relevance of financial perspective discussing the prevention of economic losses, social and environmental issues are also becoming more relevant among stakeholders [1, 4, 5]. Recent works discussed the relevance of addressing social and environmental dimensions in a more integrated perspective [2, 6–8].

The social issues embrace fair actions for workers, partners, and society and can be defined as the risks of adverse impacts felt by individuals or groups, often involving human rights, and labor practices [9, 10]. The environmental risks, in turn, consider the uncertainties and interactions between the SC and the external environment [11].

Risks—both social and environmental—can be divided according to two perspectives: the endogenous and exogenous perspectives [12]. Endogenous risks are caused by companies' activities along their supply chains (SC), and exogenous risks are brought to SC due to their interaction with the external environment where they operate [11, 13].

According to Giannakis and Papadopoulos [11], exogenous social risks can be represented by demographic challenges, social instability, and pandemic. On the other hand, endogenous social risks are represented by unfair wages and harassment. Cunha et al. [2] developed a systematic literature review (SLR), which identified 24 endogenous social risks classified in 3 categories (i.e., human rights, labour practices, and decent work conditions, and society), and 11 consequences that companies may suffer due to social risks that are classified in 6 categories (i.e., reputational, financial, operational, relationship, population, and legal).

According to Giannakis and Papadopoulos [11] and De Oliveira et al. [6], the exogenous environmental risks represent the natural and man-made disasters, while endogenous environmental risks represent the activities of a company that affects the natural environment such as greenhouse gas emissions, chemical and toxic releases and waste. De Oliveira et al. [6] also developed an SLR which identified 14 environmental risks classified in 5 categories (i.e., environmental pollution, waste, non-compliance, environmental accidents, natural and man-made disasters), and consequences classified in 3 categories (i.e., reputational, financial, legal). Furthermore, De Oliveira et al. [6] identified 19 strategies to manage these risks that are classified into 6 categories (i.e., waste management, hazardous substance management, greenhouse gas management, relationship with suppliers and customers, compliance and contingency plans).

The aforementioned scenario shows an intrinsic complexity when it comes to risk, disaster and sustainability management in the supply chain context. Andrade [14] affirms that the most appropriate situations for the use of systemic thinking are those that involve complexity. This complexity arises from the multidimensionality of a system, interconnected variables in a non-linear manner, delays in cause and effect relationships, or the complex influence of mental models in reality. These are the so-called “systemic problems”.

Mingers and White [15] highlight the recent development in the growth of the complexity thinking, pointing out the increased number of applications of systems ideas and its contributions to a wide number of domains, especially health, production and sustainability. The authors also affirm that there are potential new opportunities for systems approaches, given the context of a global economic downturn and global climate change, which may bring fresh thinking to existing problems and to a future uncertain world.

2 Objectives

The present research aims to explore the relationships between social and environmental risks by proposing and discussing hypotheses about the SCRM of both dimensions based on the elements already covered by the academic literature. The structure of the causal loop diagram (CLD) is a suitable approach to represent the dynamic nature of social and environmental risks, identify critical variables, and discuss the cause and effect relationships of these risks, their consequences, and mitigation strategies.

3 Methods

In order to address the subject through a system thinking perspective, this research uses the Vensim simulation software to develop the CLD, providing a causal tracing of the feedback structures. CLDs are an essential tool for representing the complex problem and the feedback structure of a system and consists of variables connected by arrows that denote the causal influences among the variables [16].

The arrows in the CLD leads to the creation of reinforcing and balancing loops. The first is defined as an action that produces a result which in turn causes more of the same action; and thus, resulting in growth or decline of the interaction in the loop. The second is defined as an action that prevents a change with a variable in the opposite direction [15].

Therefore, the integration among variables related to the social and environmental risks (both endogenous and exogenous) as well as the company supply chain activities, potential consequences, and implementation of strategies are presented in the

CLD. Noteworthy, the CLDs are models which represent the reality, aiding in visualizing how the different variables in a system are interrelated. Thus, according to Sterman [16], having too much detail makes it hard to see the overall feedback loop structure and how the different loops interact. Pidd [17] also explains that modelling is not a perfect representation of the reality, but a tool for thinking that reflects only a part of the reality. Therefore, the model developed in this paper focuses on the presentation of only environmental and social dimensions, leaving the economic dimension for future discussion. Also, the CLD presents relationships between variables that are not directly discussed in the separated literature about environmental and social issues of interest by the SCRM. These additional relationships emerged from brainstorming discussion between the authors. Besides the CLD model, the paper also provides a table that summarizes these relationships with an example and the correspondent source with an emphasis on the authors´ contribution.

The CLD analysis in the next section starts from simple relationships to more complex relationships through the inclusion of the variables previously defined in the academic literature of SCRM. Then, the relationships stressed in the CLD lead to the proposition of some hypotheses about the social and environmental issues in the SCRM, especially those that were not discussed in the references addressing separately the environmental and social issues of the SCRM. Thus, these hypotheses represent a synthesis of the insights based on the CLD to support the decision-makers interested in the social and environmental dimensions in the SCRM.

4 Results

Figure 1 presents two reinforcing loops. The reinforcing loop R1 indicates that more “Exogenous Environmental Risks”—arising from the external environment—causes more effect on “Company Supply Chain activities”, which in turn generates more “Endogenous Environmental Risks”—caused by companies’ supply chains—and, consequently, results in more “Exogenous Environmental Risks”. This interaction represents the situations in which, for example, natural disasters are increasingly linked to environmental pollution and climate change, making these events more frequent, longer-lasting and more intense [6]. A similar loop is defined by the addition of the “Exogenous Social Risks”. Thus, the reinforcing loop R2 indicates the idea that more “Exogenous Environmental Risks” causes more effect on the “Exogenous Social Risks”, which in turn leads on more impact on the “Company Supply Chain activities”, then, more “Endogenous Environmental Risks”, and consequently more “Exogenous Environmental Risks”. Therefore, R2 brings an essential insight from De Oliveira et al. [6] and Cunha et al. [2] when discussing the connection between the “Exogenous Environmental Risks” and the “Exogenous Social Risks”. For example, a natural disaster can generate social instability in the community.

Figure 2 expands the previous CLD (Fig. 1) by the inclusion of three balancing loops. B1 represents the main idea that more “Potential Consequences” for the company leads to more “Implementation of strategies” by the company, which in

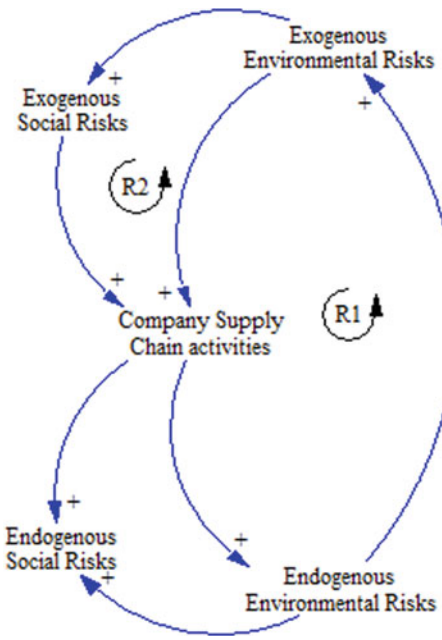


Fig. 1 Causal loop diagram: R1, and R2

turn results in less "Potential Consequences". The balancing loop B2 indicates the relationship where more "Exogenous Environmental Risks" causes more effect on "Potential Consequences" for the company, which in turn leads to more "Implementation of strategies" by the company, and consequently results in less "Exogenous Environmental Risks". The balancing loop B3 shows the interaction that more "Exogenous Environmental Risks" causes more effect on "Exogenous Social Risks", which in turn leads to more "Potential Consequences" for the company, that results in more "Implementation of strategies" by the company that generates less "Exogenous Environmental Risks". The balancing loop B4 presents the relationship in which more "Exogenous Social Risks" leads to more "Potential Consequences", and then more "Implementation of strategies", and consequently less "Exogenous Social Risks". These relationships focus on the benefits for the company that implements an SCRM—which is endorsed by literature on the subject [2, 5, 6]—and seeks to improve the "Implementation of strategies" to reduce the exogenous risks (both environmental and social), consequently reducing the "Potential Consequences" for the company.

Figure 3 also adds three balancing loops to the previous CLD (Fig. 2). These new balancing loops focus on the inner interactions involving the Social Risks (both the endogenous and exogenous) as well as an example of the high complexity among several variables. The balancing loop B5 indicates that more "Endogenous Social

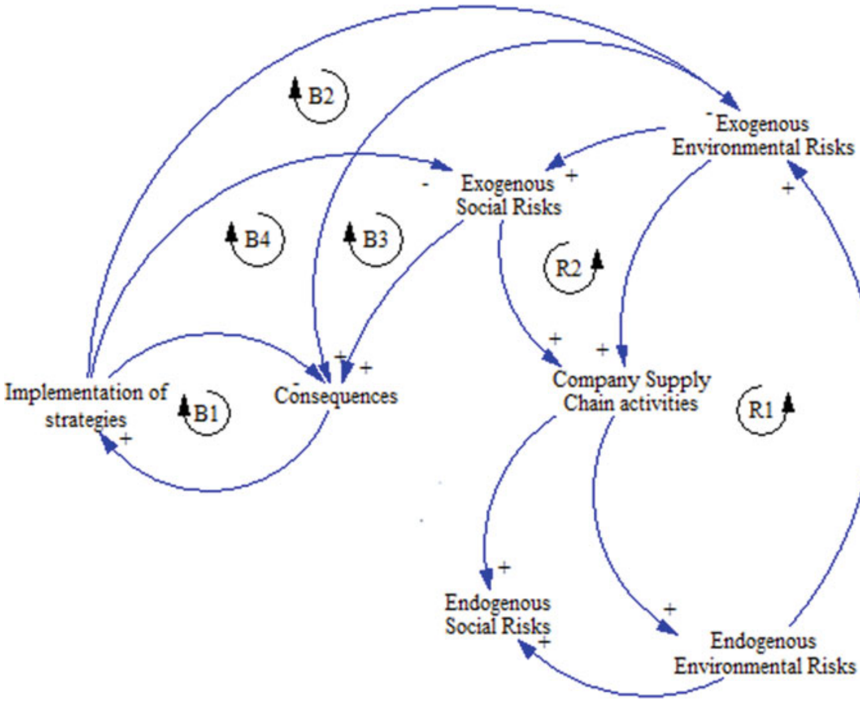


Fig. 2 Causal loop diagram: R1, R2, B1, B2, B3 and B4

Risks" causes more "Potential Consequences", which in turn leads to more "Implementation of strategies" that results in less "Endogenous Social Risks". The next balancing loop (B6) enlarge the notion discussed in the previous loop (B5) by the integration of the exogenous perspective of the social risks. Thus, B6 indicates that more "Exogenous Social Risks" causes more "Company Supply Chain activities", which in turn leads to more effect on the "Endogenous Social Risks", then, resulting in a sequence of more "Potential Consequences", more "Implementation of strategies", and consequently less "Exogenous Social Risks". The balancing loop B7 indicates that more "Exogenous Environmental Risks" causes more "Exogenous Social Risks", which in turn leads to more effect on the "Company Supply Chain activities", then, resulting in a sequence of more "Endogenous Social Risks", more "Potential Consequences" for the company, more "Implementation of strategies" by the company, and consequently less "Exogenous Environmental Risks". This last balancing loop (B7) represents an example of the several different and extended loops involving the social and environmental dimensions (both endogenous and exogenous). These extended loops represent an evidence of the high complexity involving the interested variables to the SCRM that focuses on social and environmental dimensions. These complex relationships represent another essential insight that arises from De Oliveira et al. [6] and Cunha et al. [2], especially between the relationship between "Endogenous

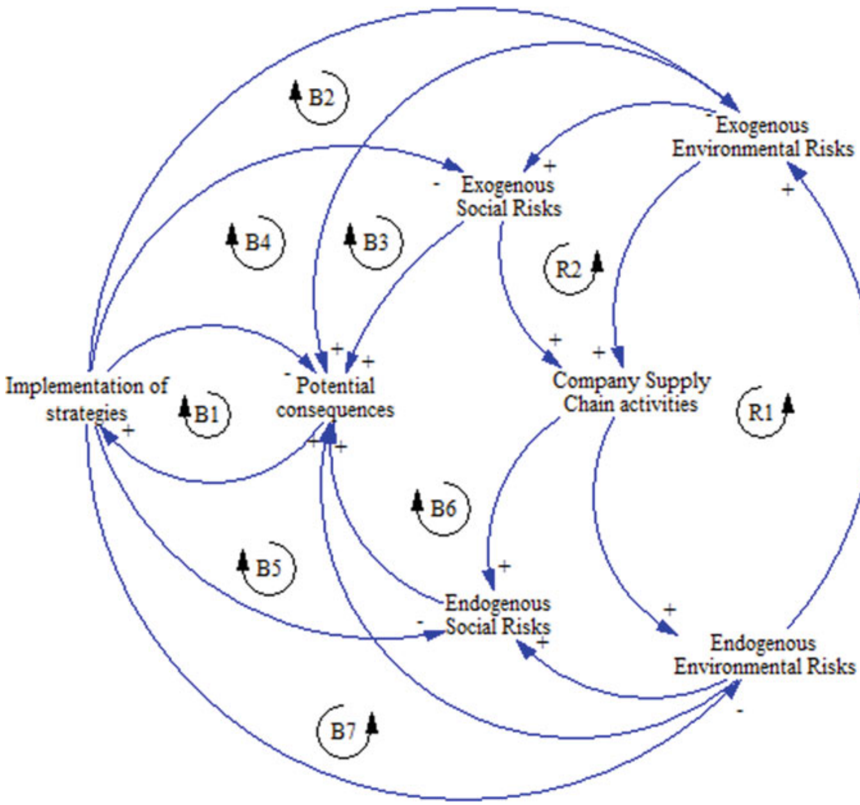


Fig. 3 Causal loop diagram: R1, R2, B1, B2, B3, B4, B5, B6, and B7

Environmental Risks" and "Endogenous Social Risks"—for instance, the emission of toxic gases in the atmosphere will negatively affect working conditions.

To endorse the discussion about the CLD aforementioned, Table 1 presents the correlations shown in Figs. 1, 2 and 3 as well as examples of these interactions and the correspondent references in which the relationships are inspired. While correlations within social variables and environmental variables arise from the literature analyzed, the correlations combining the environmental and social variables are contributions of the current research. Besides that, some relationships detailed in Table 1 bring evidence that the financial risks also affect the environmental and socials risks, even though these financial variables are not included in the CLD due to the research limitation posed in the previous section.

The analysis of the CLD through the reinforcing and balancing loops enables the definition and discussion of the following 10 hypotheses about the SCRM. The main focus are the relationships combining environmental and social dimensions. Nevertheless, some hypotheses also emphasize specific and relevant relationships

Table 1 Relationship details between social and environmental variables

Relationships between variables	Examples	References
Exogenous environmental risks → Company supply chain activities	Man-made disasters (such as wars), and natural disasters (such as hurricanes) may negatively affect companies' activities	[6]
Company supply chain activities → endogenous environmental risks	The company supply chain activities can generate endogenous environmental risks such as greenhouse gas emissions since many harmful gases are released into the atmosphere	[6]
Endogenous environmental risks → endogenous social risks	The discharge of sewage into rivers can affect the fauna of the region, leading to a decrease in the supply of fish, in addition to human health damage	Author's contribution
Endogenous environmental risks → exogenous environmental risks	The greenhouse gas emissions and other harmful emissions released by companies into the atmosphere may intensify climate change and therefore influence natural disasters	[6]
Exogenous environmental risks → exogenous social risks	A natural disaster such as pandemics may lead to economic and social instability	Author's contribution
Consequences → implementation of strategies	Consequences such as loss of company reputation make the company implement strategies to reverse the scenario	[2, 6]
Implementation of strategies → consequences	Policies regarding harassment and gender equality can reduce financial and reputational consequences for companies. As well as strict policies related to management of chemicals substances can prevent environmental accidents and hence will prevent companies to suffer from reputational and financial consequences	[2, 6]
Implementation of strategies → exogenous environmental risks	Contingency plans and development of a flexible supply network can mitigate the negative effects and make supply chains more resilient in case of man-made and natural disasters	[6]

(continued)

Table 1 (continued)

Relationships between variables	Examples	References
Exogenous environmental risks → consequences	An earthquake may cause disruptions through the supply chains of companies, leading to severe financial consequences	[6]
Endogenous environmental risks → consequences	The inefficient use of energy or water may lead to financial consequences for the companies	[6]
Implementation of strategies → endogenous environmental risks	The implementation of policies such as control and management of the effluents released into soil and rivers may decrease the risk of chemical spills into water	[6]
Exogenous social risks → Company supply chain activities	Exogenous social risks such as strikes may affect the company's activities since the employees will stop working	[2]
Exogenous social risks → consequences	Exogenous social risks such as strikes performed by employees may generate financial consequences for the companies	[2]
Implementation of strategies → exogenous social risks	Policies to avoid mass layoffs can prevent population unrest and hence, social instability	[10]
Company supply chain activities → endogenous social risks	The companies´ activities may hold a child and slave-like work and unfair wages	[2]
Endogenous social risks → consequences	Child labor can lead to reputational consequences and legal sanctions to the companies	[2]
Implementation of strategies → endogenous social risks	Audit processes can avoid the improper use of equipment, preventing the workers from suffering accidents	[8]

involving only environmental or only social issues due to the correspondent effect on the SCRM that are emphasized by the balancing and reinforcing loops in the CLD.

(i) Company Supply Chain generates endogenous social and environmental risks;
(ii) Endogenous environmental risks generated by SC influence exogenous environmental risks;
(iii) Exogenous social and environmental risks affect the Company Supply Chain;
(iv) Exogenous environmental risks influence exogenous social risks;
(v) Endogenous environmental risks influence endogenous social risks;
(vi) Social and environmental risks (both endogenous and exogenous) generate consequences for the company;

(vii) Consequences lead companies to implement risk management strategies;
(viii) The implementation of strategies mitigates social and environmental (both endogenous and exogenous) risks generated by SC;
(ix) The implementation of strategies mitigates the consequences faced by the company;
(x) Environmental and social (both endogenous and exogenous) risks are responsible for consequences to the companies.

The CLD and hypotheses provide detailed insights on the inner relationship among the social and environmental (both endogenous and exogenous) risks. Nevertheless, the relationship between these variables and the "Potential Consequences" for the company as well as the "Implementation of strategies" by the company remain similar as expected due to the main structure of SCRM as observed in the frameworks proposed by De Oliveira et al. [6] and Cunha et al. [2]. In this sense, the CLD in Fig. 3 also reinforce the main structure of SCRM in which the "Company Supply Chain activities" directly interacts with the risks (i.e., social and environmental, as well as endogenous and exogenous), that in turn involves "Potential Consequences", then the "Implementation of strategies", and consequently reducing the risks.

5 Conclusions

Considering the relevance of existing SLR in synthesizing the existing literature, this research proposes a CLD as a tool to further discuss the causal relationship between social and environmental risks in supply chains (i.e., endogenous and exogenous risks) and also, consequences and strategies. This diagram provides insights regarding the inner relationship among these variables, despite the similar structure in the relationship with the consequences ad strategies variables since they represent a fundamental structure of the SCRM. Besides that, the CLD enables the definition of 10 hypotheses based on these relationships between social and environmental dimensions. Furthermore, these interactions and insights that are relevant for decision-makers interested in an extended approach of SCRM that considers the social and environmental dimensions. The CLD presented in this paper is a simplified model of reality, which only discuss general variables within the context of environmental and social risk management. Thus, detailed interaction is outside the scope of the research. Nevertheless, the CLD analysis also presents an explanatory table containing examples of the relationships and how they can unfold. The suggestion of future research includes hypotheses validation through surveys or focus groups with specialists. Another future research venue relies on the inclusion of endogenous and exogenous financial risks in the CLD and the identification of their inner relationship with the social and environmental (both endogenous and exogenous) variables.

References

1. Bode, C., Wagner, S.M., Petersen, K.J., Ellram, L.M.: Understanding responses to supply chain disruptions: insights from information processing and resource dependence perspectives. Academy of Management Journal 54(4), 833–856 (2011).
2. Cunha, L., Ceryno, P., Leiras, A.: Social supply chain risk management: a taxonomy, a framework and a research agenda. Journal of Cleaner Production 220, 1101–1110 (2019).
3. Ferreira, F.D.A.L., Scavarda, L.F., Ceryno, P.S., Leiras, A.: Supply chain risk analysis: a shipbuilding industry case. International Journal of Logistics Research and Applications 21(5), 542–556 (2018).
4. Hofmann, H., Busse, C., Bode, C., Henke, M.: Sustainability-related supply chain risks: conceptualization and management. Business Strategy and the Environment 23(3), 160–172 (2014).
5. Seuring, S., Müller, M.: From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management. Journal of Cleaner Production 16(15), 1699–1710 (2008).
6. De Oliveira, F.N., Leiras, A., Ceryno, P.: Environmental risk management in supply chains: A taxonomy, a framework and future research avenues. Journal of Cleaner Production 232, 1257–1271 (2019).
7. Torres-Ruiz, A., Ravindran, A. R.: Multiple criteria framework for the sustainability risk assessment of a supplier portfolio. Journal of Cleaner Production 172, 4478–4493 (2018).
8. Cunha, L., Ceryno, P., Leiras, A.: Social Supply Chain Risk Management: A Case Study in a Brazilian Company. In: 26th EurOMA (European Operations Management Association) Conference, pp. 2131–2135. EurOMA, Helsinki (2019).
9. Graetz, G., Franks, D. M.: Incorporating human rights into the corporate domain: due diligence, impact assessment and integrated risk management. Impact Assessment and Project Appraisal 31(2), 97–106 (2013).
10. Lapalme, L.: The Social Dimension of Sustainable Development and the Mining Indus- Try: A Background Paper. Minister of Public Works and Government Services, Natural Resources Canada, Minerals and Metals Sector, Ottowa (2003).
11. Giannakis, M., Papadopoulos, T.: Supply chain sustainability: A risk management approach. International Journal of Production Economics 1(171), 455–70 (2016).
12. Jüttner, U., Peck, H., Christopher, M.: Supply chain risk management: outlining an agenda for future research. International Journal of Logistics: Research and Applications 6(4), 197–210 (2003).
13. Faisal, M.N.: Prioritization of risks in supply chains. In: Wu, T., Blackhurst, J. (eds.) Managing Supply Chain Risk and Vulnerability, vol. 41e66. Springer, Heidelberg (2009).
14. Andrade, A.L. Pensamento sistêmico-Caderno de campo: o desafio da mudança sustentada nas organizações e na sociedade. Bookman Editora, São Paulo (2009).
15. Mingers, J., White, L.: A review of the recent contribution of systems thinking to operational research and management science. European journal of operational research 207(3), 1147–1161 (2010).
16. Sterman, J.D.: Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw-Hill, Irwin (2000).
17. Pidd, M.: Just Modeling Through: A Rough Guide to Modeling. Lancaster University, United Kingdom (1999).

A Comparative Study of the Influence of Organizational Culture on Performance

Lillian do Nascimento Gambi and Harry Boer

Abstract This study aims to explore and compare the effect of organizational culture profiles (Rational, Hierarchical, Developmental, and Group culture) on performance as a single-factor and as a multi-factor construct. Based on data collected in 250 firms in Brazil and Denmark, two theoretical models are tested using Structural Equation Modeling. The findings show that, when considering performance as a single factor, only the Rational culture has a positive effect on performance. When performance is considered as a multi-factor construct, all the relationships between organizational culture profiles and performance groups were positive and significant. Thus, the effect of culture on performance varies depending on the type of performance measured. These findings contribute to theory showing that characteristics of each cultural profile are related to specific types of performance. Managers should understand this fit in order to ensure congruence between their organization's performance goals and characteristics of its internal culture.

Keywords Organizational culture · Performance · Structural equation modeling

1 Introduction

Most scholars and practitioners recognize the importance of culture on performance and long-term effectiveness of organizations. Uzkurt et al. [1], for instance, argue that organizational culture (OC) is one of the important drivers of firm performance; in the same vein, Valmohammadi and Roshanzamir [2] defend that OC can effectively promote overall performance.

L. do Nascimento Gambi (✉)
Federal University of Viçosa, Campus Rio Paranaíba, Rio Paranaíba 38810-000, Brazil
e-mail: lillian.gambi@ufv.br

H. Boer
Center for Industrial Production, Aalborg University, 9220 Aalborg, Denmark

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_35

Some studies [2–4] consider performance as a multidimensional construct, while others authors study the effect of OC on some aspects of performance: firm performance [1], manufacturing performance [5], innovation performance [6], or employee performance [7, 8].

Culture is a complex concept [9], generally seen as a belief system that members of an organization share to achieve goals. This system guides and constrains behavior [10, 11]. In this study, we adopt the well-established [5] Competing Values Framework (CVF) [12, 13] as a model to identify organizational culture. This model has been widely used in operations management studies [2, 5, 14]. The CVF is based on two competing dimensions: control-flexibility versus internal-external. The juxtaposition of these two dimensions creates four cultural profiles: the group, developmental, hierarchical, and rational cultures, respectively.

According to Calciolari et al. [15], CVF assumes that OC is multidimensional concept. Therefore, an organization does not have a single culture, but a dominant culture which refers to the set of values and behaviors most commonly shared. To Alvesson [16], OC is highly relevant for understanding organizations, including financial and other forms of performance.

A number of studies on the organizational culture-performance relationship showed that culture type and orientation are associated with performance. Prajogo and McDermott [3] study the effect of OC on four types of performance (product and process quality, and product and process innovation), and highlight the importance of acknowledging the link between an organization's goals and its cultural orientation. Their finding show that some benefits are not associated with certain cultural characteristics.

Mohr et al. [17] study the moderating effect of group culture on the relationship between employee turnover and operational performance and conclude that organizations with high levels of turnover should develop and adopt practices related to the group culture.

Based on their meta-analytic review, Büschgens et al. [18] argue that OC values that rely on control are, in general, negatively related to innovation, whereas flexibility is positively related to innovation. However, Janka et al. [14] find that organizations with a certain degree of stability in their culture are able to shape managerial innovation through cultural controls.

Tseng [4], studying the effect of OC on corporate performance (financial; market/customer; process; people development, and future) finds that the developmental culture has a stronger effect on performance than the group culture.

In this context, Calciolari et al. [15] argue that research could explore and compare the influence of OC and its dominant strength on different dimensions of performance to better triangulate limitations and points of strength for each culture type.

In spite of the literature presenting ample evidence that OC has influence on performance, studies comparing the influence of OC on performance as a single factor and as a multi factor construct are still missing. Therefore, this study aims to investigate the effect of OC on performance, and if this effect varies if different dimensions of performance are considered.

2 Objective

The main purpose of this paper is to compare the effect of OC profiles and performance as a single-factor and as a multi-factor construct, and answer the following research question: *Does the effect of organizational culture profile on performance vary depending on the type of performance measured?* Therefore, two models will be tested. In the first model performance will be considered as a single bundle of variables; in the second model, they will be divided according to their type.

3 Method

3.1 Sample and Method

Data were collected electronically using the web-based software SurveyMonkey®. The link to the questionnaire was sent to a random sample of 1761 Brazilian and Danish manufacturing companies. Only questionnaires returned without missing values were considered: 250 in total (14% response rate), being 52.8% Brazilian respondents, and 47.2% Danish respondents. Over 90% of the respondents occupy managerial job positions.

First, survey scales were assessed for reliability using Cronbach's alpha (performed in IBM® SPSS® Statistics 24). Second, a factor analysis was performed to identify the performance groups, and again reliability was measured for each group identified. Third, Structural Equation Modeling in IBM® SPSS® Amos 24 was used to test the relationships between the constructs.

3.2 Operationalization of the Constructs

Organizational culture: based on the CVF [12] adapted from [13], a total of 12 items were used to measure four cultural profiles on a five-point Likert scale ranging from 1 = "Strongly disagree" to 5 = "Strongly agree".

Performance: nine items were defined to measure performance based on the survey instruments presented by [3, 5, 19, 20], and measured on a five-point Likert scale with "Consistently increasing/decreasing" (productivity; unit cost; lead time; number of customer complaints; amount of scrap, rework and defects; employee turnover; rate of absenteeism) and "Very low/superior" (the speed of the product development process against that of our competitors, and "poor/superior" (rate of change in our processes and technology against that of our competitors) (Fig. 1).

To test Model 2, a factor analysis was performed to identify different groups of the performance construct. Table 1 shows the results of factor analysis.

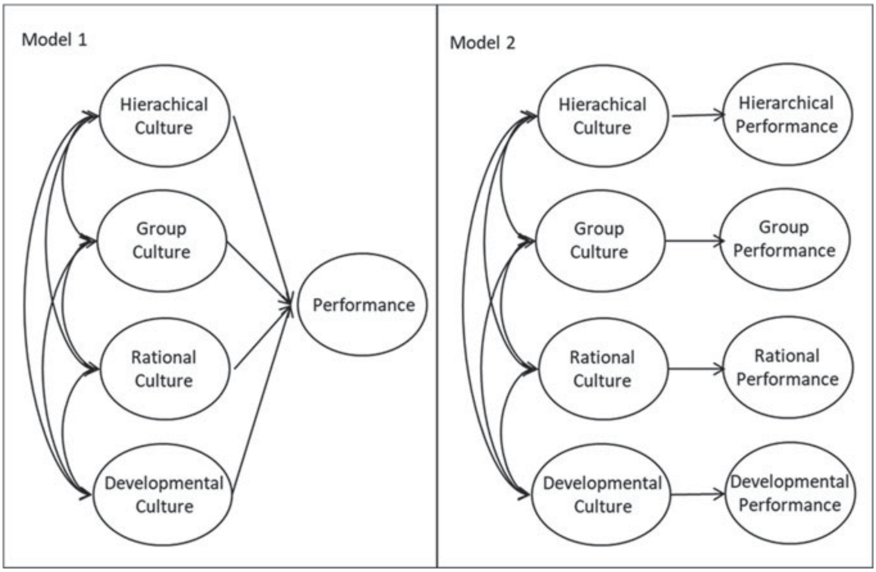


Fig. 1 Structural research models

As shown in Table 1, the factor analysis returned four factors named according to the OC profiles. All the factor loadings are above 0.688, demonstrating construct validity. Moreover, the communality of the items was above 0.61 and the percentage of total explained variance (66%) indicates that the items and the obtained factors are satisfactory for explaining the data.

Cronbach's alpha was 0.59, 0.46, 0.62 and 0.61 for Hierarchical, Group, Development, Rational and Developmental performance, respectively. These values do not reach the generally accepted threshold of 0.70. However, according to Hair et al. [21], values above 0.60 are acceptable for exploratory research. Therefore reliability was satisfactory for all set of measured items for the groups identified in the factor analysis, with exception of Group performance group, while the Hierarchical performance group is on the border. This limitation can be minimized by the fact that only two items were used to measure Group performance, while three items were used to measure Hierarchical performance. Cronbach's alpha is sensitive to the number of items in the scale, which may contribute to these low values. Besides the factor analysis showed a good sampling adequacy [22] with a Kaiser-Meyer-Olkin's (KMO) value of 0.762, showing the data is appropriate.

All the variables used, codes, factor loading, and reliability are presented in Appendix A.

Table 1 Performance—factor analysis and communality

Performance indicators		Factor loadings				Communality
Code	Description	Hierarchical	Developmental	Rational	Group	
PH1	Productivity	0.705	0.156	– 0.115	0.321	0.637
PH2	Unit cost of manufacturing product	0.740	0.208	0.129	−0.040	0.609
PH3	Leadtime	0.688	−0.075	0.375	−0.077	0.625
PD1	Speed of the product development process against that of our competitors	0.046	0.837	0.110	0.094	0.724
PD2	Rate of change in our processes and technology against that of our competitors	0.176	0.808	0.064	0.067	0.693
PR1	Number of customer complaints	0.036	0.102	0.835	0.161	0.734
PR2	Amount of scrap, rework and defects	0.245	0.119	0.707	0.274	0.650
PG1	Employee turnover	0.116	−0.026	0.257	0.777	0.685
PG2	Rate of absenteeism	0.227	0.214	0.136	0.716	0.628

3.3 Structural Model

Structural Equation Modeling (SEM) in AMOS v. 24 was used to test the paths in the models. The results are presented in Table 2.

RMSEA, $\chi 2$/df, GFI, CFI were used as indicators to measure the fit of the data to the models. As a guideline, RMSEA < 0.07 and, $\chi 2$ ($\chi 2$/df) smaller than 5.0 is considered good model fit [21] and CFI, GFI close to 1.0 represent a perfect fit [21]. The overall fit statistics for the model 1 are $\chi 2/df = 1.510$, CFI = 0.944, GFI = 0.907 and RMSEA = 0.045; and model 2, $\chi 2$/df: 1.606, CFI = 0.931, GFI = 0.901 and RMSEA: 0.049. Therefore, the measures suggest satisfactory model fit.

Table 2 Effects of organizational culture profiles and performance and fit measures of the models

Model 1—The effect of organizational culture profiles on performance as a single factor			
	Effects	Overall fit measures	
Hierarchical culture – > Performance	0.061 ns	x2/df	1.510
Developmental culture – > Performance	0.142 ns	CFI	0.944
Group culture – > Performance	0.088 ns	GFI	0.907
Rational culture – > Performance	0.655 *	RMSEA	0.045
Model 2—The effect of organizational culture profiles on performance as a multiple factor			
	Effects	Overall fit measures	
Hierarchical culture – > Hierarchical Performance	0.489 **	x2/df	1.606
Developmental culture – > Developmental Performance	0.730 **	CFI	0.931
Group culture – > Group Performance	0.519 **	GFI	0.901
Rational culture – > Rational Performance	0.629 **	RMSEA	0.049

ns $p > 0.100$; * $p < 0.050$; ** $p < 0.001$

4 Discussion

The analysis of the empirical data demonstrates that OC has influence on performance. However, the effect of culture on performance varies depending on the type of performance measured.

Model 1—The effect of organizational culture profiles on performance as a single factor.

When performance is considered as a single factor, the results show no statistical significance (with for $p < 0.001$) for the relationship of any of the culture profiles with performance. When we consider $p < 0.05$, only the Rational culture presents a positive significant effect on performance (0.655). For the other cultural profiles (Developmental, Group, and Hierarchical) the effect remains insignificant.

A possible reason for this finding can be found in [23], who investigate the associations between culture profiles, the use of quality techniques, and performance. They report that in firms with a Rational culture, it is culture, rather than the use of quality techniques, that explains performance. In the three other culture profiles, the performance effects of culture are fully or partially mediated by quality techniques. This suggests that for most culture profiles, culture may have a direct effect, but is not the only driver of performance, and we cannot exclude that is the case for the rational culture, too. Further research investigating other mediating variables is needed to shed light on this proposition.

Model 2—The effect of organizational culture profiles on performance as a multiple factor.

The results show that OC affects performance, but the effects depend on the type of performance considered. In model 1, most cultural profiles (Group, Developmental, and Hierarchical) do not have any effect on performance. However, in Model 2, when performance was divided into four types (according to the results of the factor analysis), all the cultural profiles have a positive effect on their specific performance factor. These findings show that some characteristics of culture are favorable to certain types of performance. This is aligned with Prajogo and McDermott's [3] findings. These authors studied the relationship between the four OC profiles and product quality, process quality, product innovation, and process innovation. Their results show, amongst others, that the Hierarchical culture is only (positively) related to process quality, while the Developmental culture is (positively) related to product quality, product innovation, and process innovation.

Along the same line, Calciolari et al. [15] conclude that different culture types have different performance outcomes. They argue that enhancing a specific performance dimension requires some cultural changes to align the companies' values with the targeted results.

In this study we show that characteristics of the Hierarchical culture, such as control, discipline, stability and internal focus, are positively related to productivity, unit cost and lead time. These measures reflect operational efficiency, and are aligned to the criteria of effectiveness described by Cameron and Quinn [13] for this culture: operating efficiency and timeliness.

Also with its internal focus, the Group culture is oriented towards human relations, with trust and participation as core values. In this culture the effectiveness criteria most highly valued include high levels of employee morale and satisfaction and human resource development [13]. This explains our finding that this culture has a positive effect on decreasing absenteeism and turnover.

The Developmental culture, with characteristics such as innovation, dynamism, and focus on external environment, has a positive effect on performance aspects related to product development speed and rate of change in processes and technology. This result shows that these outcomes are related to the central value for this culture: innovative outputs [13].

The Rational culture has a positive effect on the number of customers complains and amount of scrap, rework and defects, which concurs with Calciolari et al. [15], according to whom the performance outcomes of this culture include gaining market share and satisfaction of external stakeholders.

5 Conclusion

This study explores and compares the influence of four OC profiles, namely the Rational, Hierarchical, Group and Developmental cultures, on performance as a single construct and as a multi factor construct. The findings show that the effects of culture vary depending of the type of performance measured. When considering performance as a single construct, none of the relationships was significant; when performance was considered as a multi factor construct, all relationships between OC and performance were significant. Thus, the characteristics of each cultural profile are related to specific types of performance. As Prajogo and McDermott [3] and Calciolari et al. [15] highlighted: to understand this fit is important to ensure congruence between organization's performance goals and its internal culture.

The findings reported in this paper imply that companies need to develop and maintain cultural characteristics that fit to the performance priorities they pursue. Therefore, managers need to understand the culture of their organization and, if necessary, develop new characteristics depending of the expected outcome, in order to benefit most from their internal resources to achieve their performance goals.

The study has limitations related to the methodology used. For instance: the data was obtained from an electronic survey without control if the respondents understood the questions correctly, performance was operationalized in qualitative variables, and few variables were used to measure each of the performance groups. Future research should consider a greater number of variables for each performance groups, and the use of different methodologies including case studies to better understand the findings presented here. Furthermore, OC cannot be the only driver of performance. Another important question therefore is: what other drivers are there? And, then, considering that manufacturing practices are the most obvious candidates, and how do OC and manufacturing practices interact to maximize manufacturing performance?

Acknowledgments The authors thank the financial support provided by National Council for Scientific and Technological Development (CNPq), Brazil; and State of Minas Gerais Research Foundation (FAPEMIG), Brazil.

Appendix A Variables and Preliminary Statistics

Code	Dimensions and variables	Factor loadings	Reliability
Hierarchical culture			
H1	In my organization, formalized procedures generally govern what people do	0.861	0.73
H2	My organization emphasizes efficiency and control to reach predictable performance results	0.569	
H3	The management style in my organization prioritizes conformity, predictability, and stability	0.723	
Developmental culture			
D1	My organization emphasizes prospecting for opportunities and creating new challenges	0.710	0.75
D2	My organization makes an effort to anticipate the potential aspects of new manufacturing practices and technologies	0.606	
D3	My organization is a very dynamic entrepreneurial place which leads people to taking risks	0.821	

(continued)

(continued)

Code	Dimensions and variables	Factor loadings	Reliability
Rational culture			
R1	In my organization, our reward system encourages us to reach plant goals	0.782	0.72
R2	My organization is very results oriented, people are very competitive and achievement oriented	0.606	
R3	In my organization, objectives and aims are clearly defined	0.637	
Group culture			
G1	In my organization, the development of human resources, and concern about employee are highly valued	0.679	0.77
G2	In my organization, the employees are encouraged to work as a team, exchange opinions, experiences, and ideas	0.650	
G3	In my organization, employees can openly discuss their opinions and ideas with someone higher up	0.834	
PR	*Performance*		0.71
PH1	Productivity	0.705	0.59
PH2	Unit cost of manufacturing product	0.740	
PH3	Leadtime	0.688	
PD1	Speed of the product development process against that of our competitors	0.837	0.61
PD2	Rate of change in our processes and technology against that of our competitors	0.808	
PR1	Number of customer complaints	0.835	0.62
PR2	Amount of scrap, rework and defects	0.707	
PG1	Employee turnover	0.777	0.46
PG2	Rate of absenteeism	0.716	

References

1. Uzkurt, C., Kumar, R., Kimzan, H.S. and Eminoglu, G. Role of innovation in the relationship between organizational culture and firm performance: a study of the banking sector in Turkey. European Journal of Innovation Management. 16(1), 92–117 (2013).
2. Valmohammadi, C. and Roshanzamir, S. The guidelines of improvement: relations among organizational culture, TQM and performance. International Journal of Production Economics, 164(6), 167–178 (2015).
3. Prajogo, D., McDermott, C.M. The relationship between multidimensional organization culture and performance. International Journal of Operations & Production Management, 31(7), 712–735 (2011).
4. Tseng, S.M. The correlation between organizational culture and knowledge conversion on corporate performance. Journal of Knowledge Management. 14(2), 269–284 (2010).

5. Naor, M., Goldstein, S.M., Linderman, K.W. and Schroeder, R.G. The role of culture as a driver of quality management and performance infrastructure versus core quality practices, Decision Science, 39(4), 671–702 (2008).
6. Ali, M. and Park, K. The mediating role of an innovative culture in the relationship between absorptive capacity and technical and non-technical innovation, Journal of Business Research, 69 (5), 1669–1675 (2016).
7. Shahzad, F.Impact of organizational culture on employees' job performance", International Journal of Commerce and Management, 24 (3) 219–227 (2014).
8. Awadh, A. M. and Saad, A. M. Impact of organizational culture on employee performance. International Review of Management and Business Research, 2 (1), 168–175 (2013).
9. Tian, M., Deng, P., Zhang, Y. and Salmador, M.P. How does culture influence innovation? A systematic literature review, Management Decision, 56(5), 1088–1107 (2018).
10. Schein, E.H. (1984). Coming to a new awareness of organizational culture. Sloan Management Review, 25(2), 3–16 (1983).
11. Pakdil, F. and Leonard, K.M. The effect of organizational culture on implementing and sustaining lean processes", Journal of Manufacturing Technology Management, 26(5), 725–743 (2015).
12. Quinn, R. and Rohrbaugh, J.A. Spatial model of effectiveness criteria: towards a competing values approach to organizational analysis. Management Science, 29(3), 363–377 (1983).
13. Cameron, K.S.and Quinn, R.E. Diagnosing and Changing Organizational Culture: Based on the Competing Values Framework, Jossey-Bass, San Francisco, CA (2006).
14. Janka, M., Heinicke, X., Guenther, T.W. Beyond the "good" and "evil" of stability values in organizational culture for managerial innovation: the crucial role of management controls. Review of Managerial Science (2019).
15. Calciolari, S., Prenestini, A. and Lega, F. An organizational culture for all seasons? How cultural type dominance and strength influence different performance goals. Public Management Review, 20(9), 1400–1422 (2018).
16. Alvesson, M. Understanding organizational culture. Sage Publications Ltd, London (2002).
17. Mohr, D.C., Young, G.J. and Burges Jr, J.F. Employee turnover and operational performance: the moderating effect of group-oriented organizational culture. Human Resource Management Journal, 22(2), 216–233 (2012).
18. Büschgens, T., Bausch, A. and Balkin, D.B. Organizational culture and innovation: a meta-analytic review. The Journal of Product Innovation Management. 30(4), 763-781 (2013).
19. Baird, K., Hu, K. and Reeve, R. The relationships between organizational culture, total quality management practices and operational performance, International Journal of Operations & Production Management, 31(7), 789–814 (2011).
20. O'Reilly, C.A. III, Chatman, J. and Caldwell, D.F. People and organizational culture: a profile comparison approach to assessing person-organization fit, Academy of Management Journal, 34(3), 487–516 (1991).
21. Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. Multivariate Data Analysis, Prentice Hall, Upper Saddle River, NJ (2009).
22. Tabachnick, B.G. and Fidell, L.S. Using Multivariate Statistics, Pearson, New York, NY (2007).
23. Gambi, L. N., Boer, H., Gerolamo, M.C., Jørgensen, F. and Carpinetti, L.C.R. The relationship between organizational culture and quality techniques, and its impact on operational performance. International Journal of Operations & Production Management, 35(10), 1460–1484 (2015).

Work Ability Index (WAI) and Quality of Life at Work (QLW) in the Context of Occupational Accidents: A Survey with Construction Workers

Ingrid Simone Galati, José Luís Garcia Hermosilla, Jorge Alberto Achcar, Flávia Motta Corvello, and Ethel Cristina Chiari da Silva

Abstract Civil construction is a sector of great economic and social importance for a country, but it is also one of the sectors that most affect workers. The main goal of this study is to identify the factors associated with occupational accidents for construction workers, in particular their work ability index (WAI) and the quality of life at work (QLW/SF-36). In this way, the response variable is a binary variable (occurrence or not of work accidents) and the main covariates of the study are given by WAI and QLW. Other socio-professional covariates also were considered as age, marital status, gender, education, time in the job, time in the company and involvement in accident at work, whose values were obtained from questionnaires that were responded by 114 workers considered in the study. This sample of workers presented a young age profile with 95% of the individuals under the age of 45 years, low education level, good disposition to work with only 5% with low WAI and average score of quality of life around 72%. Among all the variables evaluated, only the work ability index (WAI) was associated with the occurrence of work accidents. Further investigation is needed from a longitudinal perspective and more consistent analysis of cause and effect in the work accident occurrences. The results of the study point out to the need of more comprehensive and temporal studies to confirm the obtained results and also for adoption of more frequent assessment strategies for the perceptions of the employees' ability to work.

Keywords Work ability index · WAI · Quality of life at work · QLW · Construction workers · Work accident

I. S. Galati (✉) · J. L. G. Hermosilla · J. A. Achcar · F. M. Corvello · E. C. C. da Silva
University of Araraquara/UNIARA, Voluntários da Pátria Street, 1309 Araraquara, Brazil
e-mail: isgalati@uniara.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_36

1 Introduction

The worker's ability to work can be affected by several factors among which, environment and lifestyle [1]. This type of study in Brazil is still insipient and it is more concentrated in some specific areas, such as public health, which opens space for its deepening in several other sectors, not much explored yet [2]. Under this perspective, it is important that any study involving the ability to work, should be conducted with different worker groups and also with different age groups, in order to get more consistent results on the topic [3]. In addition, it is needed to conduct studies about this theme on workers who develop activities that demand physical and repetitive efforts, that are considered as high risk activities [4].

The workers themselves understand that events such as accidents at work can be the result of carelessness or lack of attention, however they can also be the result of poor working conditions, such as overload or lack of training, or poor health conditions [5]. The prevention of functional aging and loss of ability to work usually are related to workers' health, which points out to the need for a more preventive attitude from the companies [4, 6]. The workers' exposure to adverse conditions can increase the risk of accidents at work, that is common in the construction's sector, where excessive physical effort, work at heights, dust and noise are some of its characteristics [7, 8]. Monitoring the work capacity of workers and their quality of life at work is an important aspect of personnel and organizational management, that helps to identify individuals who need care and who may be more susceptible to health problems, while promoting better maintenance of workers' productive capacity [4, 9–11].

In this context, the goal of this investigation is to identify the factors that are related to occupational accidents of the construction workers, in special, the relationship between work accidents and the work ability index and quality of life at work. This quantitative, descriptive and exploratory investigation was based on a dataset related to 114 workers (bricklayers and servants) from a medium-sized company in the construction industry.

The database of this quantitative study is composed of socio-professional information, that was collected using two instruments (questionnaires): the work ability index (WAI), and the quality of life at work (QLW), added with questions of a socio-professional nature such as gender, age, marital status, education, time in the job, working time in the company in question, Brazilian province of origin, information if the worker lives in the company's accommodation or in his own residence with his family, the number of people living in the same house, how often the worker practices physical activities outside the workplace, whether the worker have unhealthy habits such as tobacco use and how often he drinks alcohol, or if he had an accident at work. The research was approved by the Ethics and Research Committee of the University of Araraquara, S.P., Brazil (protocol n ° 2,893,482); the participation of workers was voluntary and by signing the Informed Consent Form (ICF).

2 Bibliographic Review

The work ability index (WAI) is an instrument that measures the worker's work capacity. As stated by [1], "WAI reveals how well a worker is able to do his job and it can be used as one of the methods to assess work ability in health checks and surveys in the workplace". Work ability index is an important indicator for assessing physical health, social and psychological well-being, individual efficiency and working conditions, and it is a self-responding instrument that analyzes seven dimensions [1, 2].

In order to get the worker WAI, each dimension of the WAI questionnaire must be answered and added at the end, which may result in values ranging from 7 to 49 points. The final WAI scores could be classified into four categories: bad, moderate, good and excellent, and the higher scores indicates better work capacity [12]. Another important indicator related to the work environment is the quality of life at work (QLW), an index that evaluates the development of a healthy work environment which promotes efficiency in work activity. The evaluation of these characteristics occur through the use of a questionnaire of quality of life at work, called SF-36 [13]. The questionnaire consists of 36 questions that assess eight dimensions of health: health perception, physical functioning, functional function, body pain, emotional functioning, emotional well-being, social function and energy versus fatigue [14]. Studies that investigate the association between work ability and quality of life at work seek to understand and identify factors that influence worker individual performance and satisfaction in the work environment, which can help to develop preventive measures to health and risks from the professional environment, such as accidents at work [11]. Several studies have shown some correlation between characteristics of work activity and health and the exposure to risks of the workers, which can lead to work accidents; a consensus variable in these surveys is the nature of these predominantly physical activities as in the case of locksmiths [15], rural workers such as cane cutters [7, 16], workers in the electrical sector [6] and construction workers [8].

Additional care must be taken when investigating the ability to work and quality of life at work for workers, because the application of the instruments is made based on professionals that are at work, and does not consider the others absent from work. This absence may be associated with low rates of WAI and of QLW [11, 23]. Poor working conditions can influence the increase of occupational accidents, as in the case of the civil construction area, however, this fact is not a consensus among the researchers [10, 17, 18].

3 Methodology

This cross-sectional quantitative descriptive research used two questionnaires (Work Ability Index/WAI and Quality of Life at Work/QLW / SF-36) as instruments for the data selection, added by sociodemographic and occupational issues, which were applied to a group of 114 workers of operational level (they play predominantly physical activities - servants and bricklayers).

The independent research variables were socio-demographic, WAI, quality of life, and the dependent variable was a binary variable given by involvement or not in an accident at work. The socio-demographic and occupational variables are the birth place of the worker, information if he lives in the accommodation offered by the company or in his own home together with his family, the number of people living in the same house, the frequency of physical activities outside the working environment, information on unhealthy habits such as the use of tobacco and the frequency of alcohol intake, gender, age, marital status, education, time in the job, time working at the company and if he had an accident at work.

Statistical approaches for categorical data such as chi-square tests for independence and logistic regression models were used to assess the degree of association between the variables, adopting a critical p-value < 0.05 to detect statistical significance under both approaches, using the Minitab® software version 17.

4 Data Analysis and Obtained Results

The dataset was collected through the application of two instruments (questionnaires) to each worker: the work ability index (WAI) and the quality of life (QLW/SF-36). The instruments were distributed to 114 workers of a medium sized company of the construction sector, from the countryside of São Paulo province, Brazil. The data set of the 114 workers were obtained in October 2018, revealing that 7.01% of the respondents (8 individuals) claimed to have been involved in occupational accidents. The geographical region of the investigated workers has approximately 4,900 professionals registered in the construction activity according to the Union Values Collecton Report [19], which reveals the representativeness of the study, that is, around 2.32% of this population.

This section related to the data analysis consists in three stages: a descriptive analysis of the collected data that aim to describe the distribution of workers by variable; the use of a statistical analysis based on chi-square independence tests for each categorical variable in relation to the occurrence of accidents at work, and a joint statistical analysis, carried out through the use of a logistic regression analysis, which is a recommended technique for situations in that the dependent variable is dichotomous or of binary nature, as in the case, and that captures the joint effect of all independent variables on the response.

4.1 Descriptive Analysis of the Data

The survey was carried out initially with 139 construction workers (bricklayers and servants) of two construction work places of the same company located in the São

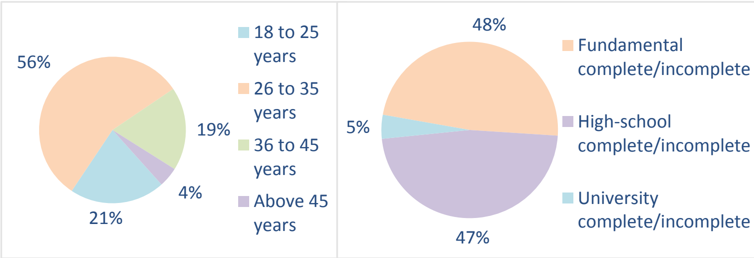


Fig. 1 Percentage of company's investigated workers by age and education in 2018

Paulo province, that were contacted and invited to answer the questions in a specific day for data collection. Of this total, 5 workers refused to participate, and 4 workers missed the appointed day for data collection, even though they accepted the invitation, which resulted in a total of 130 respondents. After having been collected the data, 16 questionnaires had to be discarded for missing information, that results in 114 valid questionnaires. The data, which formed the basis for subsequent analyzes, are broken down by variables as it is observed in the charts below with all respondents being males.

Figure 1, related to the analysis of data personal issues, shows that the majority of the interviewees is young, and they are classified respectively in five categories, 18–25 years old (21.05%), 26–35 years old (56.14%), 36–45 years old (18, 42%) and over 45 years old (4.39%), as it can see in Fig. 1, panel (a). In terms of education level, panel (b) shows that almost half of the interviewees have completed/incomplete primary education (48.25%), complete/incomplete secondary education (47.37%).

(a) Age distribution in percentage of company's investigated workers in 2018.
(b) Educational level in percentage of company's investigated workers in 2018.

Figure 2, panel (a) shows that the majority of respondents are from other Brazilian provinces, such as Minas Gerais (46.49%) and Bahia (29.82%), moreover, it was observed that 56% of the investigated workers started to work when they were over 18 years old. In panel (b) of Fig. 2 related to the information of workers' health, it

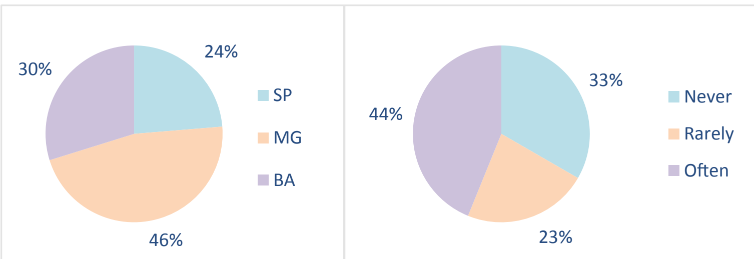


Fig. 2 Percentage of company's investigated workers by province of origin and frequency of consuming alcoholic beverages in 2018

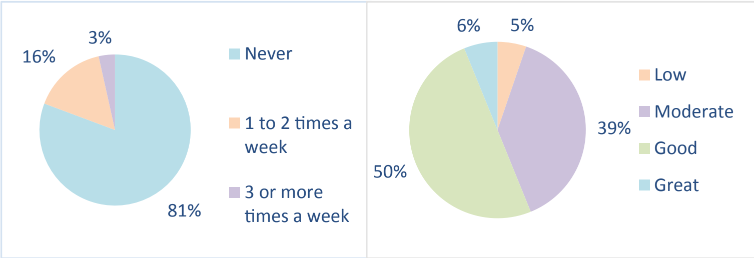


Fig. 3 Percentage of company's investigated workers by frequency of physical activity and distribution of work ability index in 2018

is showed that the majority of respondents have unhealthy habits, such as drinking alcoholic beverages frequently.

(a) Percentage of company's investigated workers by province of origin in 2018.
(b) Percentage of company's investigated workers by frequency of consuming alcoholic beverages in 2018.

Regarding to the information related to workers' health, Fig. 3, panel (a) shows that the majority of respondents (80.70%) did not have physical activity outside the work environment (80.70%); although these habits can influence the results of the WAI (Fig. 3, panel (b)), most of the workers have WAI scores between moderate (38.60%) and good (50%) and in the quality of life they obtained an average of 72.40.

(a) Percentage distribution of company's investigated workers by frequency of physical activity in 2018.
(b) Percentage distribution of Work Ability Index of the company's investigated workers in 2018.

The investigation also addressed other topics of interest such as the time of registration in the company, which showed that the majority (47%) of those investigated had 1 to 2 years of registration (Fig. 4, panel (a)); the frequency which workers

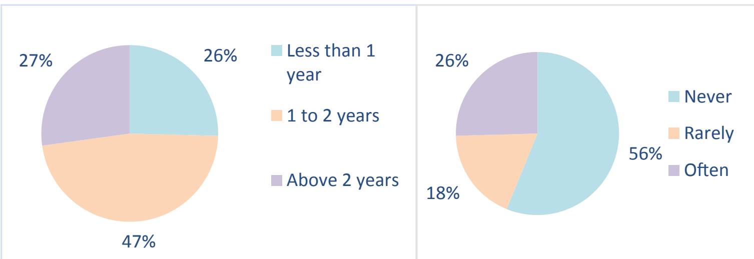


Fig. 4 Percentage of company's investigated workers by smoking of company's investigated and time of registration in 2018

smoke, was also identified, and revealed that 56% of them do not have this habit (Fig. 4, panel (b)).

(a) Percentage distribution by time of registration of company's investigated workers in 2018.
(b) Percentage distribution by frequency of smoking of company's investigated workers in 2018.

Other important information was also obtained from the study. It was observed that more than half of the workers live in the accommodation provided by the company (77.19%) and the others live with their own family (22.81%) and the activity function was also another identified aspect, that revealed that 55% of the interviewed workers were masons. Another interesting point that was investigated was regarding to the involvement of workers in work accidents, which showed that only 7% of the respondents had suffered some type of accident.

From this preliminary data analysis, it is possible to conclude that, in general, the workers do not practice physical activities outside the work environment, and the vast majority of them have unhealthy habits, such as, the use of alcoholic beverages, that could be associated with the fact that the workers live far from their families. Despite the fact of a considerable number of employees have unhealthy habits, most respondents had WAI scores between moderate and good, which could be explained by the fact that the majority of respondents are young and aged between 18 and 35 years old, that represents 77.19% of the respondents.

Regarding quality of life, the average index among all 114 interviewees is 72.40, that is considered a good score, after all, quality of life is evaluated from 0 to 100 and the higher the value, the better is the quality of life. In this way, the obtained value corroborates with the result of the WAI, since most workers have scores between moderate and good.

4.2 Chi-Square Test of Independence

The chi-square test is a standard statistical test that aims to verify whether there is independence between the categorical independent variables and the categorical dependent variables (see for example, Montgomery and Runger [20]). This type of statistical test reveals the intensity of the relationship between the variables and confirms a possible correlation between the variables, evaluating the output variables individually, without considering the influence of other aspects that may be involved. In this case, this statistical tool was used to find out if there is evidence of association among the above mentioned covariates with the response variable occurrence of accidents at work. Table 2 summarizes the p-values found in the independence tests involving each one of the covariates with the occurrence of work accidents.

For the covariates age and education and the responses WAI and quality of life, it was not possible to perform the test due to the fact that in these cases the sample is very small (less than 5 observations in each cell of the qui-square test). For the other

Table 1 Results for the chi-square tests (p-values)

Covariates	p-value
Marital status	1.000
Original province	0.135
Age that started to work	0.346
Frequency of physical activity	0.151
Frequency of smoking	0.878
Frequency of alcohol consumption	0.873
Function	0.756
Company time	0.986
Local residence	0.304

cases, from Table 1, it is observed that there is no dependence between the response work accident and all considered covariates (p-values > 0.05).

5 Use of a Logistic Regression Model

Logistic regression is a statistical technique that aims to produce, from a set of observations, a fitted model that allows the prediction of probabilities for a binary response, associated to the results of many continuous and/or categorical covariates (see for example, [20]). Also, in the data analysis assuming a logistic regression model, besides the estimation of the probability of the occurrence of an event of interest, it is also possible to identify which independent covariate have significative effect for the probability of the occurrence of binary responses. In this way, the logistic regression allowed to estimate the probability for the binary response variable (involvement in work accident) in association with the independent variables (or covariates). From the obtained results in Table 2 using the software Minitab®, it is observed that the covariate WAI is significantly associated (p-value < 0.05) with the response "involvement in occupational accidents".

Table 2 also shows additional information from the logistic regression analysis for the factors involved in accidents, such as the maximum likelihood estimators (MLE) for the regression coefficients associated to each covariate. From these results, it is possible to observe that the regression parameter estimator associated to the covariate WAI has a negative value (−0.261), that is, an indication that the higher the WAI value indicates less chance of an accident. The other covariates do not show significance (p-values > 0.05). The obtained results of this study are in agreement with the obtained results from some other studies in the literature, from where it was observed satisfactory results related to the WAI score associated with different ages, but some variables such as age, sex, unhealthy habits, physical exercise practices also did not show significative results groups [21], while other studies have found

Table 2 P-values for the logistic regression model associated to the independent variables with response involvement in work accidents

Source	MLE	P-value
Regression	5.98	0.426
Life quality (mean)	0.0403	0.438
WAI	*−0.261*	*0.032*
Frequency of drinking alcohol	−0.356	0.539
Frequency of smoking	0.585	0.324
Age	−0.018	0.793
Age when started working	−0.62	0.511
Company time (years)	0.05	0.939
Function	−0.419	0.652
Marital status	0.129	0.888
Origin province	−2.73	0.083

significative relationship between the covariates WAI, QLW with the response related to work accidents [22].

Some studies that involve workers who perform high physical demand functions have found reports of skeletal muscle pain and low back pain which could influence in the occurrence of accidents [15, 16], but these results were found because these variables were not considered in the present study. Considering WAI and QLW, this investigation revealed that most of the investigated workers have scores considered good, based on their respective scales, that is an important aspect that may be related to the fact that those workers with low scores could be unable to exercise the activity and these workers could be on sick leave, which is reasonable to suppose, a result also reported by others authors [6, 11, 23]. The level of education was another factor of interest for this investigation, which revealed a predominance of low education among the respondents; no participant was illiterate, and most of them were in a complete/incomplete elementary education level, but this covariate did not show relationship with WAI, QLW and work accidents [24]. In addition, this study also did not show relationship between age and quality of life, and between quality of life and work accidents, which is contrary to the results of some studies that have showed a opposite result, that is, the existence of a negative association between age and quality of life of workers, that is, the higher the age, the lower the quality of life [18].

6 Some Conclusions

Civil construction is a sector of great economic and social importance for the Brazilian economy, however its condition of high risk of accidents for its members is also notorious, a fact that justified the interest of this study in this area.

In this study, it was addressed personal, professional and health variables associated to the interviewees. In addition, the study also considered the WAI and QLW variables to verify their influence on work accidents. From the obtained results, it was observed that only WAI was related to the occurrence of work accidents, resulting that the WAI is inversely proportional to the occurrence of work accidents, that is, the lower the WAI, the greater is the chance of an individual to have a work accident. Through the relationship found in this study, some strategies could be adopted, such as frequently evaluation of employees' WAI, so that, specific security programs can be applied to those who have unsatisfactory WAI; it is also advisable frequently inspection of the works to verify the use of PPE's and evaluate ergonomic postures in relation to the performed activities. This study also highlights the need for further studies in the area of construction or with other workers with high physical demand, since most of the studies found in the literature considered health workers. It is also important to evaluate a larger number of employees, including in the study other variables such as the distance that employees stay from their families to work, the types of physical pain that exist, such as low back pain and skeletal muscle, making an association with the CID's (a Brazilian identification of diseases) associated to medical certificates and also, the elaboration of studies in relation to productivity of workers, so that, a relationship can be found between these variables and the individual's production. In addition, it would be also of great importance to apply a test–retest in order to have clearer results to verify these and other variables that may be significance for prevention of work accidents.

References

1. Tuomi, K., Ilmarinen, J., Jahkola, A., Katajarinne, L., Tulkki, A.: Índice de capacidade para o trabalho. EdUFSCar. São Carlos (2010).
2. Martinez, M. C., Latorre, M. R. D. O., Fischer, F. M.: Capacidade para o trabalho: revisão de literatura. Ciência & Saúde Coletiva, v. 15, n. suppl 1, pp. 1553–1561 (2010).
3. Martinez, M. C., Latorre, M. R. D. O., Fischer, F. M.: Validade e confiabilidade da versão brasileira do Índice de Capacidade para o Trabalho. Revista de Saúde Pública, v. 43, pp. 525–532 (2009).
4. Costa, C. S. N., Freitas, E. G., Mendonça, L. C. S., Alem, M. E. R., Coury, H. J. C. G.: Capacidade para o trabalho e qualidade de vida de trabalhadores industriais. Ciência & Saúde Coletiva, v. 17, pp. 1635–1642 (2012).
5. Iriart, J. A. B., Oliveira, R. P., Xavier, S. S., Costa, A. M. S., Araújo, G. R., Santana, V. S.: Representações do trabalho informal e dos riscos à saúde entre trabalhadoras domésticas e trabalhadores da construção civil. Ciência & Saúde Coletiva, v. 13, pp. 165–174 (2008).
6. Martinez, M. C., Latorre, M. R. D. O.: Fatores associados à capacidade para o trabalho de trabalhadores do Setor Elétrico. Cadernos de Saúde Pública, v. 25, pp. 761–772 (2009).
7. Alessi, N. P., Navarro, V. L.: Saúde e trabalho rural: o caso dos trabalhadores da cultura canavieira na região de Ribeirão Preto, São Paulo, Brasil. Cadernos de Saúde Pública, v. 13, pp. S111–S121 (1997).
8. Takahashi, M. A. B. C., Silva, R. C., Lacorte, L. E. C., Ceverny, G. C. O., Vilela, R. A. G.: Precarização do Trabalho e Risco de Acidentes na construção civil: um estudo com base na Análise Coletiva do Trabalho (ACT). Saúde e Sociedade, v. 21, pp. 976–988 (2012).

9. Abbasi, M., Zakerian, A., Akbarzade, A., Dinarvand, N., Ghaljahi, M., Poursadeghiyan, M., Ebrahimi, M. H.: Investigation of the relationship between work ability and work-related quality of life in nurses. Iranian Journal of Public Health, v. 46, n. 10, p. 1404 (2017).
10. Lucca, S. R., Mendes, R.: Epidemiologia dos acidentes do trabalho fatais em área metropolitana da região sudeste do Brasil, 1979-1989. Revista de Saúde Pública, v. 27, pp. 168–176 (1993).
11. Vidotti, H. G. M., Coelho, V. H. M., Bertoncello, D., Walsh, I. A. P.: Qualidade de vida e capacidade para o trabalho de bombeiros. Fisioterapia e Pesquisa, v. 22, n. 3, pp. 231–238 (2015). DOI: 10.590/1809-2950/13125822032015.
12. Kujala, V., Remes, J., Ek, E., Tammelin, T., Laitinen, J.: Classification of Work Ability Index among young employees. Occupational Medicine, v. 55, n. 5, pp. 399–401 (2005).
13. Ferreira, M. C., Alves, L., Tostes, N.: Gestão de qualidade de vida no trabalho (QVT) no serviço público federal: o descompasso entre problemas e práticas gerenciais. Psicologia: Teoria e pesquisa, v. 25, n. 3, pp. 319–327 (2009).
14. Sörensen, L. E., Pekkonen, M. M., Mannikko, K. H., Louhevaara, V. A., Smolander, J, Alén, M. J.: Associations between work ability, health-related quality of life, physical activity and fitness among middle-aged men. Applied ergonomics, v. 39, n. 6, pp. 786-791 (2008). DOI: 10.1016/j.apergo.2007.11.001.
15. Cerqueira, P. H. A., Freitas, L. C.: Avaliação da capacidade de trabalho e do perfil de trabalhadores em serrarias no município de Eunápolis, BA. Floresta, v. 43, n. 1, pp. 19–26 (2013).
16. Ferreira, E. S. S., Duran, E. C. M., Daniel, J. G. M., Toledo, V. P.: Capacidade para o trabalho entre trabalhadores rurais de uma usina de açúcar e álcool. Revista de enfermagem UFPE on line-ISSN: 1981–8963, v. 8, n. 2, pp. 294–302 (2014). DOI. 10.5205/reuol.4688-38583-1-RV.0802201409.
17. Hengen, M. F., Weis, A A., Penz, M., Moreira, L. S., Bressler, L. R., Stulp, K.: Determinação, avaliação e medidas de proteção de acidentes no trabalho em altura seguindo as recomendações da NR35. Revista Infinity, v. 2, n. 1 (2017).
18. Monteiro, C. M., Benatti, M. C. C., Rodrigues, R. C. M.: Acidente do trabalho e qualidade de vida relacionada à saúde: um estudo em três hospitais. Revista Latino-Americana de Enfermagem, v. 17, n. 1 (2009).
19. STICMA– Sindicato dos Trabalhadores nas Indústria da Construção e do Mobiliário de Araraquara. Relatório de recolhimento de valores sindicais. Araraquara (2020).
20. Montgomery, D. C., Runger, G. C.: Applied statistics and probability for engineers, 5nd edn, Wiley & Sons, New York (2010).
21. Monteiro, M. S., Ilmarinen, J., Corrêa Filho, H. R.: Work ability of workers in different age groups in a public health institution in Brazil. International Journal of Occupational Safety and Ergonomics, v. 12, n. 4, pp. 417–427 (2006). https://doi.org/10.1080/10803548.2006.11076703
22. Bellusci, S. M., Fischer, F. M.: Envelhecimento funcional e condições de trabalho em servidores forenses. Rev. Saúde Pública, v. 33, n. 6, pp. 602–9 (1999).
23. Silva Junior, S. H. A., Vasconcelos, A. G. G., Griep, R. H., Rotenberg, L.: Confiabilidade teste-reteste do Índice de Capacidade para o Trabalho (ICT) em trabalhadores de enfermagem. Revista Brasileira de Epidemiologia, v. 16, n. 1, pp. 202–209 (2013).
24. Paula, I. R., Marcacine, P. R., Castro, S. S., Walsh, I. A. P.: Capacidade para o trabalho, sintomas osteomusculares e qualidade de vida entre agentes comunitários de saúde em Uberaba, Minas Gerais. Saúde e Sociedade, v. 24, pp. 152–164 (2015). https://doi.org/10.1590/S0104-12902015000100012.

Purchase System for People with Reduced Mobility: Promoting Equity Idealized by Society 5.0

Ana Paula Braga Garcez, Ricardo Moreira da Silva, Luís Carlos Inácio de Matos, Tânia Daniela Felgueiras Miranda Lima, César Emanoel Barbosa de Lima, and Fernando Charrua Santos

Abstract The economic development of a nation is supported, in part, by entrepreneurship, as it allows job creation, adds value to new products and/or services, and is seen as a catalyst for social development. Currently, the world is moving towards "Society 5.0", which seeks a sustainable, egalitarian society centered on the human being, where Digital Transformation will impact on the improvement of people's quality of life. The aim of this paper was to analyze the process of transition from intention to entrepreneurial action of a product based on technology, entitled "purchase system for people with reduced mobility", developed within a start-up, that had as vision the "individual with reduced mobility". For it, was used the (N)ethnography (or study of individual life stories through the digital middle lens) to understand the process that analyzed using the following filters: (1) Presence of role models and mentors (2) Work Experience (3) Individual difference (4) Education and training (5) Firm Characteristics (6) Culture and Institutional environment and (7) Digital Transformation. It was possible to conclude that the purchase system

A. P. B. Garcez (✉) · T. D. F. M. Lima · F. C. Santos
Universidade da Beira Interior (C-MAST - Centre for Mechanical and Aerospace Science and Technologies), Calçada Fonte do Lameiro, 6200-358 Covilhã, Portugal
e-mail: ana.garcez@ubi.pt

T. D. F. M. Lima
e-mail: tmlima@ubi.pt

F. C. Santos
e-mail: bigares@ubi.pt

R. M. da Silva · C. E. B. de Lima
Federal University of Paraíba- Cidade Universitária, João Pessoa 58051-900, Brazil
e-mail: ricardomoreira0203@hotmail.com

C. E. B. de Lima
e-mail: cesarlimma@uol.com.br

L. C. I. de Matos
Follow Inspiration, S.A.-MACB, Zona Industrial do Fundão, Lote 154-6230-348, Fundão, Portugal
e-mail: luisdematos@followinspiration.pt

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_37

for people with reduced mobility enables inclusion, not only in its use, but since its conception; that the whole process was only possible due to the presence of a series of facilitating conditions and that such conditions were planned for society 5.0, but, are not yet available to everyone, at all times and in all places, thus that this society 5.0 is still utopian, just one concept to be implemented.

Keywords Society5.0 · Start-up · Entrepreneurship

1 Introduction

Entrepreneurship is dependent on the availability and willingness of individuals with the capacity to undertake [1], however what is discussed is if this "availability" depends solely on the individual and/or external factors. But it is a fact that entrepreneurship increases the autonomous work and the creation of new companies, in a changing world, which is moving towards a jobless, highly technological and digital society where idleness will increase greatly, together with the decrease of the "private good" and increase to the "public thing" available to everyone. On the other hand, it is true that this transformation has been taking place for a long time.

In fact, a series of past revolutions including the agricultural and industrial revolutions have brought about not only technological advances and greater convenience, but also structural changes to society. It is difficult to accurately foresee what kind of society the ongoing "Society 5.0" revolution will create. Rather than attempting to predict the future, it is important for us to be key players in the revolution, to indicate direction, and to work with a diverse range of people to create the future. Opinions on how to categorize societies vary, but the 5th Science and Technology Basic Plan identified the societies in which humankind lived in the pastas the Hunting Society (Society 1.0), Agrarian Society (Society 2.0), Industrial Society (Society 3.0) and Information Society (Society 4.0), and termed a new society to follow them "Society 5.0." [2] (Fig. 1).

The Society 5.0 is still a promise and will hardly be implemented until 2030, with rare exceptions from small sites in Japan, perhaps China or Nordic countries where there is already a culture of equality and equity in development, however, in general, its principles have already begun to be drawn. The premises that govern this new society are based to change dramatically as people accept of new environmental burden, seek decrease economic and social disparity, and beyond that, a rapid adaptation to digital transformation.

In this context of Society 5.0, the human is the central actor in decision-making and policy processes and it was with this vision that in 2016, the Japanese government began to promote the concept of Society 5.0, promoting human-centered sustainability, improving people's quality of life through technology [3].

Thus, in this new planned context, there will be no jobs for everyone, so the provision of services and small, highly technological digital ventures will grow even more. Further, there will be an evolution of the current start-up. We will need a strong

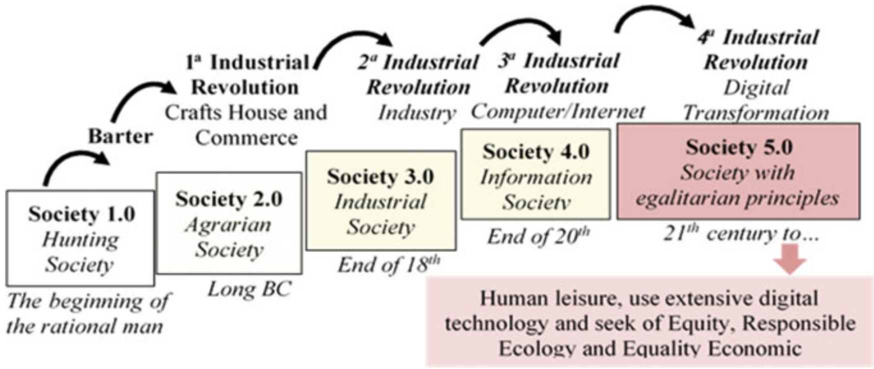


Fig. 1 Evolution of society X industrial revolutions

support base for public services, "For all"; the factories will be highly robotized industries (with very little human employment) and there will be the even greater increase in the service sector, being anchored by the new start-ups.

In fact, in this society 5.0, start-ups are seen as the engine to create economic value, due to the flexible business structure, compared to large companies that have great difficulty in changing their physical and human structures [4]. A case to be noted, for example, it is the case of Airbnb, which does not have its own material structure for accommodation, however, the management decentralization has placed it in the order of large hotel groups.

Thus, in this global environment of rapid technological advances, business models and entrepreneurial behavior will be affected, where our needs will be: (1) balance of personal and professional life (2) social responsibility [5] where the technologies will change society and the business models [6–8], for all this, this transition process will be based on entrepreneurial individuals.

In this sense, the state of the art about entrepreneurship shows that the entrepreneurial capacity is supported by several factors, associated to personality traits, which differentiate entrepreneurs from other individuals, such as: need for achievement, self-efficacy, innovation, stress tolerance, need autonomy, proactive personality, among others [9–11], aspects will be present in society 5.0.

Thus, this investigation aimed to analyze the entrepreneurial process from intention to implementation of the "purchase system for people with reduced mobility", made possible by the use of digital technology, a pillar of Society 5.0 utopic. To this end, the methodology used was (N)ethnology and the unit of analysis was the product "purchase system for people with reduced mobility" through the lens of their entrepreneur (who has reduced mobility) and used technology as a tool for social transformation, based on their own individual needs.

2 Methodology

There is an acknowledgment in the field of entrepreneurship research of the need to study business activities in their broader context, looking for in the sociology and pragmatic thinking of the entrepreneur, based on ethnology [12]. Ethnology, or the study of individual life histories, seeks to understand the transition process of people life in the context where the individual is inserted [13].

From Bishop, Star, Neumann, Ignacio, Sandusky and Schatz's studies, in 1995, (N)ethnology (net + ethnography) appears, to describe a methodological challenge: preserving observations, using data obtained from the net [14, 15]. Thus, (N)ethnology is a research method, based on participant observation and online fieldwork, which uses different forms of computer-mediated communication as a source of data for the understanding and ethnographic representation of cultural phenomena and communal, so it is an "inductive approach" to qualitative data analysis [16].

Therefore, it expands the possibilities offered by traditional ethnography by allowing the study of objects, phenomena and cultures that emerge from cyberspace, based on the development and social appropriation of information and communication technologies [17]. It is appropriate in this paper, as it is an adaptation of ethnographic research that takes into account the characteristics of digital environments and computer-mediated communication.

According to Kozinets and Netnografia [16], for the collection and analysis of data, the information must be collected and copied directly from the pages and online communities of interest and in the public domain (added by us), in which, due to the large number of information, it is prudent the researcher to use several types of filters so that only information relevant to the outline of the research is left.

Figure 2 shows the filters adopted according Newman [18], affect the entrepreneurial process: (1) Presence of role models and mentors (2) Work Experience (3) Individual difference (4) Education and training (5) Firm Characteristics (6) Culture and Institutional environment. To the filters proposed by [18] to (7) Digital Transformation was included because it became a relevant factor in the entrepreneurial route, especially in the late 20th century where different entrepreneurs emerged, for example, Steve Jobs (Apple), Mark Zuckerberg (Facebook) and others, where their business models had a great evolution worldwide.

Considering these seven filters, this article will have the Follow Inspiration enterprise as a unit of analysis, a technological startup in the area of robotics and artificial

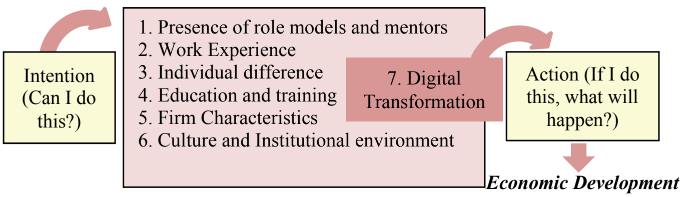


Fig. 2 The entrepreneurial process—transforming intention into economic development [18]

intelligence, in the city of Fundão in Portugal, founded by Luís de Matos (from here, called "CEO"). That developed and patented several products and services for people with special needs, like him. As a visualization object of (N)ethnography, the "purchase system for people with reduced mobility" available on the company's websites was observed.

3 Entrepreneurship and Society 5.0

In 2016, the Japanese government started promoting the concept of Society 5.0, which aims to create a sustainable society centered on the human being, improving the quality of life of people through cyber systems [3] as it is expected that the human being is the central actor in the decision-making and political processes in society [19].

In addition, Scheer [4] showed that new technologies alone do not generate any value, only if their implementation is successful, through products and processes. This technology advanced greatly suppresses manual human labor, so, the global environment of the next 20 years, will possibly have huge technological advances, creating a world without jobs. Thus, will make the individual with an entrepreneurial profile, fundamental to the development of the society of the future.

It is estimated that the new society will consist of a generation of individuals different from the current one, where digital learning will be a point of exclusion or inclusion in the new industries or in the training for new start-ups, guided by more ambitious, impatient and seeking instant gratification people. The foundation of your needs will be: (1) balance of personal and professional life and (2) social responsibility [5].

Figure 3, adapted from the report published by Keidanren [2], in a systematic way, presents the changes that can affect society:

Liberation from focus on efficiency: The Societies 4.0 pursued scale and efficiency via mass production and consumption in order to guarantee material wealth to growing populations. In Society 5.0, efficiency will no longer be the key factor in production. The industries will work with individual satisfaction needs, solving problems and creating value.

Diversity: In Society 4.0, people were required to accept uniform goods and services and live lives in conformity with standardized processes. In Society 5.0 will require people to identify divers e needs and challenges in society and turn them into real business. People will be able to live, learn and work free from suppression of individuality such as discrimination by gender, race, nationality, etc. We will make sure that wealth and information will not be concentrated so that people will be liberated from disparity, and anyone will be able to get opportunities to play a part anytime, anywhere. Data and benefits derived from them will be shared by diversified players, not concentrated, shared on specific companies. Opportunities to study and work will also be guaranteed to children born in poverty or remote areas.

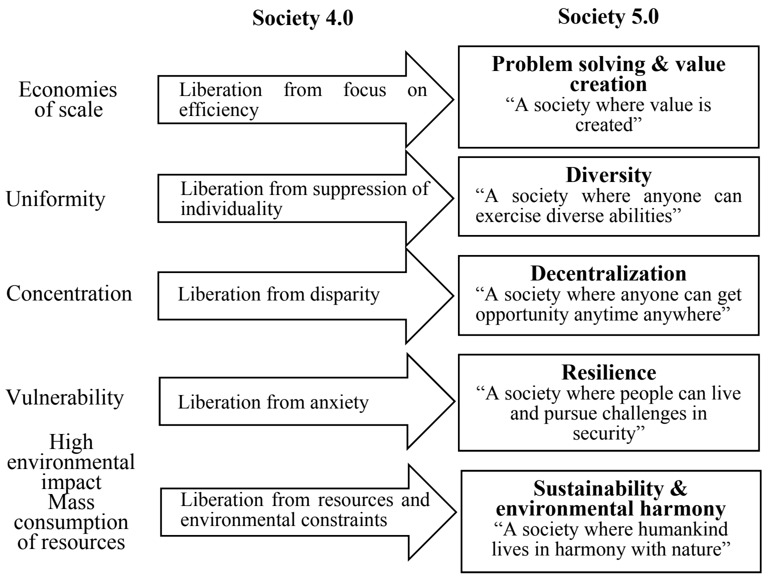


Fig. 3 Changes from society 4.0–5.0 [2]

Decentralization: The next society 5.0 will be that in which anyone can get opportunities anytime, anywhere, where it is expected that wealth and information will be distributed and decentralized throughout society and socioeconomic players will share roles horizontally.

Resilience: In Society 4.0, vulnerabilities became apparent; serious damage caused by earthquakes and floods, deterioration of public security associated with increasing disparity, growing social anxiety about terrorism and other crises social. Expected in Society 5.0, a diversified new infrastructure decentralized social that will be enhance resilience and enable sustainable development with people away from unsafety, unemployment and poverty.

Sustainability and environmental harmony: In Society 4.0 humans depended on model, with high environmental impact and mass consumption of resources. In Society 5.0 people can live in harmony with nature, because data utilization increases energy efficiency and flexibility. There is the option of not depending upon traditional energy networks and water supply. Food that is better for the environment and health will command a large premium, and wastage will drop sharply.

In fact, in the perception of the Keidanren [2] report, cutting edge technology available in society 5.0, deals with the possibility of creating value anytime, anywhere, safely and in harmony with nature. In this sense, so that the implementation of Society 5.0 does not become a purely political ideological concept, it is necessary to integrate several dimensions such as: innovation policy, entrepreneurial spirit and entrepreneurial skills in individuals.

4 From Intention to Economic Development Through "Purchase System for People with Reduced Mobility" Developed by Follow Inspiration

Intention to development of "purchase system for people with reduced mobility" started from the needs of his CEO, who has "reduced mobility" and needed to complete a college degree. (The UN Convention and its optional protocol, incorporated into the law of several countries, is composed of fifty articles that address the civil, political, economic, social and cultural rights of persons with disabilities, and define them, in Article 1 as: "The term persons with disabilities is used to apply to all persons with disabilities including those who have long-term physical, mental, intellectual or sensory impairments which, in interaction with various attitudinal and environmental barriers, hinders their full and effective participation in society on an equal basis with others"); therefore, the entrepreneurial intention was not an economic need, but a physical, motor and plus, an academic-professional need.

Reference [20]'s theory of entrepreneurship establishes that entrepreneurship must lead to action based on an entrepreneurial intention. In order to study this context, it is necessary to realize that for a new business to arise, planning is necessary: The act of undertaking is a type of planned behavior, where the models of intentionality must be adequate. In this sense, the entrepreneur's self-perception of his abilities defines his way of acting, where Bandura [21] states that this perception determines whether a behavior will be initiated and how much effort will be spent.

The CEO, in 2012, it founded Follow Inspiration, a technology startup based in Fundão, where in recent years it has been developing the wiiGO project, the first fully autonomous shopping cart to help people with reduced mobility transport their purchases, as well as others. technological solutions specially adapted to the specificities of its users and industry (Fig. 4).

Fig. 4 The robot of "purchase system for people with reduced mobility" [22]

It is pioneering the way it develops autonomous solutions using computer vision and sensory fusion, thus revolutionizing the way robots move between people and within factories. Thus created a revolutionary technology and culminated in the registration of several patents already granted in the United States of America and Europe and with application in France, Spain, Germany and Portugal, capable of turning any robot into an intelligent and autonomous robot [22].

So, in addition to the entrepreneurial intention, to effectively achieve the creation of the "purchase system for people with reduced mobility", other factors complemented the action process:

(i) **Presence of role models and mentors**: is one of the factors that positively influences entrepreneurship, and these are represented by: investors, consultants and teachers, more experienced colleagues and more experienced entrepreneurs [23, 24]. CEO demonstrated that his mentors were his familiar when he reported that "Fortunately I have a family and friends who supported me and gave me the mental, psychological and also social structure".
(ii) **Work experience**: CEO had not this skill, however, he reports that the "strength of the family" has somehow overcome the lack of experience. This reported fact is consistent with the studies by [25] because in relation to start-ups, the lack of experience of aspiring entrepreneurs is mitigated by the presence of mentors.
(iii) **Individual difference**: Energy, passion, optimism, self-efficacy, self-confidence, need for fulfillment, power, autonomy, need for control and over-confidence, narcissism, arrogance, aggressiveness, indifference to others and obsessive behavior are specific to each individual [26–28] positively influence the entrepreneurial process. CEO reported having some of these motivations (Table 1).
(iv) **Education and training**: Aspiring entrepreneurs who receive entrepreneurial education, have a more positive attitude towards what they do not receive [29]. The CEO has an undergraduate and master's degree (in progress) in Computer Science and Engineering, and an improvement in Comunilog Consulting that added several managerial skills, including entrepreneurship.
(v) **Firm characteristics**: Scheer [4] stated that the potential of start-up can really add value to cutting edge technology because of the flexibility of their business models. In this direction, CEO confirms that "A shopping autonomous car was developed to help people with reduced mobility to transport their purchases within a commercial area, with this we have created a technology capable of unequivocal recognition, where the person only needs to place himself in in front of the equipment, press a button and in less than 3 s the robot will be able to recognize it and pass it to follow it".
(vi) **Culture and institutional environment**: CEO idealized his assistant robot even when he was graduating. He says that "at the end of my academic career I had to develop my final thesis and I didn't see myself in the projects that teachers had for me", but it was in this environment the idea and the action come true. This fact is in line with the thinking of [30] when he states that "in his

Table 1 Motivations of CEO

Motivations	The reported
Energy, passion and e need for fulfillment	"I have two goals: to eliminate the prejudice of society towards people with reduced mobility and to eliminate the prejudice that exists with robotics use"
Need for control	"As my journey has transformed me, I am trying to transform society"
Overconfidence	"Throughout my journey I try to do everything, as normal as possible, without the people sitting next to me feeling like I'm in a wheelchair"
Self-efficacy	"Whoever works with me had to develop the technology feeling the difficulty of the problem effectively. When we were designing the shopping cart, there was a philosophy: each employee of my team, had to spend at least a whole day sitting in a wheelchair and had to move around with it, to understand the purpose of the product"

start-up, the entrepreneur who creates his company in a university environment benefits from its intellectual capital, such as: human capital, relational capital and structural capital". In fact, the CEO says "We are now a team of 15 people, with several awards won and new investments, who help in this mission.

(vii) **Digital transformation**: In Scheer's [4] perspective, technology alone is just an invention, but it only becomes useful when it generates products and services. CEO had this conviction because he states that: "The assumption of technology is to be simple (…) Robotics can not only provide us with good feelings, but they have to help us effectively (…) for a normal person, technology makes easy things, for people with reduced mobility, technology makes things possible". With this concept, "technology" itself is not a big deal, but its use for purposes, means Digital Transformation, and it is the one that adds value to the human being.

5 Conclusions

The "entrepreneurial intention" of Follow Inspiration were two needs of its own founder and CEO: (a) to complete an undergraduate course and (b) physical mobility. He devised a "purchasing system for people with reduced mobility" to be used in supermarkets. From there, opened a start-up, partnered and built the robot that became a commercial product, put into operation, holder of several awards, because in addition to all positive economic aspects, it deals with inclusion.

In addition to the entrepreneurial intention, seven factors are necessary for the invention or idea to become a product and add value: (i) Presence of role models and mentors (ii) Work Experience (iii) Individual difference (iv) Education and training

(v) Firm Characteristics (vi) Culture and Institutional environment and (vii) Digital Transformation, Of these, the CEO only lacked the "Work Experience", but it was supplied by the "family strength" and by his motivational self-forces: energy, passion, need for achievement, need for control, self-confidence and self-efficacy.

In fact, what happened was a sum of skills, enabling conditions and timing that made the "purchase system for people with reduced mobility", summed up in an intelligent robot, add other values besides the economic in the life of the CEO and his team, but add social values too. Actions like this are typical and point to characteristics of the future society 5.0, where it will be necessary:

(a) Liberation from focus on efficiency, where in the purchase system for people with reduced mobility, the principal focus was the human race, their individual needs and the solving problems;
(b) Diversity, when CEO was able to create the opportunity to learn, work and produce without the discrimination by his reduced mobility;
(c) Decentralization, when CEO had the opportunity, he distributed his product in an open and decentralized way, showing a new inclusion opportunity;
(d) Resilience, when CEO fights inequality, not only with his product, but through his statements and;
(e) Sustainability and environmental Harmony, when the purchase system for people with reduced mobility increases a new opportunity for efficiency and flexibility, use for clean energy and seek health for the people.

Society 5.0 is still a utopia, however its main value is the full equality of social and economic values, in a society that takes care of the planet. The "purchase system for people with reduced mobility" is bigger than a robot, it is a chance and an opening for everyone to understand the word "equality".

Acknowledgments This work has been supported by Fundação para a Ciência e Tecnologia (FCT) and C-MAST- Centre for Mechanical and Aerospace Science and Technologies, under project UIDB/00151/2020 and the projects Centro-01-0145-FEDER-000017 - EMaDeS - Energy, Materials and Sustainable Development, project 026653, POCI-01-0247-FEDER-026653.

References

1. Brandstätter, H. Personality aspects of entrepreneurship: A look at five meta-analyses. Personality and Individual Differences, 51(3), 222–230 (2011).
2. Keidanren. Society 5.0. www.keidanren.or.jp/en/policy/2018/095_outline.pdf (2018).
3. Shiroishi, Y., Uchiyama, K., & Suzuki, N. Society 5.0: For Human Security and Well-Being. Computer, 51(7), 91–95 (2018).
4. Scheer, A. Unternehmung 4.0. Wiesbaden: Springer Fachmedien Wiesbaden. -2 (2020).
5. Liu, J., Zhu, Y., Serapio, M., & Cavusgil, S. T. The new generation of millennial entrepreneurs: A review and call for research. International Business Review, 28(5), 101581 (2019).

6. Dregger, J., Niehaus, J., Ittermann, P., Hirsch-Kreinsen, H., & Ten Hompel, M. The digitization of manufacturing and its societal challenges: A framework for the future of industrial labor. 2016 IEEE International Symposium on Ethics in Engineering, Science and Technology, ETHICS 2016, 4–6 (2016).
7. Lasi, H., Fettke, P., Kemper, H. G., Feld, T., & Hoffmann, M. Industry 4.0. Business and Information Systems Engineering, 6(4), 239–242. (2014).
8. Wang, L., Törngren, M., & Onori, M. Current status and advancement of cyber-physical systems in manufacturing. Journal of Manufacturing Systems, 37, 517–527 (2015).
9. Rauch, A., & Frese, M. Let's put the person back into entrepreneurship research: A meta-analysis on the relationship between business owners' personality traits, business creation, and success. European Journal of Work and Organizational Psychology, 16(4), 353–385 (2007).
10. Baron, R. A., Franklin, R. J., & Hmieleski, K. M. Why Entrepreneurs Often Experience Low, Not High, Levels of Stress: The Joint Effects of Selection and Psychological Capital. Journal of Management, 42(3), 742–768 (2016).
11. Karabulut, A. T. Personality Traits on Entrepreneurial Intention. 5th International Conference on Leadership, Technology, Innovation and Business Management, Procedia - Social and Behavioral Sciences 229, 12–21 (2016).
12. Watson, T. J. Entrepreneurship in action: Bringing together the individual, organizational and institutional dimensions of entrepreneurial action. Entrepreneurship and Regional Development, 25(5–6), 404–422 (2013).
13. Holman Jones, S. Autoethnography. The Blackwell Encyclopedia of Sociology (2007).
14. Correia, R. R., Alperstedt, G. D., & Feuerschutte, S. G. O Uso do Método Netnográfico na Pós-Graduação em Administração no Brasil. Revista de Ciências da Administração, 1(1), 163 (2017).
15. Abelha, D. M., Neto, S. P. de S., Souza, S. de M. de, & Guedes, F. J. R. A Netnografia e a Análise de Comunidades Virtuais: um Estudo de Caso Aplicado Aos Discentes da Ufrrj. Anais do IX Simpósio de Excelência em Gestão e Tecnologia (2012).
16. Kozinets, R. V. Netnografia: realizando pesquisa etnográfica online. Pense, Ed., Porto Alegre, Brasil (2014).
17. Corrêa, M. D. V., & Rozados, H. B. F. A netnografia como método de pesquisa em Ciência da Informação. Encontros Bibli: revista eletrônica de biblioteconomia e ciência da informação, 22(49) (2017).
18. Newman, A., Obschonka, M., Schwarz, S., Cohen, M., & Nielsen, I. Entrepreneurial self-efficacy: A systematic review of the literature on its theoretical foundations, measurement, antecedents, and outcomes, and an agenda for future research. Journal of Vocational Behavior, 110 (May 2018), 403–419 (2019).
19. Shiroishi, Y., Uchiyama, K., & Suzuki, N. Better Actions for Society 5.0: Using AI for Evidence-Based Policy Making That Keeps Humans in the Loop. Computer, 52(11), 73–78 (2019).
20. Gartner, W. B. Words lead to deeds: Towards an organizational emergence vocabulary. Journal of Business Venturing, 8(3), 231–239 (1993).
21. Bandura, A. Self-efficacy: Toward a unifying theory of behavioral change. Advances in Behaviour Research and Therapy, 1(4), 139–161 (1977).
22. Follow Inspiration Homepage, http://followinspiration.pt/technology/ last accessed 2020/05/20.
23. Mouraz, A., & Sousa, A. An Institutional Approach to First-Year Adjustment. Journal of Hispanic Higher Education, 15(3), 221–239 (2015).
24. Hayter, C. S., Lubynsky, R., & Maroulis, S. Who is the academic entrepreneur? The role of graduate students in the development of university spinoffs. Journal of Technology Transfer, 42(6), 1237–1254 (2017).
25. Clarysse, B., Tartari, V., & Salter, A. The impact of entrepreneurial capacity, experience and organizational support on academic entrepreneurship. Research Policy, 40(8), 1084–1093 (2011).

26. Miller, D. A downside to the entrepreneurial personality? Entrepreneurship: Theory and Practice, 39(1), 1–8, (2015).
27. Kannadhasan, M., Singh, P., Charan, P., & Balivada, P. K. Personality characteristics and the process of start-up: the moderating role of institutional environment. DECISION, 45(4), 287–300 (2018).
28. Kerr, S. P., Kerr, W. R., & Xu, T. Personality Traits of Entrepreneurs: A Review of Recent Literature. Foundations and Trends® in Entrepreneurship, 14(3) (2018).
29. Fernández-Pérez, V., Montes-Merino, A., Rodríguez-Ariza, L., & Galicia, P. E. A. Emotional competencies and cognitive antecedents in shaping student's entrepreneurial intention: the moderating role of entrepreneurship education. International Entrepreneurship and Management Journal, 15(1), 281–305 (2019).
30. Matricano, D. Higher education and start-up intentions: The role of intellectual capital in entrepreneurial processes. Industry and Higher Education (2019).

Application of the Proknow-C Methodology in the Search for Literature About Energy Management Audit Based on International Standards

Everton Luiz Vieira, Bruna Novaes dos Santos, Natalia Almansa Zampieri, Sérgio Eduardo Gouvêa da Costa, and Edson Pinheiro de Lima

Abstract Energy management can be understood as the sum of all the measures and activities that are planned or carried out to minimize the energy consumption of a company or institution. It influences the organizational and technical processes, as well as the behavior and work patterns, in order to reduce, within economic restrictions, energy consumption and increase energy efficiency. Structuring a literature review to build knowledge and select journals for theoretical foundation is essential. In view of this fact, the present study aims to characterize the theme "Energy Management Audit based on international standards", as well as its foundations, theoretical outline and the research opportunities identified in the literature. The method used was Proknow-C (Knowledge Development Process-Constructivist). As a result, 15 relevant articles were found and aligned with the research theme in an international database. It was also possible to identify the main approaches proposed by the authors of the bibliographic portfolio in relation to energy management audits based on international standards.

Keywords Audit · Power management · Proknow-C · International standards

1 Introduction

Currently, the market has been increasingly oriented to give preference to services and products of companies committed to actions to protect the environment. Within these actions, the use of energy stands out. In the energy rationalization activity, organizations which have a strategic vision can have their image valued before their stakeholders [1].

Energy takes an important role in the managed costs of a company, with increasingly competitive prices in the market, stimulated by the reduction of competitors'

E. L. Vieira (✉) · B. N. dos Santos · N. A. Zampieri · S. E. G. da Costa · E. P. de Lima
Pontifical Catholic University of Parana, 1155, Curitiba, Parana 80215-901, Imaculada Conceição, Brazil
e-mail: vieiraeverton@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_38

costs, energy availability or environmental restrictions. Whatever the incentive to implement energy efficiency is to use the learning and knowledge of engineering, economics and management concepts.

Hence, based on these joint discussions and practical importance (both fields), how is the current scientific scenario about energy management auditing based on international standards?

This study is justified by its contribution to the scientific community, through the survey and analysis of the results of the use of energy management auditing based on international standards, aiming to assist in the obtainment of knowledge and identify research opportunities on the topic. Thus, the specific objectives were defined: (i) select a significant bibliographic portfolio about energy management auditing based on international standards; (ii) carry out the bibliometric analysis of the portfolio.

2 Literature Review

This chapter shows the literature review, beginning with the definitions of energy management and auditing in energy management.

2.1 Energy Management

According to Fiedler and Mircea [2] energy management can be understood as the sum of all measures and activities that are planned or carried out to minimize the energy consumption of a company or institution. It influences organizational and technical processes, as well as behavior and work patterns, in order to reduce energy consumption and increase energy efficiency, within economic constraints.

Fernando et al. [3] cite that energy management standards, such as the Energy Star, the ISO 14001 Environment Management System (EMS) standard and the ISO 50001: 2011 Energy Management System have been introduced globally. However, there is still a deficit in the practice of Energy Management in organizations due to difficulties in benchmarking, the complexity of business activities and the resources necessary for companies to properly implement energy management [4]. Energy management practices differ from sector to sector and they depend on energy consumption and intensity, organizational size, quality management and geographic coverage [5].

2.2 Energy Management Audit

According to Abdelaziz et al. [6] energy audit is an inspection, survey and analysis of energy flows and energy conservation to reduce the amount of energy input into the system without adversely affecting the output. Energy auditing is the key to energy management decision making.

The audit helps organizations to analyze their energy use and discover areas where energy use can be reduced and where waste occurs, carry out planning and practice viable energy conservation methods that will improve their energy efficiency, will serve to identify all energy flows in a facility, quantify energy use, in an attempt to balance the total energy consumption with its use [7].

Through the audit many benefits can be achieved. Some of these benefits are [7]: Reduction in specific energy consumption and pollution environment; Reduction in operating costs (roughly 20–30%) in systematic analysis; It improves the overall performance of the total system and the profitability and productivity; Slower depletion of natural resources and reduced demand supply gap; It prevents equipment failures.

3 Methodology

For the selection of the theoretical framework and construction of the necessary research knowledge, it was used the Proknow-C methodology (Knowledg Development Process—Constructivist), proposed by Ensslin et al. [8], which consists of a series of procedures, until the arrival of the filtering and selection of articles that are relevant to the research topic [9]. The method is divided into two main phases, the first deals with the selection from the raw articles bank and the second with the articles filtering process. The first phase can be seen in Fig. 1.

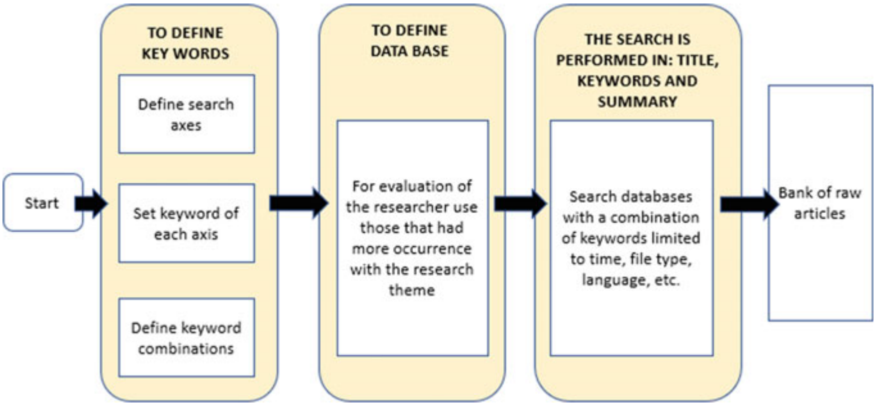


Fig. 1 The Proknow-C method. Adapted from Ensslin et al. [8]

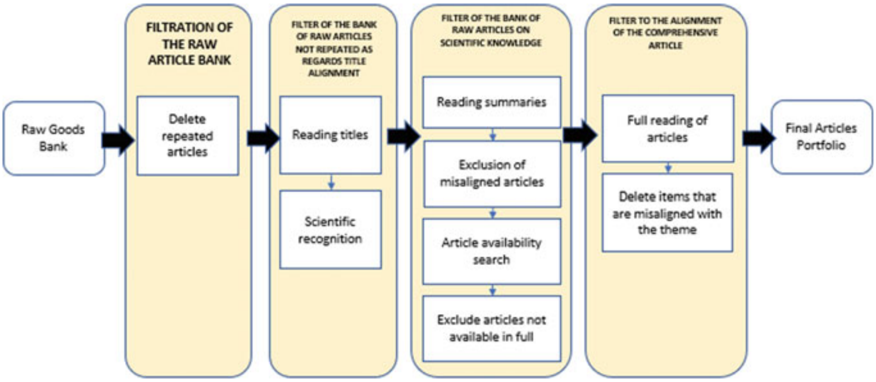


Fig. 2 Filtering the raw articles bank. Adapted from Ensslin et al. [8]

Three research axes were defined, called "energy management", "audit" and "standards". For the energy management axis, six keywords were chosen: Energy management, energy efficiency, electricity, energy, electricity management, power management system. For the audit axis: audit, evaluation, assessment. And for the standards axis: ISO 5001, Carbon Trust, Energy Star, Sustainable energy authority of Ireland. After defining the keywords, combinations were made between them, resulting in 69 combinations.

The search was performed in two databases with the keyword combinations (Scopus and Web of Science), using the search fields: title, abstract and keywords. The searches were restricted to the periods from 2000 to 2020 and to documents such as articles from journals and congresses. To conclude the selection step from the raw articles bank, an adherence test was carried out to check whether there is a need to include new keywords, so that the portfolio is as aligned as possible.

Then, the filtering process of the raw articles bank begins, as shown in Fig. 2.

The filtering of the raw articles database begins with the exclusion of repeated articles. The second step is to read the titles of the articles. From this, the scientific recognition of articles is carried out. It starts by searching for the number of citations in Google Scholar that each article has. After that, the reading of the abstracts of the articles begins, to make the selection of the articles that are aligned with the research theme, for then keep it in the database or discard it.

4 Results

The process obtained a gross total of 522 articles, of which 365 were found in the Scopus database and 157 in the Web of Science database. From these, 308 duplicates were excluded. Then, the remaining 214 titles were read to verify the alignment of

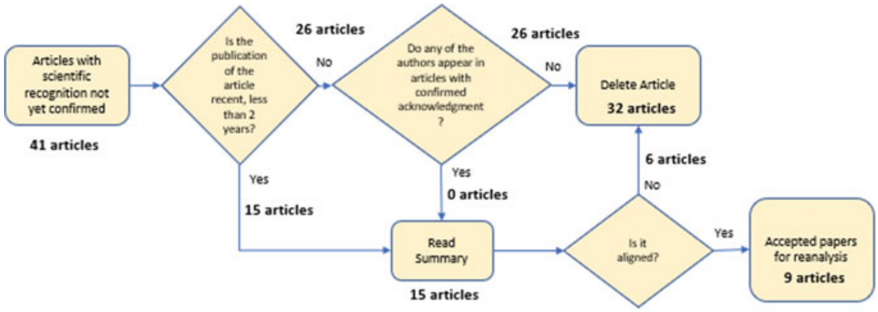


Fig. 3 Filter to select articles with lesser scientific recognition. Adapted from Ensslin et al. [8]

the articles to the research theme, resulting in 83 articles. The next step identified the scientific recognition of the articles, resulting in 42 most mentioned articles, corresponding to 99% of the citations, after that the abstracts were read, resulting in 30 articles. The articles with unconfirmed scientific recognition totaled 41, which went through a new filter for selection, as shown in Fig. 3.

After filtering the articles with lesser scientific recognition, 9 more articles were added to the 30 that the reading of the abstracts was done, totaling 39 articles to check the availability of the entire document. After this verification, 36 articles remained for a complete reading of the document, to confirm the alignment with the research topic (Table 1).

After reading entirely the articles, 15 articles remained, representing the bibliographic portfolio about indicators for auditing energy management based on standards, as shown in Table 2.

Bibliometric analysis consists of an important phase in the qualification process of the bibliographic portfolio. The journals' evaluation highlights the Journal of cleaner Production and Proceedings of the ECEEE Industrial Summer Study, which concentrate 2 articles in each of the bibliographic portfolio, as shown in Fig. 4.

Regarding the scientific recognition of the articles in the portfolio, Fig. 5 shows the 7 articles with the highest scientific recognition among the articles in the bibliographic portfolio.

All authors had only one article mentioned in the bibliographic portfolio, thus, there were no prominent authors. Then, the number of times that each keyword appears in the bibliographic portfolio was identified: energy management, efficiency, ISO, performance, systems, are the most used words in the articles, a word cloud was created to illustrate those whom most appeared in the bibliographic portfolio, as shown in Fig. 6.

The approaches used in the research are highlighted in Table 2.

Table 1 Bibliographic portfolio

Articles
Reference [10] Javied, T.; Huprich, S.; Franke, J. Cloud based Energy Management System Compatible with the Industry 4.0 Requirements. IFAC-PapersOnLine, v. 52, n. 10, pp. 171–175, 2019
Reference [11] Laskurain, I., Ibarloza, A., Larrea, A., & Allur, E. (2017). Contribution to energy management of the main standards for environmental management systems: The case of ISO 14001 and EMAS. Energies, 10(11), 1758
Reference [12] Rizzon, B., Clivillé, V., Galichet, S., Ochalek, P., & Ratajczak, E. (2015, October). Decision problem of instrumentation in a company involved in ISO 50001. In 2015 International Conference on Industrial Engineering and Systems Management (IESM) (pp. 409–416). IEEE
Reference [13] Glavaš, H., Zovko-Ribić, F., Dorić, D., Talapko, D., "Development of Energy Management Standards," 2018 International Conference on Smart Systems and Technologies (SST), Osijek, 2018, pp. 185–189
Reference [14] Kimura, O.; Noda, F. Does regulation of energy management systems work? A case study of the Energy Conservation Law in Japan. Proceedings of the ECEEE Industrial Summer Study, pp. 647–657, 2014
Reference [15] Gutiérrez, A. S., Eras, J. J. C., Santos, V. S., Herrera, H. H., Hens, L., & Vandecasteele, C. (2018). Electricity management in the production of lead-acid batteries: The industrial case of a production plant in Colombia. Journal of cleaner production, 198, 1443–1458
Reference [16] Tallini, A.; Cedola, L.. Evaluation methodology for energy efficiency measures in industry and service sector. Energy Procedia, v. 101, pp. 542–549, 2016
Reference [17] Nabitz, L., Hirzel, S., Rohde, C., Wohlfarth, K., Behling, I., & Turner, R. (2016). How can energy audits and energy management be promoted amongst SMEs? A review of policy instruments in the EU-28 and beyond. Proceedings of the ECEEE Industrial Summer Study, 401–415
Reference [18] Imel, M. R.; Gastesi, R.; Stone, R. Monroe County, Florida A case study in sustainable energy management. Energy Engineering, v. 112, n. 1, pp. 47–66, 2015
Reference[19] Wu, C., Therkelsen, P., Wrobel, J., Langlois, P., Scheihing, P. Moving the masses to ISO 50001 whit 50001 ready. ECEEE industrial summer study proceedings, 323–332
Reference [20] Pelser WA, Vosloo JC, Mathews MJ, Results and prospects of applying an ISO 50001 based reporting system on a cement plant, Journal of Cleaner Production (2018)
Reference [21] Scheihing, P. Save energy through the superior energy performance program. Chemical Engineering Progress, v. 110, n. 9, pp. 48–51, 2014
Reference [22] Lee J., Yuvamitra, K., Guiberteau, K., Kozman, A. T. (2014) Six-Sigma Approach to Energy Management Planning, Strategic Planning for Energy and the Environment, 33:3, 23–40
Reference[23] Kanneganti, H., Gopalakrishnan, B., Crowe, E., Al-Shebeeb, O., Yelamanchi, T., Nimbarte, A.,… & Abolhassani, A. (2017). Specification of energy assessment methodologies to satisfy ISO 50001 energy management standard. Sustainable Energy Technologies and Assessments, 23, 121–135
Reference [24] Apriyanti, D.; Prasetyo, T.; Warsito, B. The Sustainability of Energy Management System Implementation in Pilot Company's Industry of Indonesia. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2019. p. 012069

Table 2 Approaches used in the search for articles in the Bibliographic portfolio

Reference [10] Cloud based energy management system compatible with the industry 4.0 requirements	This document describes a cloud-based, platform-independent Web application that implements power management in a standardized and easy-to-use manner. As part of a general solution, the multiuser system supports planning, implementation, registration and archiving based on functions of the required work steps that emerge from the implementation of the standard. Modern communication technologies and transmission protocols allow flexible connection of different manufacturers
Reference [11] Contribution to energy management of the main standards for environmental management systems: The case of ISO 14001 and EMAS	This work aims to clarify the contribution of ISO 14001: 2015 and EMAS III to energy management. In addition, the work summarizes the results of an empirical exploratory study carried out in eight Spanish organizations, four with an EMS implemented and certified based on ISO 14001: 2015 and another four with an EMS registered in EMAS III. The findings show that the organizations certified by ISO14001 and EMAS carry out energy management practices, even if they do not have formal EnMSs implemented. Implications for managers and policy makers are discussed, along with paths for future researches
Reference [12] Decision problem of instrumentation in a company involved in ISO 50001	This article deals with the interest of the company Adixen Vacuum Products in a standard to assist in the decision to implement the ISO 5000 standard. The idea is to build the preference model of the decision maker and establish a generic procedure on the decision supported by an MCDA tool. Our proposition is to use the ACUTA method to obtain this preference model
Reference [13] Development of energy management standards	The article provides a chronological overview of the development of energy management standards and explains the implementation of the standard. The first and the most important step is to ensure Management's commitment and then carry out the energy audit in accordance with EN 16247. In addition, to identify the use of essential energy and establish the energy baseline. The system's behavior is defined based on changes in the individual energy performance indicators (EnPI). The definition of the EnPI must be monitored to assess the state of efficiency of the system. Energy management standards in the form of ISO50001 are still evolving. New standards are being developed to further define the requirements of the energy management standard; ISO 50002: 2014, ISO 50003: 2014, ISO 50004: 2014, ISO 50006: 2014, 50015: 2014, ISO 50007: 2017 and ISO 50008 under development

(continued)

Articles [10, 11, 14–18, 20, 22–24] address the audit process in energy management, suggesting tools for the implementation and control of ISO 50001, article [12] proposes a reference model for decision makers for energy management. Article [19] proposes the use of software to implement the ISO 50001 standard, it is a self-guided program, where the manager can follow the suggested steps to certify his

Table 2 (continued)

Reference [14] Does regulation of energy management systems work? A case study of the energy conservation law in Japan	This article examines the Japanese experience of regulating energy management in industrial and commercial facilities with the aim of providing in-sights for current debates about energy management systems (EnMSs). The Energy Conservation Act (ECL) in Japan is a mandatory energy management regulation that applies to approximately 12,000 companies that consume more than 1,500 kL of crude oil equivalent per year. Compared to ISO 50001, an international ENMS standard, ECL is unique in several ways, such as the inclusion of performance standards, that is, a 1% improvement in energy intensity per year. Based on the literature review and interviewing surveys of regulated companies in Japan, the article argues that while the regulation played an important role in establishing basic EnMSs, in many cases it was not effective in promoting tangible efficiency activities energy beyond mere compliance with the regulation. The article concludes that programs that aim to improve MSs need to be complemented with a more informative approach, such as energy audits and personalized consultancy, which supports companies that do not have the capacity to use their EMs
Reference [15] Electricity management in the production of lead-acid batteries: the industrial case of a production plant in Colombia	The methodology combines the guidelines of the ISO 50001 standard with the energy management structure for factories. The result is a structured approach to detect inefficiencies and identify their sources. The management methodology was implemented during 2016. In the training area, 222 MWh were saved during 2016. This savings represents 3.9% less electricity than predicted by the area's energy baseline. In addition, the emission of roughly 40 tCO_2.eq. associated with the generation of electricity production have been saved. In addition, at the plant level, 424 MWh were saved, which represents 3.6% less electricity than predicted by the plant's energy baseline. In total, around 76 tCO_2.eq. were saved as a result of electricity savings at the plant
Reference [16] Evaluation methodology for energy efficiency measures in industry and service sector	An energy audit was carried out to identify the Profile of the Energy Company, to rationalize energy consumption to increase energy efficiency, to assess the potential for energy savings and to reduce the environmental impact. For any business context, a series of energy efficiency measures have been proposed, selecting high-profit energy saving options by applying a priority criterion. Technical and economic indicators about best practices were reported, focusing on the tertiary sector and also on industry. The study, based on feasibility assessments, aims to establish a possible correlation between energy performance indicators (IPE) and a limited number of energy system parameters, in terms of energy production, operation and consumption. The comparative assessment of energy saving measures provides a useful method for assessing the applicability of standard energy saving measures in similar contexts and the cost-benefit ratio of the solutions, depending on a limited number of parameters

(continued)

Table 2 (continued)

Reference [17] How can energy audits and energy management be promoted amongst SMEs? A review of policy instruments in the EU-28 and beyond	The purpose of this document is to provide a structured and comprehensive review of existing policy instruments for energy audits and energy management systems in SMEs, including regulatory, voluntary, financial and information-based elements. The results indicate that there are 50 instruments in the EU-28. Another 15 instruments were identified in Brazil, Canada, China, India, Japan, Norway, Switzerland and the USA. In our analysis, we provide an overview of the different instruments by grouping them and discussing the main design features of their implementation. Through our analysis, we aim to increase the transparency of the current implementation of policy instruments that deal with energy audits and energy management systems for SMEs in the EU-28 and beyond. This will allow researchers and policy makers to further improve policy making on industrial energy efficiency
Reference [18] Monroe County, Florida a case study in sustainable energy management	This article provides information about the project, with an emphasis on how the project team has used and continues to use elements of the Plan-Do-Check-Act continuous improvement cycle found in ISO 50001: 2011 energy management systems. Examples of elements include an energy review and baseline development, identification of significant energy uses, controls and operational procedures for significant energy uses (e.g. training), action plans and development of Energy Performance Indicators (EnPI)
Reference [19] Moving the masses to ISO 50001 whit 50001 ready	This article explores the approach taken by DOE and the Lawrence Berkeley National Laboratory (LBNL) to break that barrier. 50001 Ready is a self-guided recognition program developed by DOE and LBNL to support installation-level adoption of ISO 50001 business practices, providing national recognition for self-guided adoption of energy management principles without the need for third party audits or verification
Reference [20] Results and prospects of applying an ISO 50001 based reporting system on a cement plant	This study reports an electric power management system to improve the productivity of the cement plant at minimal cost. The system consists of an automated energy performance report, which covers the approach of the ISO 5000 Verification Plan Act. The system collects data from various sources to provide valuable information and graphics about these reports. Large systems that consume electricity can then be isolated, monitored and compared with continually updating benchmarks to identify missed savings opportunities. The system has been implemented in a South African plant where the cost of electricity from cement has reduced by 25%. Qualitative consultations confirmed that the system promotes the implementation of the management practices of ISO 50001. The system allows to monitor the energy performance of the equipment and to continuously improve operations. These results prove that the profitability of the cement plant can be improved with minimal capital investment, using an energy management system

(continued)

Table 2 (continued)

Reference[21] Save energy through the superior energy performance prog ram	This article talks about the SEP program - Superior energy performance program, which follows the PDCA cycle for its implementation, showing the benefits of the program in terms of savings in energy consumption
Reference [22] Six-Sigma approach to energy management planning	This article presents an energy management planning procedure based on six sigma, focusing on five main steps: defining, measuring, analyzing, improving and controlling. An overview is provided of the main equipment that consumes energy in the manufacturing industries. Different energy saving opportunities are then investigated. The results of this research provide information and a clear understanding for establishing an energy management plan, which can be used as part of the ISO 50001 implementation
Reference [23] Specification of energy assessment methodologies to satisfy ISO 50001 energy management standard	The objective of this work is to develop an energy evaluation methodology and a report format adapted to the needs of ISO 50001. The energy evaluation methodology developed integrates the energy reduction aspect of an energy evaluation with the requirements of the Sects. 4.4.3 (Energy review) to 4.4.6 (Objectives, Goals and Action Plans) in ISO 50001, thus allowing facilities to reduce the time and other resources needed to facilitate the implementation of ISO 50001
Reference[24] The sustainability of energy management system Implementation in Pilot Company's Industry of Indonesia	The survey results show that 24 industries from 28 pilot industries, or about 86%, still implement EnMS. There are 10 sectors that have obtained ISO 50001 certification to monitor the implementation of EnMS and the improvement of energy performance through ISO 50001 surveillance audits, carried out by the certification body. Sector that still implements EnMS, but has not yet received ISO 50001, the certification will monitor the implementation of EnMS and the improvement of energy performance through internal audit activities, carried out by the company itself

energy management process. The article [13] provides a chronological overview of the development of energy management standards and explains the implementation of the standard, the standards of ISO 50002, ISO 50003, ISO 50004, ISO 5006, ISO 5007 are covered. The article [20] talks about the SEP—Superior Energy Performance Program, which suggests the PDCA cycle for its implementation, showing benefits of the program in terms of savings in energy consumption.

5 Conclusions

Using the Proknow-C intervention method, it was possible to select a bibliographic portfolio that represents the research theme, containing 15 articles that are relevant to the theme. Through the bibliometric analysis it was possible to acquire the necessary knowledge, because the analysis allowed to identify the most scientifically relevant

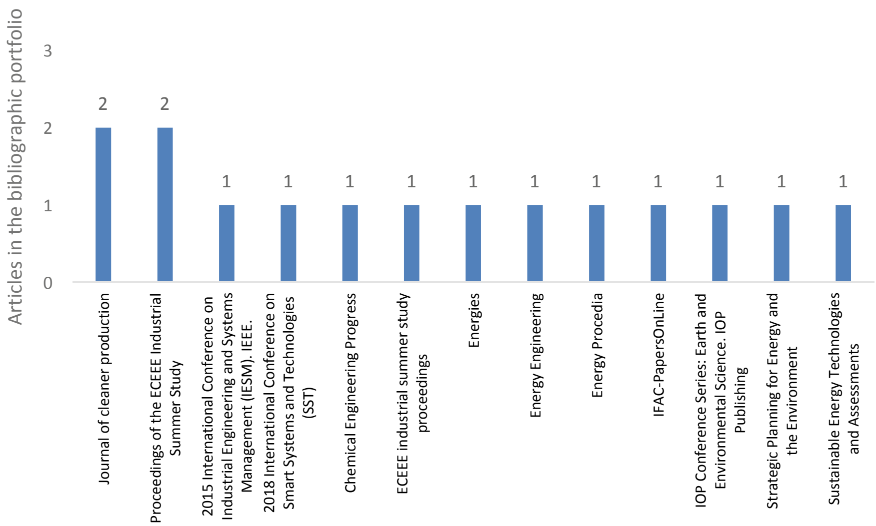


Fig. 4 Number of articles in the bibliographic portfolio per journal (2020)

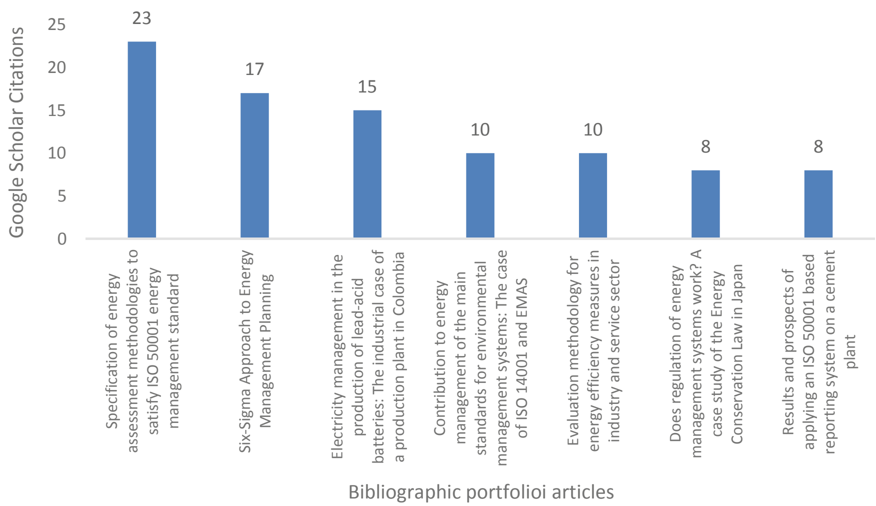


Fig. 5 Articles with the highest scientific recognition among the articles in the bibliographic portfolio, research data (2020)

articles, taking into account points such as: journals where the articles were published, authors with high scientific recognition, among other points that allow to configure a rich portfolio in information for the research area.

There is a great lack of implementation studies for auditing energy management in the context of international standards. This finding can be considered as a gap

Fig. 6 Cloud of keywords that most appeared in the articles of the bibliographic portfolio, research data (2020)

in scientific research, as it is a relevant topic for industries today. In this way, it is possible to affirm that the research theme is in progress, which allows for different combinations of audit methods, indicators and methods for implementing energy management in companies.

It is worth mentioning that this work is limited to the sample of the researched journals and the keywords used. The analysis was limited to scientific articles from journals and conferences, referring to auditing for energy management based on international standards, made available for free on the CAPES portal. For future research, it is suggested that the process, illustrated here, be replicated both for the same research topic and for other topics.

References

1. Tanaka, Kanako. Review of policies and measures for energy efficiency in industry sector. Energy policy, v. 39, n. 10, p. 6532–6550, 2011.
2. Fiedler, T., & Mircea, P. M. (2012, October). Energy management systems according to the ISO 50001 standard—Challenges and benefits. In 2012 International Conference on Applied and Theoretical Electricity (ICATE) (pp. 1–4). IEEE.
3. Fernando, Y., Bee, P. S., Jabbour, C. J. C., & Thomé, A. M. T. (2018). Understanding the effects of energy management practices on renewable energy supply chains: Implications for energy policy in emerging economies. Energy Policy, 118, 418–428.
4. Ngai, E. W. T., Chau, D. C. K., Poon, J. K. L., & To, C. K. M. (2013). Energy and utility management maturity model for sustainable manufacturing process. International Journal of Production Economics, 146(2), 453–464.
5. Gordić, D., Babić, M., Jovičić, N., Šušteršič, V., Končalović, D., & Jelić, D. (2010). Development of energy management system–Case study of Serbian car manufacturer. Energy Conversion and Management, 51(12), 2783–2790.
6. Abdelaziz, E. A.; Saidur, Rahman; Mekhilef, Saad. A review on energy saving strategies in industrial sector. Renewable and sustainable energy reviews, v. 15, n. 1, p. 150–168, 2011.
7. Saidur, Rahman. A review on electrical motors energy use and energy savings. Renewable and Sustainable Energy Reviews, v. 14, n. 3, p. 877–898, 2010.
8. Ensslin, L., Ensslin, S. R., Lacerda, R. T. D. O., & Tasca, J. E. (2010). ProKnow-C, knowledge development process-constructivist. Processo técnico com patente de registro pendente junto ao INPI. Brasil, 10(4), 2015.

9. Afonso, M. H., Souza, J. D., Ensslin, S. R., & Ensslin, L. (2011). Como construir conhecimento sobre o tema de pesquisa? Aplicação do processo Proknow-C na busca de literatura sobre avaliação do desenvolvimento sustentável. Revista de Gestão Social e Ambiental, 5(2), 47–62.
10. Javied, T.; Huprich, S.; Franke, J. Cloud based Energy Management System Compatible with the Industry 4.0 Requirements. IFAC-PapersOnLine, v. 52, n. 10, p. 171–175, 2019.
11. Laskurain, I., Ibarloza, A., Larrea, A., & Allur, E. (2017). Contribution to energy management of the main standards for environmental management systems: The case of ISO 14001 and EMAS. Energies, 10(11), 1758.
12. Rizzon, B., Clivillé, V., Galichet, S., Ochalek, P., & Ratajczak, E. (2015, October). Decision problem of instrumentation in a company involved in ISO 50001. In 2015 International Conference on Industrial Engineering and Systems Management (IESM) (pp. 409–416). IEEE.
13. Glavaš, H., Zovko-Ribić, F., Dorić, D., Talapko, D., "Development of Energy Management Standards," 2018 International Conference on Smart Systems and Technologies (SST), Osijek, 2018, pp. 185–189.
14. Kimura, O.; Noda, F. Does regulation of energy management systems work? A case study of the Energy Conservation Law in Japan. Proceedings of the ECEEE Industrial Summer Study, p. 647–657, 2014.
15. Gutiérrez, A. S., Eras, J. J. C., Santos, V. S., Herrera, H. H., Hens, L., & Vandecasteele, C. (2018). Electricity management in the production of lead-acid batteries: The industrial case of a production plant in Colombia. Journal of cleaner production, 198, 1443–1458.
16. Tallini, A.; Cedola, L.. Evaluation methodology for energy efficiency measures in industry and service sector. Energy Procedia, v. 101, p. 542–549, 2016.
17. Nabitz, L., Hirzel, S., Rohde, C., Wohlfarth, K., Behling, I., & Turner, R. (2016). How can energy audits and energy management be promoted amongst SMEs? A review of policy instruments in the EU-28 and beyond. Proceedings of the ECEEE Industrial Summer Study, 401–415.
18. Imel, M. R.; Gastesi, R.; Stone, R. Monroe County, Florida A case study in sustainable energy management. Energy Engineering, v. 112, n. 1, p. 47–66, 2015.
19. Wu, C., Therkelsen, P., Wrobel, J., Langlois, P., Scheihing, P. Moving the masses to ISO 50001 whit 50001 ready. ECEEE industrial summer study proceedings, 323–332.
20. Pelser WA, Vosloo JC, Mathews MJ, Results and prospects of applying an ISO 50001 based reporting system on a cement plant, Journal of Cleaner Production (2018).
21. Scheihing, P. Save energy through the superior energy performance program. Chemical Engineering Progress, v. 110, n. 9, p. 48–51, 2014.
22. Lee J., Yuvamitra, K., Guiberteau, K., Kozman, A. T. (2014) Six-Sigma Approach to Energy Management Planning, Strategic Planning for Energy and the Environment, 33:3, 23–40.
23. Kanneganti, H., Gopalakrishnan, B., Crowe, E., Al-Shebeeb, O., Yelamanchi, T., Nimbarte, A., … & Abolhassani, A. (2017). Specification of energy assessment methodologies to satisfy ISO 50001 energy management standard. Sustainable Energy Technologies and Assessments, 23, 121–135.
24. Apriyanti, D.; Prasetyo, T.; Warsito, B. The Sustainability of Energy Management System Implementation in Pilot Company's Industry of Indonesia. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2019. p. 012069.

Stakeholders Assessment for Risk Management into the Wind Power Supply Chain

Jorge Arnaldo Troche-Escobar and Francisco Gaudêncio Mendonça Freires

Abstract The supply chain of wind power projects is exposed to a set of events with potential to disrupt their performance. This work aims to evaluate wind projects in Brazil to understand the actors' strategies into the supply chain. The methodology was qualitative and followed the method of Matrix of Alliances and Conflicts: Tactics, Objectives and Recommendations (MACTOR) based on the key actors and objectives identified into the projects. The individual strategies of the different actors allow to identify differences and concordances between their objectives and to define alternatives through the convergence of the objectives into the project. Groups of actors with the highest degree of influence and the most dependence level were also identified. Finally, proposals were made to align the objectives of each actor with the purpose of the project.

Keywords Wind power supply chain · Risk management · MACTOR · Stakeholders assessment

1 Introduction

Supply chain management includes the exchange of information, communications, and the development of relationships across the chain [1]. Supply chain risk management (SCRM) is the coordination or collaboration among the actors into the chain to prevent interruptions on operations [2]. An inefficient supply chain management can conduct to short, medium, and long-term impacts. Thus, as proposed by Fan and Stevenson [2], risk management requires a holistic approach to the supply chain rather than focusing only on a focal company.

J. A. Troche-Escobar (✉)
Doctoral Student, Polytechnic School, Federal University of Bahia, Salvador, BA, Brazil
e-mail: jorge.troche@gmail.com

F. G. M. Freires
Professor, Polythechnic School, Federal University of Bahia, Salvador, BA, Brazil
e-mail: gaudenciof@yahoo.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_39

The understanding of the actors' individual strategies in terms of objectives and choices are useful information to identify the degree to which a project fails [3]. The complexity of the actor's system is determined by the capacity or weight of each one into the system, influencing on a greater or lesser degree the decisions of another players. Here is important to understand that each actor tries to defend its own interests [4], even though, they are committed to the overall project's objective. So, we have a stakeholder interaction where it is important to explore the priorities of each one within a set of objectives. Those interactions point out key issues and future actions to improve the supply chain.

The development of projects on the wind power supply chain is exposed to variety of risks (direct and indirect font) and includes a high number of companies with important level of investments [5, 6]. An efficient management of the supply chain is a key factor where is required the identification of uncertainties and coordination of actions [7]. On this line, the present paper aims to evaluate the Brazilian wind power projects' supply chain. The research was conducted on the direction of the next questions: to understand which are the main stakeholders into the Brazilian supply chain of a wind energy project; and to understand how are their interactions based on a set of projects' objectives.

2 Wind Power Supply Chain and Stakeholders

The wind energy experienced a fast growth into the Brazilian energy matrix into the last years [8]. Good wind quality, development of technology, and tax incentives are factors that helped to develop a strong local supply chain [6]. Brazilian and international companies where attracted to take part on the technological development of the local industry, including large number of specialized service providers.

Brazilian wind power projects are currently onshore and involves private companies under the directives of different governments (Federal, states and cities) and influenced by actors such as the local population. Wind farms are concentrated in two main regions: Southeast (Rio Grande do Sul, Santa Catarina, and Paraná) and Northeast (especially Bahia, Rio Grande do Norte and Ceará). The supply chain of wind energy involves a great number of actors, where coordination between the groups is key to mitigate the uncertainties that result from its complexity [9]. The main actors can be concentrated on, supply of parts and components, distribution by specialized transport companies, construction, and operation of the wind farms. Specialized maintenance may be required in specific situations, in addition to specialized services [10].

To Adam Cobb [11], stakeholders are individuals or groups with interest on a decision. That means that not only actors involved directly on the decisions, but also, actors that are affected by those decisions (and their positions) must be considered. On wind power projects, we can identify three blocks of stakeholders: first, companies operating directly on the sector, second, government (local or federal), and third, the population directly affected by wind projects. The Brazilian wind power projects dynamizes the economy of remote places with the movement of workers, equipment, and demand of services. Government apply incentives, as special taxes on equipment and parts on the assembly of wind park projects to attract investment [12].

3 Methodology

The study has a qualitative approach with stakeholders of the Brazilian wind power projects. The MACTOR method (matrix of alliances and conflicts: tactics, objectives, and recommendations) is a prospective method of analysis and planning of scenarios where is considered the potential disruptive effects of actors or stakeholders into the system [13]. The multi-stakeholder approach tries to understand the strategy of each actor, an approach that is gaining importance into the literature as governance study [14].

It was defined a list of stakeholders and general objectives to be analyzed. The list was confirmed by previous lectures and coordination with participants. Then it was applied the MACTOR method with the specific software (MACTOR®—version 5.1.2 2003/2004). According to Godet [13] the stages to run the method are: (i) Construction of a list of actors or stakeholders of the project; (ii) Identification of strategic vulnerabilities and objectives to be confronted or mitigated; (iii) To confront each actors and objectives identifying similarities or differences; (iv) Valuation of positions, where each pair actor-objective are punctuated; (v) Evaluation of powers and strategic recommendations for each actor, considering the priorities and availability of resources; (vi) Integrating power relations in the analysis of convergence and divergence between actors; (vii) To make recommendations for future scenarios.

As result of the MACTOR method assisted by the software we obtain a series of reports including tables and graphics about the interaction of stakeholders into the system. On this paper, and considering the limitation on pages, it will be discussed: the matrix of convergencies between actors (1CAA) that shows the distance and proximity between actors considering the set of objectives; the matrix of direct influences; power relationship between actors, understanding the most influential into the system; and, the map of convergency between actors and objectives.

3.1 Identification of Stakeholders and Objectives

Based on previous lectures, direct observation, and interaction of participants, the list of stakeholders and objectives are condensed on Table 1. Stakeholders were selected considering their importance to the supply chain of wind power projects. Objectives are the projects' strategies with the aim to mitigate risk factors that can disrupt the operations affecting the accomplishment of schedules and signifying losses and damages.

Table 1 List of stakeholders and project's objective

Code	Stakeholder	Code	Stakeholder
A1	Suppliers of blades	O1	To deliver stocks
A2	Wind turbine suppliers	O2	Good communication
A3	Suppliers of cubes, axis and nacelle	O3	Quality of products
A4	Suppliers of towers	O4	Schedule accomplishment
A5	Transportation	O5	Security on operations
A6	Building contractors	O6	Quality on O&M services
A7	Public opinion	O7	To regulate the system
A8	Maintenance service		
A9	Government		
A10	Wind park operators		

3.2 Input Data

Two matrices are prepared as data input to the MACTOR method: (i) matrix of direct influences (MDI) and, (ii) the matrix of stakeholders' position regarding the objectives (2MAO). The first matrix represents a reciprocal influence among the actors, which can be expressed as: against, on favor, and neutral. The values on MDI matrix (Table 1) are: 4 when actor i can question the existence of actor j; 3 when actor i can question the accomplishment of objectives by actor j; 2 when actor i can question the success of projects by actor j; 1 when actor i can question the operational management of the projects by actor j; and, 0 when there is no representative influence between the pair of actors. The 2MAO matrix represents the position of each actor among the list of objectives (on this case, a list of supply chain risk factors). The positions can be considered as neutral, on favor, or against the objective. The values on 2MAO matrix (Table 2) are: 4 when the objective depends on the existence of the actor; 3 when the objective compromises the mission of the actor; 2 when the objective compromises the success of the actor; 1 when the objective compromises the operational procedures of the project; and 0 when the objective has a weak relationship with the actor.

Table 2 shows a first vision of stakeholders' interactions. The sum of influences (rows) identifies four stakeholders with higher influences: wind turbine suppliers (A2); wind park operators (A10); public opinion (A7); and government (A9). The sum of columns shows the stakeholders that receives more influence into the system: transportation (A5); suppliers of cubes, axis and nacelle (A3); suppliers of towers (A4); maintenance service (A8); and suppliers of blades (A1).

The MACTOR software is run after MDI and 2MAO (Tables 2 and 3) are defined and input on the software. The aim of this analysis is to search answers about mitigation strategies of the main risk factors on the supply chain of wind power projects identified on the Brazilian context.

Table 2 Direct Influence Matrix (MDI)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	∑Aj
A1	0	0	1	1	3	0	0	3	0	0	**8**
A2	2	0	2	2	3	3	0	3	0	0	**15**
A3	0	0	0	0	3	0	0	0	0	0	**3**
A4	0	0	0	0	3	0	0	0	0	0	**3**
A5	1	1	1	1	0	0	0	0	2	0	**6**
A6	2	2	2	2	2	0	0	0	0	0	**10**
A7	1	1	1	1	2	1	0	1	3	3	**14**
A8	2	2	2	2	2	0	0	0	0	0	**10**
A9	1	1	1	1	2	2	1	2		3	**14**
A10	2	2	2	2	3	3	0	3	3	0	**20**
∑Ai	**11**	**9**	**12**	**12**	**23**	**9**	**1**	**12**	**8**	**6**	

Table 3 Actors versus Objectives Matrix (2MAO)

2 MAO	O1	O2	O3	O4	O5	O6	O7	Sum of Abs
A1	1	1	4	1	4	4	0	**15**
A2	3	2	3	3	2	2	2	**17**
A3	2	2	3	3	3	4	0	**17**
A4	3	2	1	3	4	2	0	**15**
A5	0	4	0	4	3	0	2	**13**
A6	2	1	2	3	3	1	0	**12**
A7	0	0	0	0	3	0	3	**6**
A8	4	3	3	1	2	0	0	**13**
A9	0	3	3	0	3	2	4	**15**
A10	0	2	3	0	3	3	2	**13**
Number of positions	**15**	**20**	**22**	**18**	**30**	**18**	**13**	

4 Results and Discussions

On the next sections there are represented relationships between actors-actors and actors-objectives. The results will be presented and discussed grouping the output in three subjects: direct and indirect influences; relationship between actors and objectives; and convergence between actors.

4.1 Direct and Indirect Influences Between Actors

The second order direct influence matrix (MDII) determines the direct and indirect influence among the actors (Fig. 1a). While into the MDI matrix (Table 2) the analysis was made from each individual actor into the system. The MDII covers the influence between the set of actors, where the incidence of an intermediate actor is included and explored. Two actors may not represent a direct influence on the MDI matrix, but they have important influences through the intermediary actors. Values are calculated as: Ii, degree of direct and indirect influence between each actor, determined by the sum of the rows; and Di, the degree of direct and indirect dependence between each actor, by the sum of the columns.

a Matrix of influences between actors MDII

MDII	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	Ii
A1	3	3	4	4	7	0	0	3	2	0	23
A2	7	5	8	8	13	3	0	5	2	0	46
A3	1	1	1	1	3	0	0	0	2	0	8
A4	1	1	1	1	3	0	0	0	2	0	8
A5	3	2	4	4	6	3	1	4	2	2	25
A6	5	3	6	6	10	2	0	4	2	0	36
A7	8	7	9	9	13	7	1	8	8	6	75
A8	5	3	6	6	10	2	0	4	2	0	34
A9	10	9	11	11	14	7	1	8	6	4	75
A10	10	8	11	11	17	7	1	9	5	3	79
Di	50	37	60	60	90	29	3	41	27	12	409

b Map of influences and dependencies

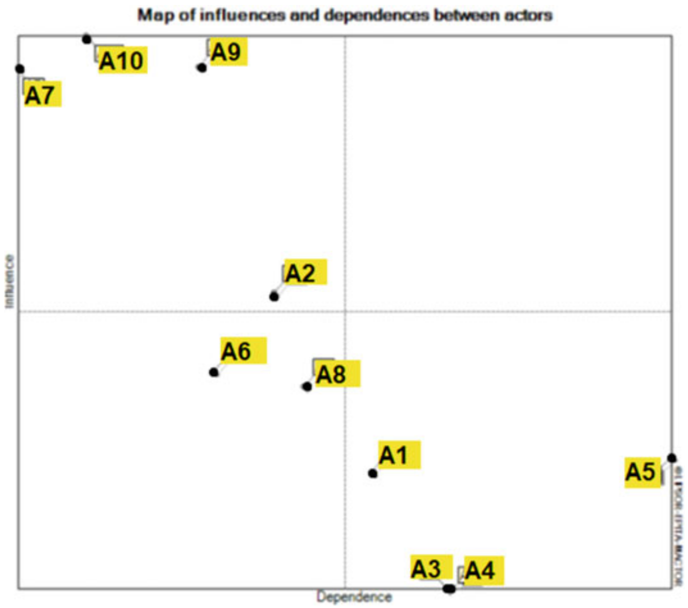


Fig. 1 **a** Matrix of influences between actors MDII; **b** Map of influences and dependencies

The most influential actor into the system are the wind park operators (A10) with $I = 79$. Followed by A9 (government) and A7 (public opinion) both with $I = 75$. This sequence is somehow waited since it represents the order of the projects' development planning. Companies projects the construction of wind parks, the governments act into the development of policies and incentives, and the public opinion acts based on the results.

Between the actors that receives more influence into the system were: transportation (A5) with the higher level with $D_5 = 90$, followed by suppliers of cubes, axis, and nacelle (A3) and suppliers of towers (A4), both with $D = 60$. Following, suppliers of blades (A1) and maintenance services (A8). This result represents the lower incidence of transportation services but at the same time their importance to achieve projects schedules. And, in the same line, the identification of suppliers of parts and components, as cubes, axis, nacelle and blades, that receives direct incidence on the development of projects, and are important to the accomplishment of objectives.

Another approach to identify and evaluate the degree of dependence and influence of the system is through the map of influences and dependencies (Fig. 1b). The values are distributed into a Cartesian representation where the vertical axis represents the influence (Ii), while the dependence (Di) are identified into the horizontal axis. It is also divided into four zones as discussed on the next paragraphs.

The first zone, actors of greater influence, but less dependence into the system. They are Wind turbine suppliers (A2), Public opinion (A7), Government (A9), and, Wind park operators (A10). This result confirms and are in line with the last findings of the three most influential stakeholders. Here is included the wind turbine suppliers, who are almost in the middle zone with a relative influence compared with the actors on this zone. Those four actors must then be considered as influencers into the stakeholders' structure.

The study did not identify any stakeholder into the zone of actors with greater influence, and at the same time, a greater degree of dependence. This result shows that the Brazilian wind power projects supply chain have influencer stakeholders but any of them receives a stronger influence into the supply chain. This case can occur as example, when a local government that develops policies receives at the same time a high pressure from investors to follow a specific line or to accomplish their requirements to increase investment.

Among the actors with less influence and less dependence we have Building contractors (A6) and Maintenance service (A8). Those actors are required to the development of previously stablished wind power projects and, this way, they have less influence between the actors analyzed. Those actors are supplier of services that receives more incidence into the chain.

Into the last zone, of actors with high level of dependence and lower level of incidence, we can identify the group of suppliers: cubes, axis and nacelle (A3), towers (A4) and suppliers of blades (A1). On the same way to the group presented on the last paragraph, those are suppliers that need the development of projects to start the production on those groups of elements defined as parts and components. On the same level, we have the actors of transportation (A5), that at the same way, are required once accomplished the development of projects and production of parts and components.

4.2 Relationship Between Actors and Objectives

The study of relationship between actors and objectives receives input from Table 3 (2MAO). On this first assessment was determined each actor's position as favorable, neutral and against each objective. This information results on the weighted value position matrix (in relation to competitiveness) (3MAO) describing the position of each actor in front of each objective (Fig. 2a). Positive values represent the degree of mobilization of the actor in relation to the goals and negative values represent the opposition rate (this study did not identify negative values).

The actors (A9) Government and (A10) Wind park operators (Fig. 2a) have the highest level of mobilization between the studied stakeholders. This result confirm that the strategies defined by those actors are required to define the rest of the actors' planning inside the wind power supply chain. In contrast, actors (A3) Suppliers of cubes, axis and nacelle and (A4) Suppliers of towers have the lowest mobilization degree, depending directly on the input of the projects' requirements.

The objectives with the greatest degree of mobilization among the actors (3MAO) are the safety of operations (O5), quality of services and products (O3) and the systems regulation (O7). Those objectives reflect the priority of the set of actors, as the case of safety on operations, considering that the projects represent a high level of investment, requiring an important level of safety plans. The quality of products and services can be understood at the same level, since any disagreement to this objective represent important barriers to accomplish the schedules and at the same time, high level of investment. The priority of system regulation is related to the need of definition of important and clear rules that guide the definition of investments. Companies will give priority to markets with strong and reliable structure of regulation systems.

4.3 Convergency Between Actors

The matrix of convergencies of objectives between actors (Fig. 2b) or simple convergency actor versus actor (1CAA) identifies for each pair of actors the number of common positions that they have about objectives (in favor or against). This information identifies the number of possible alliances. The positions "neutral" and "indifferent" (coded by zero) are not considered on this study.

The actors with the highest number of convergences are (A2) Wind turbine suppliers, followed by actors (A1) Suppliers of blades, (A3) Suppliers of cubes, axis, and nacelle, (A4) Suppliers of towers, and (A6) Building contractors. This group of actors conforms a strong convergence of interests since all them will participate on

a Matrix of weighted position (3MAO)

3MAO	O1	O2	O3	O4	O5	O6	O7	Mobilisation
A1	0,2	0,2	1,0	0,2	1,0	1,0	0,0	3,7
A2	2,7	1,8	2,7	2,7	1,8	1,8	1,8	15,1
A3	0,1	0,1	0,1	0,1	0,1	0,1	0,0	0,5
A4	0,1	0,1	0,0	0,1	0,1	0,1	0,0	0,5
A5	0,0	0,6	0,0	0,6	0,5	0,0	0,3	2,1
A6	1,5	0,7	1,5	2,2	2,2	0,7	0,0	8,9
A7	0,0	0,0	0,0	0,0	8,4	0,0	8,4	16,7
A8	2,1	1,6	1,6	0,5	1,1	0,0	0,0	6,9
A9	0,0	6,0	6,0	0,0	6,0	4,0	8,0	29,8
A10	0,0	5,2	7,8	0,0	7,8	7,8	5,2	33,6
Number of agreements	6,7	16,3	20,6	6,5	28,9	15,4	23,6	
Number of disagreements	0,0	0,0	0,0	0,0	0,0	0,0	0,0	
Degree of mobilisation	6,7	16,3	20,6	6,5	28,9	15,4	23,6	

b Matrix of actors convergencies (1CAA)

1CAA	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1	0	6	6	6	3	6	1	5	4	4
A2	6	0	6	6	4	6	2	5	5	5
A3	6	6	0	6	3	6	1	5	4	4
A4	6	6	6	0	3	6	1	5	4	4
A5	3	4	3	3	0	3	2	3	3	3
A6	6	6	6	6	3	0	1	5	4	4
A7	1	2	1	1	2	1	0	1	2	2
A8	5	5	5	5	3	5	1	0	3	3
A9	4	5	4	4	3	4	2	3	0	5
A10	4	5	4	4	3	4	2	3	5	0
Number of convergences	41	45	41	41	27	41	13	35	34	34

c Map of convergencies between actors

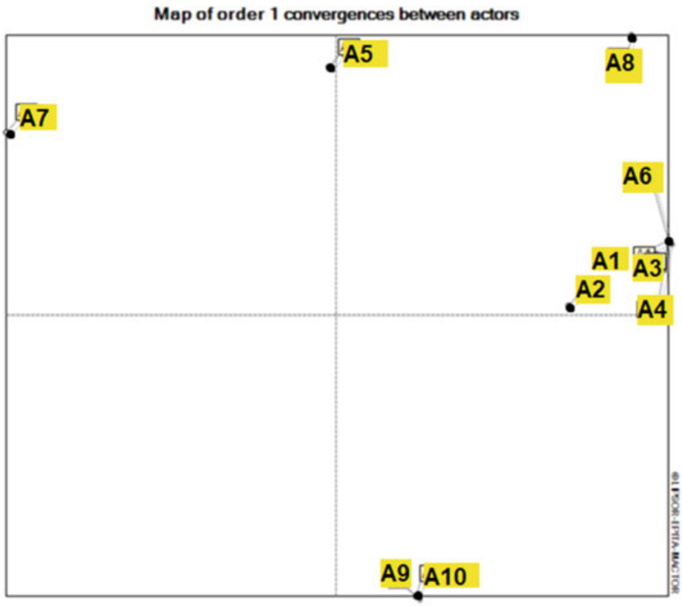


Fig. 2 **a** Matrix of weighted position (3MAO); **b** Matrix of actors convergencies (1CAA); **c** Map of convergencies between actors

the stage of development of wind power projects and will communicate strongly with the projects' requirement.

Next, (A8) Maintenance service, (A9) Government and (A10) Wind park operators. As on the previous results, it is normal that A9 and A10 are set on the same level of convergence. The actor A8 represents the importance of maintenance service to guarantee the operation of wind projects. This also could be aligned with the priority of objectives identified on the previous section.

As the end of the analysis, the map of convergences of order 1 between the actors (Fig. 2c) where represents the actors in relation to their convergences (data in 1CAA, 2CAA, 3CAA). That is, the closer to each other, the more intense is the convergence. The map confirms the previous results showing high convergence between A9 and A10 and at the same time, a group including A2, A3, A4, A6 and A1. Those results were discussed between the previous figures and tables. The map on Fig. 2c also allows to identify another three actors with more distance of convergence with the rest of the group. The actor (A8) Maintenance service that although having a great level of convergence with objectives, is less dependent of specific actors. The actor (A5) Transportation with middle level of convergence, and (A7) Public opinion that is the most isolated level of convergence inside the group. This result shows that public opinion receives less importance between the actors, considering a positive feedback facing future wind power projects, with expectation on investments, local economy incentives, and job market possibilities.

4.4 Risk Management Recommendations

Risk management into the supply chain of a wind project involves the coordination of all actors or stakeholders that takes part on the development of those projects. This paper evaluated the participation of ten actors according to eight objectives into the system. The study is focused not only on objectives from an individual perspective, but also on a perspective that encompasses all actors along the supply chain.

The analysis of direct and indirect influences between actors identified that the actors (A10) Wind park operators, (A9) Government, and (A7) Public opinion are the most influential into the system. Actor (A2) Wind turbine suppliers is also included in this group from the influence map. The most dependent actors in the system are (A5) Transportation, (A3) Suppliers of cubes, axis and nacelle, and, (A4) Suppliers of towers. Actors that we may consider intermediaries in this perspective are (A6) Building contractors, and, (A8) Maintenance service. This data shows that there are two external actors within the group of influences, represented by the government and the public opinion. The success of wind projects from the perspective of these two actors can be understood as a need for active participation and communication of projects both to the community and for regulatory agencies, elsewhere Federal, State or Cities. Involvement by the public opinion can be obtained not only through communication by companies, but also through participation in the definition of mitigation plans into the communities affected by wind power projects.

The evaluation of actors and objectives shows actor (A10) Wind park operators, with greatest degree of mobility into the system. This can be understood as the dependence of wind power projects on national energy policies. In this way, much of the success of projects depends on a clear definition of policies, incentives, and regulations of the activities involved in them. This evaluation also identified the actors A3 and A4 as with the lowest degree of mobilization among the objectives. We can understand this result as being suppliers of parts and components that follows the evolution of demand through active and future wind projects.

Into the levels of actors' convergence, two mains groups were identified: first, the convergence between actors A2, A1, A3, A4, and, A6. These actors have objectives into the system with convergence to the projects development, as the supply of parts and components. To manage risk, common strategic objectives can be drawn including an identified group of actors with the purpose of mitigating risks. A second group of actors with a high degree of convergence are: A8, A9, and A10. As it was identified in the different stages of the study, these actors present a similar degree of influence into the system, so it is important to understand that a series of strategic objectives can be worked as essential for the accomplishment of the projects' objectives and through this, to mitigate the risks. Here we can include accomplishment of policies from governments regarding energy requirement, and the design and projection of future projects.

Into the group of objectives with the greatest degree of influence among the actors are the safety of operations (O5), quality of services and products (O3) and good communication (O2). The safety of operations can be identified as influential in the success of the projects, since on the one hand they involve high investment in infrastructure and on the other hand the possibility of having a high impact on the rest of the system. In the same line, the quality of products and services can have the same degree of incidence in the projects. Finally, the need to maintain and improve communication in wind projects can be considered as important to maintain and improve coordination of supply activities within wind projects. These three objectives must be evaluated and defined with short and long-term strategies to maintain the growth of the industry with the best maturity and risk management indicators.

5 Conclusions

This paper evaluated the interaction between the different actors in a wind project. The MACTOR method was applied to the actors of the supply chain according to a series of risk mitigation objectives into the system. This method considers the understanding that each actor has a degree of freedom, defining their goals and strategies individually. At the same time, there are common goals, even if they are not drawn together from the beginning but are convergent through the interaction of activities in the search for the success of wind projects.

The study identified two actors, government, and wind power operators as the main stakeholders into the wind power projects supply chain. This shows the importance to work together and define strategies that would be aligned and guide the definition of plans on the supply chain. The definition of strong strategies on this level will allow the maturity of the Brazilian wind power supply chain. It will be important on the definition of short, medium, and long-term strategies and mitigate risks by uncertainties inside the supply chain.

The study also identified the convergence between actors into the projects' development level, as suppliers of parts and components. Those actors develop their plans based on the design of the wind power projects. To mitigate risks on this level will be necessary to maintain a high level of coordination on the supply chain and avoid any issue on the projects' schedules.

The paper shows the importance to identify convergencies between actors and objectives to define common strategies and reduce uncertainties. The communication between those stakeholders on the appropriate level will assist on the mitigation of risk and uncertainties into the supply chain. It is also important to emphasize that this study does not restrict the identification of possible changes into the future. Those changes could affect or define new convergences on objectives and strategies.

This research aims to continue with the case study of specific wind power projects to analyze the main stakeholders' decisions and evaluate how is developed the risk management into the project. This new research will allow to identify the main challenges on each wind power supply chain stakeholders, and to the establishment of specific risk management strategies for the industry.

References

1. Vanpoucke, E., Vereecke, A., Muylle, S.: Leveraging the impact of supply chain integration through information technology. International Journal of Operations & Production Management. 37, 510–530 (2017). https://doi.org/10.1108/IJOPM-07-2015-0441.
2. Fan, Y., Stevenson, M.: A review of supply chain risk management: definition, theory, and research agenda. Int Jnl Phys Dist & Log Manage. 48, 205–230 (2018). https://doi.org/10.1108/IJPDLM-01-2017-0043.
3. Park, C., Han, S., Lee, K.-W., Lee, Y., Park, C.Y., Han, S.H., Lee, K.-W., Lee, Y.M.: Analyzing Drivers of Conflict in Energy Infrastructure Projects: Empirical Case Study of Natural Gas Pipeline Sectors. Sustainability. 9, 2031 (2017). https://doi.org/10.3390/su9112031.
4. Svensson, G., Ferro, C., Hogevold, N., Padin, C., Sosa Varela, J.C.: Developing a theory of focal company business sustainability efforts in connection with supply chain stakeholders. Supply Chain Management: An International Journal. 23, 16–32 (2018). https://doi.org/10.1108/SCM-12-2015-0461.
5. Chopra, S., Meindl, P.: Supply Chain Management: Strategy, Planning, and Operation, Global Edition. Pearson (2015).
6. Martins, F.R., Pereira, E.B.: Enhancing information for solar and wind energy technology deployment in Brazil. Energy Policy. 39, 4378–4390 (2011).
7. de Lucena, A.F.P., Szklo, A.S., Schaeffer, R., Dutra, R.M.: The vulnerability of wind power to climate change in Brazil. Renewable Energy. 35, 904–912 (2010). https://doi.org/10.1016/j.renene.2009.10.022.

8. Bayer, B.: Experience with auctions for wind power in Brazil. Renewable and Sustainable Energy Reviews. 81, 2644–2658 (2018). https://doi.org/10.1016/j.rser.2017.06.070.
9. Prostean, G., Badea, A., Vasar, C., Octavian, P.: Risk variables in wind power supply Chain. Procedia-Social and Behavioral Sciences. 124, 124–132 (2014). https://doi.org/10.1016/j.sbspro.2014.02.468.
10. Yuan, J., Sun, S., Shen, J., Xu, Y., Zhao, C.: Wind power supply chain in China. Renewable and Sustainable Energy Reviews. 39, 356–369 (2014).
11. Adam Cobb, J.: How Firms Shape Income Inequality: Stakeholder Power, Executive Decision Making, and the Structuring of Employment Relationships. AMR. 41, 324–348 (2015). https://doi.org/10.5465/amr.2013.0451.
12. Adami, V.S., Antunes Júnior, J.A.V., Sellitto, M.A.: Regional industrial policy in the wind energy sector: The case of the State of Rio Grande do Sul, Brazil. Energy Policy. 111, 18–27 (2017). https://doi.org/10.1016/j.enpol.2017.08.050.
13. Godet, M.: Actors' moves and strategies: The mactor method: An air transport case study. Futures. 23, 605–622 (1991). https://doi.org/10.1016/0016-3287(91)90082-D.
14. Mathivathanan, D., Kannan, D., Haq, A.N.: Sustainable supply chain management practices in Indian automotive industry: A multi-stakeholder view. Resources, Conservation and Recycling. 128, 284–305 (2018). https://doi.org/10.1016/j.resconrec.2017.01.003.

Working in the 4.0 Era: An Ontology for Competence Management in the Fourth Industrial Revolution

Rosemary Francisco, Eduardo de Freitas Rocha Loures, Eduardo Alves Portela Santos, and Fernando Deschamps

Abstract Industry 4.0 is creating a radically more dynamic work environment, which calls for considerable changes in the role of industry professionals. As industries need to respond to evolving trends quickly, as well professionals need to be able to work and constantly learning in this new work environment. Besides, due to the continuous advances in technology and the adoption of these technologies in the industries processes, the level of complexity in the workplace is increasing, which results in the need for a new professional role. However, the main challenge is how to prepare and qualify these professionals to acquire these competences. In order to provide a better understanding of the new professional role and their relationship with the industry 4.0 working environment, this paper introduces an ontology for Competence Management in the Fourth Industrial Revolution. Considering the recent scientific and business developments for preparing the industries and workers for this new working era, competences and skills needed for professionals in industry 4.0 were reviewed, as well as challenges and opportunities. Based on a systematic literature review in scientific sources and grey literature, this work identified what technologies are being adopted and what the professional competences are for working in this working environment. Since Industry 4.0 is spreading all over the world, this study contributes to this understanding and also provides a starting point for further research regarding workforce competence management for Industry 4.0.

Keywords Industry 4.0 · Workforce skillset · Competence management · Ontology

---

R. Francisco (✉)
UNISINOS University, São Leopoldo, RS, Brazil
e-mail: rosemaryf@unisinos.br

E. de Freitas Rocha Loures · E. A. P. Santos · F. Deschamps
Industrial and Systems Engineering Graduate Program, Pontifical Catholic University of Paraná, Curitiba, PR, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_40

1 Introduction

Industry 4.0 has been conceptualized as the fourth industrial revolution [1], whose impact reflects on the economy, work, government and also in society [2–4]. New smart technologies are adopted to improve production processes. They are incorporated not only in organizations but also in the lives of people who are part of this context, workers in this industry [5]. New skills and competences are necessary for these workers, such as creativity and improvisation in solving unforeseen problems, without compromising production goals [6].

Despite being among the priority areas, few studies present what the most efficient approaches to promote the competence development in the work environment are [7]. Also, little is known about what are the main challenges faced by the workers in a workplace supported by the fourth industrial revolution (4IR) technologies [8]. Therefore, it is essential to support and promote learning in the real work environment [9, 10]. Besides, continuous qualification and competence development are considered priority areas that must be addressed by organizations that are joining industry 4.0 [11].

This paper aims to examine the new required professional role in current research on Industry 4.0 in order to synthesize the accumulated knowledge and create an initial ontology for competence management in the Fourth Industrial Revolution. Considering the future challenges to restructuring the jobs [12], competence management can be an important element in the effective operation of an organization. The following questions are to be answered:

- What are the 4IR technologies?
- What challenges does the 4IR bring to the workers?
- What competences are needed for the 4IR workforce?

After the introduction, the method adopted to conduct the systematic literature review is presented. The third section is dedicated to the descriptive analysis and results discussion. The initial schema of the ontology is also illustrated in this section. Finally, the conclusions and future recommendations are presented.

2 Method

A systematic literature review was conducted to identify the current state of research on professional competences in Industry 4.0. Two procedures were used to search for the articles: (1) a search in the scientific databases following the phases of PRISMA method [13] (see Fig. 1), and (2) a backward/forward approach proposed by [14].

To conduct the search in the scientific databases in the identification phase, we use the electronic databases, namely *Web of Science*, *SCOPUS*, and *Science Direct*. The search string applied was ((“fourth industrial revolution” OR “4th industrial revolution” OR “Industry 4” OR “Industrie 4”) AND workforce AND (skills OR

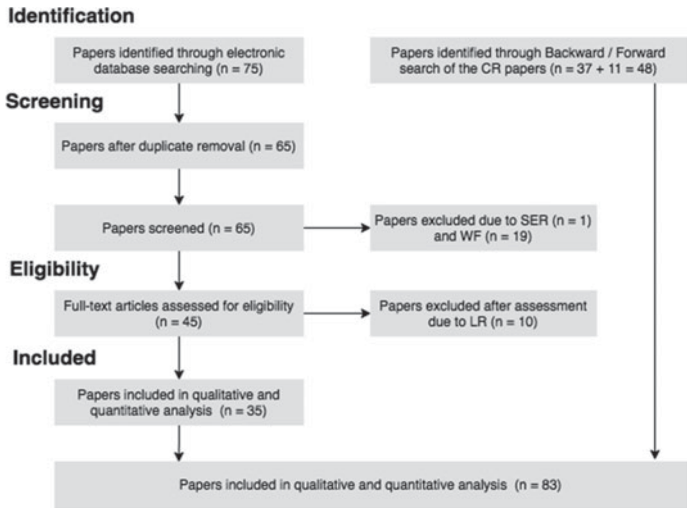


Fig. 1 Phases of the systematic literature review according to PRISMA

competences OR competencies)). The terms were used for search in the title, abstract, and keywords of the articles without restriction by a period of time. The result of the search was a total of 45 papers in *Web of Science* database, 29 papers in *SCOPUS* database, and only 1 in Science Direct.

An inclusion and exclusion criteria were defined to guide the screening and eligibility phases. A careful review of abstracts and full text was performed in the eligibility phase. Based on inclusion criteria defined (see Table 1) only articles that dealt with workforce competences, 35 out of the 45, articles were selected.

The closely related (CR) papers were also used to guide the backward/forward procedure. This second identification allowed to identify other 48 documents specifically dedicated to Industry 4.0 and workforce (skills and competences). From these 48 documents, 14 are classified as grey literature, knowledge artefacts that are not the product of peer-review process such as the scientific papers [15]. Hence, 83 documents were selected for the subsequent literature analysis.

To organize the many files in a single database, we used Mendeley, and to conduct the qualitative and quantitative analysis, we use NVivo. Based on the key questions, we analyzed the data collected by coding the data into categories and subcategories following the methods proposed by [16]. We applied two methods: descriptive and simultaneous coding. The descriptive coding allowed us to derive basic codes from the data gathered. Through this method, we obtained the main categories from the data. Then, we used the simultaneous coding method to apply multiples codes within a single datum. Thus, when we identified two meanings in one specific code, the simultaneous coding was applied to create the subcategories.

Table 1 Inclusion and exclusion criteria and their explanations

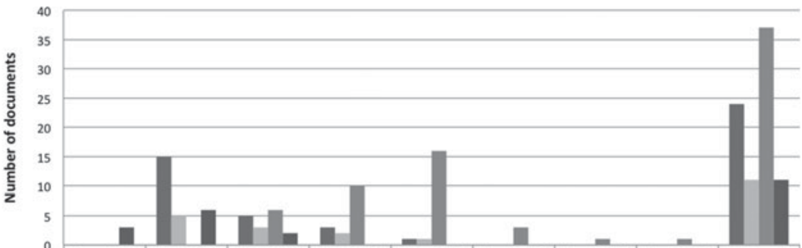
I/E	Criteria	Criteria explanation	Number of papers
Exclusion	Search engine reason (SER)	A paper has only its title, abstract, and keywords in English but not its full-text	1
	Without full-text (WF)	A paper without full text to be assessed	19
	Loosely related (LR)	A paper doesn't focus on industry 4.0 and workforce (skills and competences)	10
Inclusion	Partially related (PR)	A research about industry 4.0 and workforce (skills and competences) but focusing only on Higher Education and not in the workplace	11
	Closely related (CR)	The research efforts of a paper are explicitly and specifically dedicated to Industry 4.0 and workforce (skills and competences)	24
	Backward (BW)	References of CR papers that are explicitly and specifically dedicated to Industry 4.0 and workforce (skills and competences)	37
	Forward (FW)	Papers that cited the CR papers and are explicitly and specifically dedicated to Industry 4.0 and workforce (skills and competences)	11

3 Results and Discussion

The first contribution on competences regarding Industry 4.0 was found in the year 2013. Since 2015 the number of contributions has been increasing. Some contributions were published in the following year (see Fig. 2).

The systematic literature review disclosed a lack of empirical studies. Since the fourth industrial revolution is at the beginning of its existence, the first appearance of the subject date from 2013 [1], most of the studies are theoretical. Of the 83 documents examined, 35 were classified as literature review, 14 were considered grey literature, 14 conducted a survey, 12 conducted a case study, 2 conducted a research experiment. The six remains used research methods such as content analysis (3), design science research (1), simulation (1), and text mining analysis (1).

The analysis also reveals that not only the manufacturing industry is concerned regarding the fourth industrial revolution and its impacts on the workforce competences. The following sectors are also conducting studies regarding this subject:



	Year = 2020 (n=3)	Year = 2019 (n=26)	Year = 2018 (n=16)	Year = 2017 (n=15)	Year = 2016 (n=18)	Year = 2015 (n=3)	Year = 2014 (n=1)	Year = 2013 (n=1)	Total (n=83)
Closely related (CR)	0	15	5	3	1	0	0	0	24
Partially related (PR)	0	5	3	2	1	0	0	0	11
Backward (BW)	0	0	6	10	16	3	1	1	37
Forward (FW)	3	6	2	0	0	0	0	0	11

Fig. 2 Number of articles by year and category

Agriculture [17], Construction [18, 19], Fashion [20], Footwear [21], Maritime [22], Mining [23] and Textile [21, 24].

In the following, the results of the content analysis are presented, structured according to the aforementioned research questions.

3.1 What Are the 4IR Technologies?

As can be seen in Table 2, the analysis identified 45 emerging technologies. The top 5 mentioned in the documents are Artificial intelligence (10 documents), Big data (13 documents), Cloud computing (10 documents), Cyber-physical systems (13 documents), and Internet of Things (15 documents).

An interesting point to be highlighted is the fact that little is known empirically about the adoption of these technologies and their real impact on the working environment. The majority of the mentions are based on predictions mainly from the grey literature [25, 31, 35–37].

3.2 What Challenges Does the 4IR Bring to the Workers?

The biggest challenge the 4IR brings to the workers lies in coping with the constant IT and technology qualification [50, 51]. Since there is a variety of technologies being adopted (see Table 2), the workers need technology affinity [22, 32, 52]. Workers need to deal with the 4IR technologies available in their working environment as well as other emergent technologies that can have been adopted in the future. Besides, with the adoption of the technologies also emerges the concern about information security [30].

Table 2 The 4IR technologies identified

3D Printing [3, 19, 25–27]	Cybersecurity [11, 26, 28–30]
5G [31]	Digital design [26]
Advanced algorithms [8, 19, 32]	Digital Twins technologies [8, 11, 31]
Advanced analytics [8, 19, 26, 29, 33, 34]	Energy storage [26, 27, 35]
Advanced human-machine interfaces [19, 34, 36]	High performance computing [26]
Advanced materials [26, 27, 35]	In Memory databases [33]
Advanced robotic [3, 11, 26, 27, 29, 32, 35, 37, 38]	Intelligent Automation [29]
Advanced traceability systems [11]	Internet of Services [11, 36, 39]
Artificial intelligence [8, 11, 26, 29, 31, 32, 35, 40–42]	Internet of Things [8, 11, 19, 26–29, 31, 33, 36, 38, 39, 41, 43, 44]
Augmented reality [8, 11, 19, 24, 31, 34–36, 44]	Location detection technologies [11, 19]
Authentication and fraud detection [19]	Mobile devices [11, 19, 23, 27, 29, 32, 33]
Automation [25, 29, 39, 42, 45]	Multilevel customer interaction and customer profiling [19]
Autonomous vehicles [3, 25, 27, 32, 37]	Next gen-computing [26, 27, 35]
Big data [8, 11, 19, 25, 27–29, 32–34, 37, 41, 46]	RFID technologies [11, 19, 39]
Biomanufacturing [26]	Robot Process Automation [29]
Biotechnology [26, 27, 35]	Simulation and integration [11, 25, 26, 37]
Blockchain [26, 31, 35]	Smart sensors [8, 11, 19, 24, 32, 36, 37, 39]
Cloud computing [8, 11, 27–29, 31, 33, 39, 43]	Social Media [29, 33, 34]
Cloud services [11, 43]	Speech recognition [8, 36]
Cognitive automation [26]	Ubiquitous computing [31, 35]
Collaborative robots (cobots) [9, 11, 23, 26, 31, 34, 38, 40, 47]	Virtual reality [11, 31, 34–36, 38, 44]
Complex network protocol [11]	Wearables [19, 34, 36]
Cyber-physical systems [8, 11, 24, 30, 34, 36, 38, 39, 41, 42, 44, 48, 49]	

Another challenge observed is related to the lack of knowledge regarding the processes followed by the workers [25]. Without this explicit knowledge, it is difficult for them to understand and also coordinate the efforts necessary to make better use of 4IR technologies. Besides, a critical challenge also is related to deal with the existence of parallel work structures: the old way of working and the new way of working, due to the adoption of the 4IR technologies, that can be built in parallel with the day-to-day tasks [43].

The diversity of the working environment is also a challenge founded in the analysis [53, 54]. Due to the demographic changes [26, 31, 37, 55], and also the globalization [29, 56, 57], more diversity is encountered in the 4IR working environment. Besides, since women represent a high percentage of new graduates with

IT skills developed [27, 36, 51, 58], diversity related to gender also increases. This situation drives workers to the need for social competences to deal with diversity in the working environment.

Furthermore, the level and kind of competences required for the workers are increasing [59]. For instance, a need competency found in the literature is the "Sustainable mindset" [55]. This competence requires that the workers have consciousness regarding the impact on their working on the environment and bring creative ideas to solve this problem.

3.3 What Competences Are Needed for the 4IR Workforce?

The most cited reference regarding competences is the 21st century required skills provided by the World Economic Forum document [60]. Twenty documents mention and use it to define the key competencies needed for the 4IR workforce. Another grey literature also used with this regard is [51].

A specific overview of 4IR workforce competences is provided by [55]. Other papers also referenced this article since it provides a significant list of 4IR workforce competences. The authors classified the competences in four main categories: **personal**, **social**, **methodological**, and **technical**.

Towards the personal competence, an important aspect found in the literature, for all workers' roles, even operators, was the mention regarding the transformation of the workers into "knowledge workers" [61]. This means that the workers need to have the **motivation to learn**, **flexibility** [22, 46, 62], and also be **capable of reviewing their own experience and knowledge continuously** [57].

Besides, as already mentioned, the 4IR working environment is more collaborative. Therefore, social competences as **communication** as well as **negotiation** are highly required in this environment [22, 46, 57, 63].

Since 4IR impacts in a more dynamic work environment, the workers need methodological competences. For instance, it is crucial to have **problem solving** competence [22, 46, 57, 63, 64] to deal intelligently and creatively with the challenges of this environment. Moreover, **time management**, **process management**, and **project management** are also substantial methodological competences for 4IR workers.

Finally, because the working environment is surrounded by technology, the 4IR workers need technical competences [22, 46, 57]. **IT affinity** competence can empower the workers and allows them to be more productive and efficient in their task execution. For instance, knowing how to **program** smart equipment to automate a manual task can boost productivity and help to improve engagement and job satisfaction.

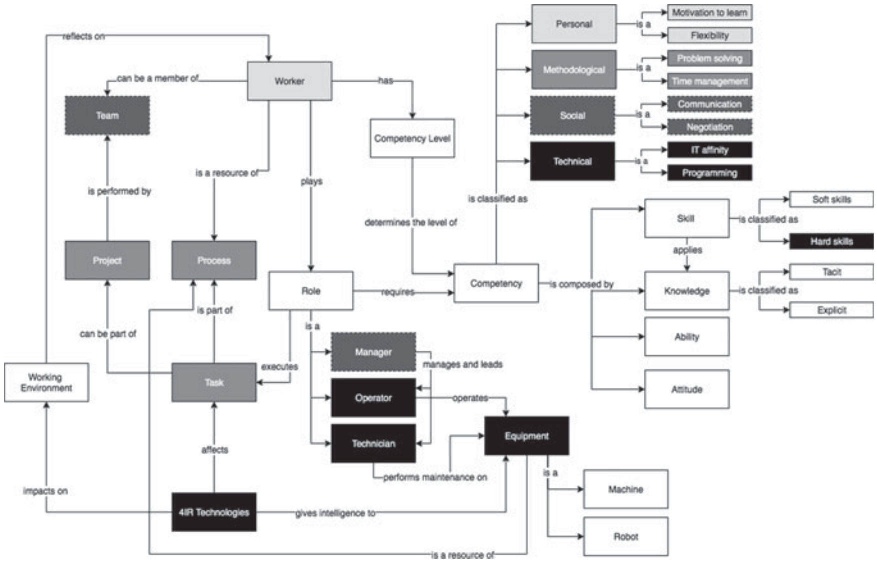


Fig. 3 Initial schema of the 4IR competence management ontology

3.4 Initial Schema of the 4IR Competence Management Ontology

An initial schema of the 4IR competence management ontology is developed by incorporating the identified key concepts mentioned in the sections above (see Fig. 3). From an ontological perspective [65], the proposed schema is a conceptualization. It represents the key concepts of the 4IR competence management and the relationships among them.

As illustrated, the 4IR technologies impact the working environment whose consequences reflect on the worker. This dynamic environment demands personal competences from the worker. The worker has a competency level that allows him/her plays a role to execute him/her process or project tasks. To execute the tasks effectively, the worker needs methodological competences. The projects are performed by a team, which leads to the need for social competences. Furthermore, to be capable of dealing with smart equipment, technical competences are required.

4 Conclusions and Future Recommendations

The new and dynamic work environment impacted by a strong digital and technological transformation implies to the industry professionals, such as operators, and managers, a need for continuous learning process throughout their professional life, the called "lifelong learning". This learning process must be supported and promoted directly on the work environment; the papers name this learning process as "on the job training". The learning cycles became shorter and more specific to promote the acquisition of new skills and competences required, transforming all the industry workers to "industry knowledge workers".

Therefore, the biggest challenge regarding competences development in the fourth industrial revolution is to keep the workers learning. The ontology created provides a knowledge representation that connects the key concepts of Workforce competences in Industry 4.0 and their relations in both theoretical and practical aspects.

Although studies mention the workplace impact of 4IR technologies adoption by the Industries, little is known empirically about how these adoptions are affecting the role of the workers. Future researches can address this situation by observing how the adoption of the 4IR technologies is reflecting on the workers' role.

Also, since there is evidence in the literature regarding the need for lifelong learning and on the job training, future researches could investigate how these 4IR technologies adopted to increase productivity could also be used to improve the qualification of the workers at the workplace.

References

1. Liao, Y., Deschamps, F., Loures, E. de F.R., Ramos, L.F.P.: Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. Int. J. Prod. Res. 55, 3609–3629 (2017). https://doi.org/10.1080/00207543.2017.1308576.
2. Liao, Y., Loures, E.R., Deschamps, F., Brezinski, G., Venâncio, A.: The impact of the fourth industrial revolution: a cross-country/region comparison. Production. 28, (2018). https://doi.org/10.1590/0103-6513.20180061.
3. Pradhan, A., Agwa-Ejon, J.: Opportunities and challenges of embracing smart factory in South Africa. In: PICMET 2018 - Portland International Conference on Management of Engineering and Technology: Managing Technological Entrepreneurship: The Engine for Economic Growth, Proceedings (2018). https://doi.org/10.23919/PICMET.2018.8481968.
4. Schneider, P.: Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field. Rev. Manag. Sci. 12, 803–848 (2018). https://doi.org/10.1007/s11846-018-0283-2.
5. Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J., Heikkilä, P., Kuula, T., Liinasuo, M., Mach, S., Mehta, R., Petäjä, E., Walter, T.: Empowering and engaging industrial workers with Operator 4.0 solutions. Comput. Ind. Eng. (2019). https://doi.org/10.1016/j.cie.2019.01.052.
6. Sousa, M.J., Rocha, Á.: Digital learning: Developing skills for digital transformation of organizations. Futur. Gener. Comput. Syst. 91, 327–334 (2019). https://doi.org/10.1016/j.future.2018.08.048.
7. Engelmann, A., Schwabe, G.: Enabling Workers to Enter Industry 4. 0 : A Layered Mobile Learning Architecture. In: Proceedings of the 51st Hawaii International Conference on System Sciences. pp. 23–32 (2018).
8. Longo, F., Nicoletti, L., Padovano, A.: Smart operators in industry 4.0: A human-centered approach to enhance operators' capabilities and competencies within the new smart factory context. Comput. Ind. Eng. 113, 144–159 (2017). https://doi.org/10.1016/j.cie.2017.09.016.

9. Liboni, L.B., Cezarino, L.O., Jabbour, C.J.C., Oliveira, B.G., Stefanelli, N.O.: Smart industry and the pathways to HRM 4.0: implications for SCM. Supply Chain Manag. An Int. J. 24, 124–146 (2019). https://doi.org/10.1108/SCM-03-2018-0150.
10. Nelles, J., Kuz, S., Mertens, A., Schlick, C.M.: Human-centered design of assistance systems for production planning and control: The role of the human in Industry 4.0. In: 2016 IEEE International Conference on Industrial Technology (ICIT). pp. 2099–2104. IEEE (2016). https://doi.org/10.1109/ICIT.2016.7475093.
11. Luiz Da Silva, V., Kovaleski, J., Pagani, R.N., Corsi, A., Kovaleski, J.L., Augusto, M., Gomes, S.: Human factor in smart industry: a literature review. Futur. Stud. Res. J. 12, 31–53 (2020). https://doi.org/10.24023/FutureJournal/2175-5825/2020.v12i1.473.
12. Pejic-Bach, M., Bertoncel, T., Meško, M., Krstić, Ž.: Text mining of industry 4.0 job advertisements. Int. J. Inf. Manage. 50, 416–431 (2020). https://doi.org/10.1016/j.ijinfomgt.2019.07.014.
13. Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Altman, D., Antes, G., Atkins, D., Barbour, V., Barrowman, N., Berlin, J.A., Clark, J., Clarke, M., Cook, D., D'Amico, R., Deeks, J.J., Devereaux, P.J., Dickersin, K., Egger, M., Ernst, E., Gøtzsche, P.C., Grimshaw, J., Guyatt, G., Higgins, J., Ioannidis, J.P.A., Kleijnen, J., Lang, T., Magrini, N., McNamee, D., Moja, L., Mulrow, C., Napoli, M., Oxman, A., Pham, B., Rennie, D., Sampson, M., Schulz, K.F., Shekelle, P.G., Tovey, D., Tugwell, P.: Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement (Chinese edition), (2009). https://doi.org/10.3736/jcim20090918.
14. Webster, J., Watson, R.T.: Analyzing the Past to Prepare for the Future: Writing a Literature Review. MIS Q. 26, xiii–xxiii (2002).
15. Adams, R.J., Smart, P., Huff, A.S.: Shades of Grey: Guidelines for Working with the Grey Literature in Systematic Reviews for Management and Organizational Studies. Int. J. Manag. Rev. 19, 432–454 (2017). https://doi.org/10.1111/ijmr.12102.
16. Saldaña, J.: The Coding Manual for Qualitative Researchers. SAGE Publications Ltd, London (2016).
17. Ra, S., Shrestha, U., Khatiwada, S., Yoon, S.W., Kwon, K.: The rise of technology and impact on skills. Int. J. Train. Res. 17, 26–40 (2019). https://doi.org/10.1080/14480220.2019.1629727.
18. García de Soto, B., Agustí-Juan, I., Joss, S., Hunhevicz, J.: Implications of Construction 4.0 to the workforce and organizational structures. Int. J. Constr. Manag. 1–13 (2019). https://doi.org/10.1080/15623599.2019.1616414.
19. Low, S.P., Gao, S., Ng, E.W.L.: Future-ready project and facility management graduates in Singapore for industry 4.0. Eng. Constr. Archit. Manag. ahead-of-p, (2019). https://doi.org/10.1108/ECAM-08-2018-0322.
20. Wang, B., Ha-Brookshire, J.E.: Exploration of Digital Competency Requirements within the Fashion Supply Chain with an Anticipation of Industry 4.0. Int. J. Fash. Des. Technol. Educ. 11, 333–342 (2018). https://doi.org/10.1080/17543266.2018.1448459.
21. Martins, J.T.: Relational capabilities to leverage new knowledge. Learn. Organ. 23, 398–414 (2016). https://doi.org/10.1108/TLO-03-2016-0022.
22. Cicek, K., Akyuz, E., Celik, M.: Future Skills Requirements Analysis in Maritime Industry. Procedia Comput. Sci. 158, 270–274 (2019). https://doi.org/10.1016/j.procs.2019.09.051.
23. Lööw, J., Abrahamsson, L., Johansson, J.: Mining 4.0—the Impact of New Technology from a Work Place Perspective. Mining, Metall. Explor. 36, 701–707 (2019). https://doi.org/10.1007/s42461-019-00104-9.
24. Saggiomo, M., Loehrer, M., Kerpen, D., Lemm, J., Gloy, Y.-S.: Human-and Task-Centered Assistance Systems in Production Processes of the Textile Industry: Determination of Operator-Critical Weaving Machine Components for AR-Prototype Development. In: 2016 49th Hawaii International Conference on System Sciences (HICSS). pp. 560–568. IEEE (2016). https://doi.org/10.1109/HICSS.2016.76.
25. Aulbur, W., CJ, A., Bigghe, R.: Skill Development for Industry 4.0, (2016).
26. Chenoy, D., Ghosh, S.M., Shukla, S.K.: Skill development for accelerating the manufacturing sector: the role of 'new-age' skills for 'Make in India.' Int. J. Train. Res. 17, 112–130 (2019). https://doi.org/10.1080/14480220.2019.1639294.

27. Schwab, K., Samans, R.: Global Challenge Insight Report : The Future of Jobs. (2016).
28. Flynn, J., Dance, S., Schaefer, D.: Industry 4.0 and its potential impact on employment demographics in the UK. In: Advances in Transdisciplinary Engineering. pp. 239–244 (2017). https://doi.org/10.3233/978-1-61499-792-4-239.
29. Foerster-Metz, U.S., Marquardt, K., Golowko, N., Kompalla, A., Hell, C.: Digital Transformation and its Implications on Organizational Behavior. J. EU Res. Bus. 1–14 (2018). https://doi.org/10.5171/2018.340873.
30. Heynitz, H., Bremicker, M., Amadori, D.M., Reshke, K.: The Factory of the Future: Industry 4.0- The challenges of tomorrow, (2016).
31. Microsoft: 2019 Manufacturing Trends Report. (2018).
32. Frey, C.B., Osborne, M.A.: The future of employment: How susceptible are jobs to computerisation? Technol. Forecast. Soc. Change. 114, 254–280 (2017). https://doi.org/10.1016/j.techfore.2016.08.019.
33. Hecklau, F., Orth, R., Kidschun, F., Kohl, H.: Human Resources Management: Meta-study - Analysis of Future Competences in Industry 4.0. In: Proceedings of the 13th European Conference on Management, Leadership and Governance. pp. 163–175 (2017).
34. Romero, D., Stahre, J., Wuest, T., Noran, O., Bernus, P., Fast-Berglund, Å., Gorecky, D.: Towards an Operator 4.0 Typology: A Human-Centric Perspective on the Fourth Industrial Revolution Technologies Digital learning platform for the smart digital factory, E-DIG View project TOWARDS AN OPERATOR 4.0 TYPOLOGY: A HUMAN-CENTRIC PERSPECTIVE ON THE. 29–31 (2016).
35. World Economic Forum: Insight Report: Readiness for the Future of Production Report 2018. (2018).
36. Gehrke, L., Kühn, A.T., Rule, D., Moore, P., Bellmann, C., Siemes, S., Dawood, D., Singh, L., Kutik, J., Standley, M.: A Discussion of Qualifications and Skills in the Factory of the Future: A German and American Perspective, (2015).
37. Lorenz, M., Rüßmann, M., Strack, R., Lueth, K.L., Bolle, M.: Man and Machine in Industry 4.0. (2015).
38. Richert, A., Shehadeh, M., Plumanns, L., Gros, K., Schuster, K., Jeschke, S.: Educating engineers for industry 4.0: Virtual worlds and human-robot-teams. In: Proc. of IEEE Global Engineering Education Conference (EDUCON). pp. 142–149 (2016). https://doi.org/10.1109/EDUCON.2016.7474545.
39. Dombrowski, U., Wagner, T.: Mental Strain as Field of Action in the 4th Industrial Revolution. In: Procedia CIRP. pp. 100–105. Elsevier B.V. (2014). https://doi.org/10.1016/j.procir.2014.01.077.
40. Kamaruzaman, F.M., Hamid, R., Mutalib, A.A., Rasul, M.S.: Conceptual framework for the development of 4IR skills for engineering graduates. Glob. J. Eng. Educ. 21, 54–61 (2019).
41. Lieu Tran, T.B., Törngren, M., Nguyen, H.D., Paulen, R., Gleason, N.W., Duong, T.H.: Trends in preparing cyber-physical systems engineers. Cyber-Physical Syst. 5, 65–91 (2019). https://doi.org/10.1080/23335777.2019.1600034.
42. Romero, D., Bernus, P., Noran, O., Stahre, J., Berglund, Å.F.: The operator 4.0: Human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems. In: IFIP International Conference on Advances in Production Management Systems (APMS). pp. 677–686 (2016). https://doi.org/10.1007/978-3-319-51133-7_80.
43. Erol, S., Jäger, A., Hold, P., Ott, K., Sihn, W.: Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production. In: Procedia CIRP (2016). https://doi.org/10.1016/j.procir.2016.03.162.
44. Quint, F., Sebastian, K., Gorecky, D.: A Mixed-reality Learning Environment. In: Procedia Computer Science. pp. 43–48. Elsevier (2015). https://doi.org/10.1016/j.procs.2015.12.199.
45. Manyika, J., Chui, M., Miremadi, M., Bughin, J., George, K., Willmott, P., Dewhurst, M.: A future that works: Automation, employment, and productivity. (2017).
46. Foerster-Pastor Foerster-Metz, U.S., Golowko, N.: Employability skills for the Romanian outsourcing industry. Proc. Int. Conf. Bus. Excell. 11, 1068–1080 (2017). https://doi.org/10.1515/picbe-2017-0110.

47. Nair, V.V., Kuhn, D., Hummel, V.: Development of an easy teaching and simulation solution for an autonomous mobile robot system. Procedia Manuf. 31, 270–276 (2019). https://doi.org/10.1016/j.promfg.2019.03.043.
48. Shamim, S., Cang, S., Yu, H., Li, Y.: Management approaches for Industry 4.0: A human resource management perspective. In: 2016 IEEE Congress on Evolutionary Computation, CEC 2016. pp. 5309–5316 (2016). https://doi.org/10.1109/CEC.2016.7748365.
49. Stern, H., Becker, T.: Development of a Model for the Integration of Human Factors in Cyber-physical Production Systems. Procedia Manuf. (2017). https://doi.org/10.1016/j.promfg.2017.04.030.
50. Arntz, M., Gregory, T., Zierahn, U.: The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis. (2016). https://doi.org/10.1787/5jlz9h56dvq7-en.
51. Bakhshi, H., Downing, J.M., Osborne, M.A., Schneider, P.: The Future of skills: Employment in 2030, (2017).
52. Prifti, L., Knigge, M., Kienegger, H., Krcmar, H.: A Competency Model for "Industrie 4.0" Employees. In: Proceedings der 13. Interantionalen Tagung Wirtschaftsinformatik. pp. 46–60 (2017).
53. Müller, S., Willicks, F., Stiehm, S., Richert, A., Jeschke, S.: Demography Management in Industry 4.0: First Results of a Qualitative Study. In: Proceedings of the 12th European Conference on Management, Leadership and Governance ECMLG (2016).
54. Ilie, L., Bondrea, I.: Changing Labour Market Needs and the Challenges for Academic Leadership. In: ECMLG 2016 - Proceedings of the 12th European Conference on Management, Leadership and Governance. pp. 80–88 (2016).
55. Hecklau, F., Galeitzke, M., Flachs, S., Kohl, H.: Holistic Approach for Human Resource Management in Industry 4.0. Procedia CIRP. 54, 1–6 (2016). https://doi.org/10.1016/j.procir.2016.05.102.
56. Becker, T., Stern, H.: Future Trends in Human Work area Design for Cyber-Physical Production Systems. In: Procedia CIRP. pp. 404–409. Elsevier B.V. (2016). https://doi.org/10.1016/j.procir.2016.11.070.
57. Régio, M.M. de A., Gaspar, M.R.C., do Carmo Farinha, L.M., De Passos Morgado, M.M.A.: Industry 4.0 and telecollaboration to promote cooperation networks: A pilot survey in the portuguese region of castelo branco. Int. J. Mechatronics Appl. Mech. 2017, 243–248 (2017). https://doi.org/10.17683/ijomam.issue1.40.
58. Jevnaker, B.H., Olaisen, J.: The dynamics of societal and corporate ideas: The knowledge work design of the future. In: Proceedings of the European Conference on Knowledge Management, ECKM. pp. 565–573. Academic Conferences Limited (2019). https://doi.org/10.34190/KM.19.055.
59. European Commission: Communication on new skills agenda, human capital, employability and competitiveness 2016. (2016).
60. World Economic Forum: The Future of Jobs Report. (2018).
61. Chryssolouris, G., Mavrikios, D., Mourtzis, D.: Manufacturing Systems: Skills & Competencies for the Future. In: Procedia CIRP. pp. 17–24. Elsevier B.V. (2013). https://doi.org/10.1016/j.procir.2013.05.004.
62. ManpowerGroup: The skills revolution – Digitization and Why Skills and Talent Matter, https://www.manpowergroup.com/workforce-insights/world-of-work/the-skills-revolution, (2016).
63. Costello, O., Kent, M.D., Kopacek, P.: Integrating Education into Maintenance Operations: an Irish case study. IFAC-PapersOnLine. 52, 415–420 (2019). https://doi.org/10.1016/j.ifacol.2019.12.573.
64. Lee, Y., Moon, G.G., Kwon, Y.-K.: Implementing liberal arts education in the era of the Fourth Industrial Revolution: lessons and implications for Korea's higher education policy. Int. Rev. Public Adm. 24, 282–294 (2019). https://doi.org/10.1080/12294659.2019.1700646.
65. Guarino, N., Oberle, D., Staab, S.: What Is an Ontology? In: Handbook on Ontologies. pp. 1–17. Springer Berlin Heidelberg, Berlin, Heidelberg (2009). https://doi.org/10.1007/978-3-540-92673-3_0.

Autonomous Inventory and Capacity Management in an Omnichannel Retailing Scenario: A Review

Eduardo C. L. Linhares and Ricardo L. Machado

Abstract Retail is experiencing omnichannel disruption providing a multiple-choice solution for the consumer. In this scenario, supply chain management becomes more challenging in meeting demand. The challenge of integrating the capacity and inventory sizing arises in order to meet the demands generated in the physical and virtual selling channels. This research aims to understand how the supply chain´s inventory and capacity management are addressed in the literature, applying machine learning algorithms to reach omnichannel goals. In this sense, a systematic literature review was carried out firstly in 340 articles published from January 2014 to June 2019. From this initial sample, 94 articles were selected in the final investigation. Despite increasing publications related to omnichannel retailing, it was found that there are few machine learning-based models for supply chain management. Also, a conceptual framework is suggested to integrate shoppers to interaction points and interaction points to collection points in the omnichannel structure.

Keywords Omnichannel · Supply chain management · Systematic literature review

1 Introduction

A blended market is growing as an omnichannel framework that coordinates the integration of fragmented supply chain (SC) processes, aiming to enhance consumer experience disruptively [1]. In this scenario, conventional and online retailers have been increasingly changing sales channels using technology and internet resources to operate stores in an integrated way [2, 3].

E. C. L. Linhares (✉) · R. L. Machado
Pontifical Catholic University of Goias, Av. Universitaria, 1440, S. Universitario, Goiânia, GO 74605-010, Brazil
e-mail: linhares.du@gmail.com

R. L. Machado
e-mail: rmachado@pucgoias.edu.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_41

Marchet [4] argue that omnichannel is still evolving due to company adaptation, considering their operations maturity, product characteristics, consumer needs, and convenience service [5]. Retailers should adopt new strategies in pricing, purchasing, and customer relationship to succeed in an omnichannel arrangement [6]. Also, it is relevant to know how to capture value, provide customer needs, reduce the sales cycle, and keep a profitable business. Customer decision processes, concerning pre-purchase, purchase, and post-purchase, can be understood through approaches such as social media, online communities, big data, and artificial intelligence (AI) [5, 7, 8]. AI adoption in SC management is a path for market differentiation perceived and valued by the consumers [7], becoming a meaningful way to improve market share [9].

Omnichannel is strongly related to e-commerce. Coles [10] suggested incorporating e-commerce data using a machine learning (ML) algorithm to achieve improved solutions for initial shipments and replenishments to physical stores and replenishment shipments.

Companies can increase customer' variety, retention, profitability, and satisfaction using touchpoints with personalized content and sales performance measurement [7]. Hübner et al. [11] state that improving delivery options constitutes a priority for retailers, including speed and service improvements to meet forward and backward demands. Also, the authors support that intelligent models have the capability of self-adapting to a dynamic environment, generating effective solutions for complex systems [11].

Integration of online with offline channels require a responsive supply chain to fulfill customer's expectations. In this context, the optimization of physical and information flows to improve SC performance indicators becomes a competitive factor [12]. Internet of Things (IoT) initiatives are being adopted to integrate information channels for consumers and purchase channels [13]. IoT devices scattered along the purchase path generate enormous data that needs to be processed in decision-relevant information, making big data analytics an essential tool in strategic planning [14].

Melacini and Tappia [15] highlight inventory carrying costs and home delivery as the most critical stages that impact operations costs and greenhouse gas emissions. Marchet et al. [16] showed that the integration of the distribution center (DC), store inventory, and transportation has a direct impact on the total costs of home delivery.

Brick-and-mortar store managers must decide what assortment of products must be on the space-limited shelves and which product to keep in distribution centers to match the offline and online customer demand. Hübner [11] proposes a mixed-integer non-linear problem (MINLP) algorithm for improving service level and profit margin simultaneously. Chen [17] formulated a mixed-integer program (MIP) to develop placement decisions and minimize costs.

Xu and Cao [18] developed an analytical model to identify optimal replenishment and allocation policy. A mixed-integer linear program (MILP) model of the capacity sharing among existing routes in an omnichannel retail setting is proposed by Paul et al. [1]. Du et al. [19] designed a model to characterize customer's behavior. In their study, they suggest a price policy and physical showroom organization to mitigate consumer disappointment. One of the main challenges of online sales is small size orders, large assortment, varying workloads, and tight delivery schedules [20]. The order fulfillment strategy in an omnichannel retail environment becomes a hard task. For this, a heuristic and linear program was used to propose an optimization model to satisfy both the consumer and retailer objectives [21].

Hübner et al. [22] discuss the implications of different design approaches for last-mile order fulfillment and the variety of customer preferences and retails features in different countries. Buldeo et al. [23] demonstrated the impacts caused by the growing omnichannel scenario on city logistics. Zhang et al. [24] propose an optimal SC distribution and demand network with minimal cost based on the particle swarm optimization algorithm.

A stochastic discrete event simulation is used to implement crowdsourced logistics providers as a solution for last-mile deliveries but has some flip sides as a social dimension, the uncertainty of demand availability, and transportation diversity [25]. Pereira et al. [26] proposed the use of ML to group customers and ensured better demand forecasting. Kharfan [27] developed a demand prediction model using store count, lifecycle, calendar, and product attributes as inputs in an ML algorithm to forecast seasonal demand. Nuzzolo et al. [28] considered agent-based simulation to solve freight distribution problems in cities.

Retail omnichannel is already a reality that companies must adapt [29]. Inventory and capacity management to address assortment planning and integrated replenishment policy in omnichannel retailing appears to have a gap in the literature, as suggested by Melacini et al. [30]. The development of integrated ML algorithms solutions is still in early stages [7] and is pointed as a possibility for future research in ML to cover the store inventory allocation [27]. To meet a competitive service level for customers, automation and AI will be mandatory [9]. Given the relevance of the subject, the main objective of this research is to develop a conceptual basis for an autonomous inventory and capacity management in an omnichannel retailing scenario.

The article is structured in five sections. The next section presents a review of the main concepts used in the research. Then, the research methodology is described. After, models and results from the selected articles are analyzed and discussed. Finally, conclusions are presented, research limitations are identified, and remaining gaps for future research are related.

2 Conceptual Background

The omnichannel purchase journey goes through initial product discovery, information research, purchase, payment, order fulfillment, and product return [31], granting customers with multiple possible channels of interaction before, during, and after purchase, providing a seamless shopping experience [7]. These channels can be websites, social media, mobile apps, kiosks, correspondence, catalogues, call centers, gaming consoles, televisions, and many others [32], each one supplying products information and order fulfillment on the consumer's preferred channel [33, 34].

As the retailing experience is vanishing the distinction between brick-and-mortar and online channels [6], the SC is undergoing a very rapid and disruptive transformation. Omnichannel proposes a unified service experience to customers, with low variability and high levels of satisfaction through information from interactions and fulfillment operations [35]. Therefore, rethinking strategies is critical for retailers to maintain competitiveness. Also, customer relationship management must adopt tools including e-commerce, social media, online interactions, mobile transactions, big data, artificial intelligence algorithms, and augmented reality, tending to be less human-to-human interactions, attending greater distances, and being time unrestrained [8].

Progressively, more customers' information is available, raised from smart devices connected to the internet [7]. Since the data volume is enormous, big data is not practical in spreadsheets. Thereby, ML algorithms are more accurate in identifying customers, customizing marketing, and performing a better return on investment [36]. ML reduces search time and increases sales. There are different types of advice: items previously viewed or browsed, items inspired by shopping's trends, items viewed by customers, similar items, feedback rating systems, and comments. The predictions consider multiple features such as price, product name, image definition, product variations, customers memberships, purchase history, sales rank, stock-outs, geographies, age, gender, marital status, and others [36].

Adoption of ML and Deep Learning (DL) algorithms are proven to be more accurate in demand predictions in comparison to traditional techniques such as forecasting, moving average, and linear regression [10, 37, 38]. Since traditional methods use historical sales data, they naturally fall behind compared to techniques using ML, where multiple data sources can be adopted, gaining significant insights from different variables, as suggested by Kharfan [27]. Also, according to Coles [10], ML allows keeping customer service levels, operating with lower inventory, and reduced costs.

3 Research Methodology

Among the several scientific methodological possibilities to solve the research questions, literature review (LR) was chosen, considering its suitedness for consolidating emerging trends and research gaps for omnichannel retailing, as suggested by Lagorio et al. [39]. A five-step-based method was structured based on proposals suggested by Denyer and Tranfield [40] and Mayring [41]. According to these authors, a LR must perform research question formulation, articles searching, articles selection and evaluation, analysis and synthesis of the results obtained in the investigation and reporting and using the results. Therefore, we propose an evaluation of the methodology and models reached by publications related to omnichannel retail problems.

SCOPUS and Web of Science (WoS) databases were adopted because they have the most relevant international peer-reviewed repository for this research. The

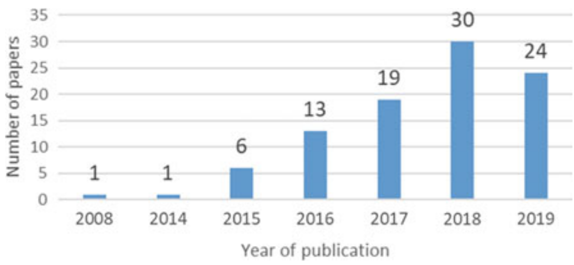


Fig. 1 Number of papers selected and classified by year of publication

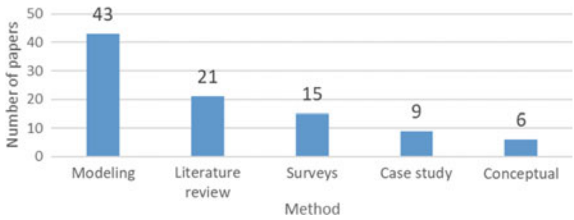


Fig. 2 Quantity of papers selected and classified by the primary methodology adopted

keywords used on the search engines were ‘omnichannel’ and ‘omni-channel’ considering the title, abstract, or keywords of the articles. The period restriction was defined from January 2014 to June 2019. A total of 546 articles was obtained in the first search. An amount of 206 references was excluded from the initial selection because they were duplicated in the databases studied, leaving 340 papers for selection and analysis. We considered only papers that adopted LR, optimization, simulation, artificial intelligence, or ML techniques for research solutions in an omnichannel retailing scenario in their title, abstract, author keywords, or index keywords. As a result of this decision, 94 articles were selected for the analysis. The articles were classified by year of publication and document type, as illustrated in Figs. 1 and 2, respectively.

Figure 1 shows that among the 94 papers selected, 57.4% (corresponding to 54 publications) were published from January 2018 to June 2019, showing a rising trend of research theme-related optimization, simulation, and AI applied to omnichannel.

The analysis of the primary research methodology present in the articles showed that authors developed researches in the proposition of models and LR, and less on strictly conceptual models, as presented in Fig. 2. This gap in the literature motivated this work to follow in this direction and present a conceptual basis.

It was found that ML for demand forecasting and mathematical optimization for network design solutions are the most often approached, respectively. Therefore, we observe an opportunity for research for allocation and assortment problem, and inventory management, as proposed by this research, addressing ML-based models.

4 Managerial Implications

Optimization models are representations of a decision-making process for cost reduction and service level improvement [42]. Freitag [43] discussed marketing coordination, oriented by a linear optimization model for customer segmentation, selection, and contact. Modak [44] developed a model using pricing optimizations, delivery, and stocking policy to achieve profit maximization.

Pricing in an omnichannel retailing multi competitive environment is a complex context for decision making. Inspiration for optimal price strategies is presented in literature with the game theory. Zhou [45] suggests a Stackelberg master–slave game model to describe the equilibrium in price changing. Zhang et al. [46] examine the return policy and the link with pricing and inventory strategies, revealing that omnichannel adoption is not advantageous in all circumstances. Harsha et al. [47] encourage two pricing policies for optimal shared inventory, with a significative estimated 13.7% increment in revenue at a U.S. retailer.

Gallino et al. [48] discussed the effects of ship-to-store functionality in a U.S. retailer, where physical stores prioritize carrying inventory with higher local demand. Niranjan et al. [49] propose a mixed-integer programming model for fulfillment decisions. In contrast, Xu and Cao [18] address the replenishment problem with an analytical model, supporting the managerial decision of the appropriate inventory for physical store direction and online orders reservation.

A behavior of pseudo-showroom, where a customer inspects a product in physical store before buying in the online store have an impact on the assortment decision for obtaining higher profit [50]. In some cases, the retailer induces the pseudo-showrooming by having a low-demand product on physical stores and sell the related high demand product exclusively online [51].

Gao and Su [52] stylize a model for inventory decision and to understand how three information mechanisms (physical showroom, virtual showrooms, and availability information) relates to product value and availability uncertainty, and how it translates to higher profits. Albeit et al. [53] identify the optimal offline assortment and the relation on the customer's shopping preferences in physical stores and total profits on offline and online channels.

As stated by Gupta et al. [54], the integration of online and offline operations, increase the need to consider more variables for SC optimization, and the direct zigzag search method for price and inventory optimization proved more effective than conventional non-dominated sorting genetic algorithm-II.

The need for responsive last-mile delivery is a factor of competitiveness and customer retention. With this scope, Faugère and Montreuil [55] present an optimization-based network design for locker banks with profit maximization. Paul et al. [1] propose an exact and heuristic model for the decision of which orders to transfer from a DC to a physical store and which to deliver directly to the customer with a minimum total cost. Chen et al. [56] propose a method using axiomatic design and regret/rejoice theory, with promising results validated in a case study.

Melacini and Tappia [15] use an ABC model to show that carrying costs and home delivery are the most relevant phases of distribution network design with an economic and environmental perspective, depending on the level of integration of DC, store inventory, and transportation operations [16, 49]. Abdulkader et al. [57] address vehicle routing problem in a fleet that deliveries online orders and replenishes physical stores.

Millstein and Campbell [58] bring forth managerial insights for profit maximization and service level uplift. In contrast, Yadav et al. [59] provide a flexible distribution solution to integrate online stores with local distribution network retailers. Martino et al. [12] propose a deviation analysis and key performance indicators (KPIs) impact evaluation. Ovezmyradov and Kurata [60] discuss the customer reaction when facing stockout and the responses of ordering policy and expected profits with an optimization model.

Hu and Xu [61] investigate optimal decisions of agricultural SCs based on differential game theory, such as traceability, technology adoption, marketing, growing efforts, and profit maintenance. Weidinger et al. [20] consider the adoption of mixed shelves with products positioned randomly across the warehouse and the impact on the picking route and warehouse productivity. Omnichannel retailing brings variability of workforce capacity and operability. Ilk, Brusco and Goes [62] put forward a genetic algorithm for staff-cost minimization framework in a warehouse operation.

ML algorithms adoption for demand forecasting and decision-making processes are growing on the omnichannel retailing due to the advancement in technology [27]. Despite Carbonneau et al. [37] did not find statistical evidence of improvement in ML techniques (neural networks, recurrent neural networks, and support vector machines) to forecast the bullwhip effect.

Wang [63] proposes the integration of a clustering technique and classification method to improve marketing strategies and provide more customized services on the telecommunications retail industry. Pereira et al. [26] use clustering for the identification of customer behavior and subsequently forecast demand of products in online and offline stores using an artificial neural networks algorithm. Dl is shown to be an alternative tool for forecast accuracy improvement compared to traditional methods [37, 64].

Real-time interaction with consumers can enhance the shopping experience and supporting buying decisions and improve demand prediction using ML algorithms [65]. In this sense, Qureshi [3] discuss the integration of cognitive radio technology with ML algorithms to enrich the customer experience, as well as the use of big data technology and data mining techniques for real-time business data processing [66].

Zhang et al. [67] propose a model using a multi-objective algorithm and the incorporation of Pareto concept, showing higher effectiveness than the multiple-objective genetic algorithm, and also introduces a particle swarm optimization-based model for cost minimization in a high-dimensional solution [24]. Lee [68] proposes a genetic algorithm to predict the order placement and adopt anticipatory shipping to the nearest distribution center before the actual purchase to reduce transportation costs and ensure a seamless customer shopping experience.

Multiple scenarios and stage evaluation prove to be an effective alternative to reduce risk in SC decisions [69]. Nuzzolo et al. [28] classify the literature on agent-based simulation models for urban freight distributions.

Moreover, Tao et al. [70] formulate a system dynamics simulation model to understand how omnichannel retailing impacts profits, customer behavior, and service level. Castillo et al. [25] compare the effectiveness of a crowdsourced logistics (CSL) to a dedicated courier fleet and show that in most scenarios, dedicated fleets achieve higher on-time delivery rates and lower total deliveries than CSL.

It is the perceived interest of researchers in the proposition of models that help the decision-making process present in omnichannel retailing. The optimization models appear more frequently in the literature. However, models that utilize the available information from big data through ML algorithms still have a gap of research.

5 Conclusions

Retailing in an omnichannel environment has multiple scenario variables such as market type, product profile, competition intensity, customer profile, and local consumer preferences. Thus, there are innumerable possibilities to find optimized solutions for different scenarios. Given that inventory management and the decision of how to fulfil online and offline orders are critical points for positioning as an omnichannel player, we propose a conceptual framework for autonomous inventory management with simultaneous evaluation of multiple features as location, weather, competitor price, consumer profile, product demand, and local trends [71].

ML algorithms for decision-making of the path of fulfillment, followed by an agent-based simulation to optimize the ML parameters and hyperparameters are recommended. The use of artificial intelligence associated with simulation modelling has few research publications [12, 26, 28].

Development of an omnichannel model in a real case is recommended for future research, to compare the performance of the automation solution with traditional SC management, to identify ML algorithms, and to propose new models integrating AI with big data to find insights of solutions in other SC problems.

Acknowledgements This study received financial supported by CAPES—Brazilian Federal Agency for Support and Evaluation of Postgraduate Education.

References

1. Paul, J., Agatz, N., Spliet, R., Koster, R.: Shared Capacity Routing Problem – An Omni-channel Retail Study. European Journal of Operational Research 273(2), 731–739 (2019). doi: https://doi.org/10.1016/j.ejor.2018.08.027.
2. Qureshi, F. F., Iqbal, R., Qasim, M., Doctor, F., Chang, V.: Integration of OMNI channels and machine learning with smart technologies. Journal of Ambient Intelligence and Humanized Computing (2017). doi: https://doi.org/10.1007/s12652-017-0646-6.
3. Zhegus, O. V.: Integrated approach to organization of sales in retail. Marketing and Management of Innovations (1), 62–72 (2017). doi: https://doi.org/10.21272/mmi.2017.1-06.
4. Marchet, G., Melacini, M., Perotti, S., Rasini, M., Tappia, E.: Business logistics models in omni-channel: a classification framework and empirical analysis. International Journal of Physical Distribution & Logistics Management 48(4), 439–464 (2018). doi: https://doi.org/10.1108/IJPDLM-09-2016-0273.
5. Kim, H., Lee, D., Ryu, M. H.: An optimal strategic business model for small businesses using online platforms. Sustainability 10(3), 1–11 (2018). doi: https://doi.org/10.3390/su10030579.
6. Brynjolfsson, E., Jeffrey, Y., Hu, M. S. R.: Competing in the age of Omnichannel Retailing. MIT Sloan Management Review (2013).
7. Matias B.: Improving Complex Sale Cycles and Performance by using Machine Learning and Predictive Analytics to Understand the Customer Journey. Massachusetts Institute of Technology, USA (2018).
8. Steinhoff, L., Arli, D., Weaven, S., Kozlenkova, I. V.: Online relationship marketing. Journal of the Academy of Marketing Science. Journal of the Academy of Marketing Science 47(3), 369–393 (2019). doi: https://doi.org/10.1007/s11747-018-0621-6.
9. Blanco, A.P.: Artificial Intelligence and the Consumer Packaged Goods Supply Chain. Massachusetts Institute of Technology, USA (2018).
10. -10] Coles, J. B.: Cross-Channel Predictive Analytics for Retail Distribution Decisions. Massachusetts Institute of Technology, USA (2017).
11. Hübner, A.: A decision support system for retail assortment planning. International Journal of Retail & Distribution Management 45(7/8), 808–825 (2017). doi: https://doi.org/10.1108/IJRDM-09-2016-0166.
12. Martino, G., Fera, M., Iannone, R., Miranda, S.: Business Models and ICT Technologies for the Fashion Supply Chain. Lecture Notes in Electrical Engineering. Springer International Publishing Lecture, (2019). doi: https://doi.org/10.1007/978-3-319-98038-6.
13. Caro, F., Sadr, R.: The Internet of Things (IoT) in retail: Bridging supply and demand. Business Horizons 62(1), 47–54 (2018). doi: https://doi.org/10.1016/j.bushor.2018.08.002.
14. Avilés-Sacoto, S. V., Avilés-González, J. F., Garcia-Reyes, H., Bermeo-Samaniego, M. C., Cañizares-Jaramillo, A. K., Izquierdo-Flores, S. N.: A glance of i4. 0 at supply chain and inventory management," International Journal of Industrial Engineering: Theory, Applications and Practice 26(4), (2015).
15. Melacini, M., Tappia, E.: A Critical Comparison of Alternative Distribution Configurations in Omni-Channel Retailing in Terms of Cost and Greenhouse Gas Emissions. Sustainability 10(2), 307 (2018). doi: https://doi.org/10.3390/su10020307.
16. Marchet, G., Melacini, M., Perotti, S., Rasini, M., Tappia, E.: Logistics in omni-channel retailing: Modelling and analysis of three distribution configurations. In: 2017 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), pp. 21–26. IEE, Bari, Italy (2017). doi: https://doi.org/10.1109/SOLI.2017.8120963.
17. Chen, A. I.-A.: Large-Scale Optimization in Online-Retail Inventory Management. Massachusetts Institute of Technology, USA (2017).
18. Xu, J., Cao, L.: Optimal in-store inventory policy for omnichannel retailers in franchising networks. International Journal of Retail and Distribution Management, IJRDM-09–2018–0199 (2019). doi: https://doi.org/10.1108/IJRDM-09-2018-0199.

19. Du, S., Wang, L., Hu, L.: Omnichannel management with consumer disappointment aversion. International Journal of Production Economics 215, 84–101 (2018). doi: https://doi.org/10.1016/j.ijpe.2018.05.002.
20. Weidinger, F., Boysen, N., Schneider, M.: Picker routing in the mixed-shelves warehouses of e-commerce retailers. European Journal of Operational Research 274(2), 501–515 (2019). doi: https://doi.org/10.1016/j.ejor.2018.10.021.
21. Markowicz, F.: Optimizing Order-Routing Decisions: Leveraging Omni- Channel Supply Chain Fulfillment. Massachusetts Institute of Technology, USA (2017).
22. Hübner, A., Kuhn, H., Wollenburg, J.: Last mile fulfilment and distribution in omni-channel grocery retailing. International Journal of Retail & Distribution Management 44(3), 228–247 (2016). doi: https://doi.org/10.1108/IJRDM-11-2014-0154.
23. Buldeo Rai, H., Verlinde, S., Macharis, C.: City logistics in an omnichannel environment. The case of Brussels. In: World Conference on Transport Research Society, pp. 310–317. Belgium (2019). doi: https://doi.org/10.1016/j.cstp.2019.02.002.
24. Zhang, S., Zhu, H., Li, X., Wang, Y.: Omni-channel product distribution network design by using the improved particle swarm optimization algorithm. Discrete Dynamics in Nature and Society, (2019). doi: https://doi.org/10.1155/2019/1520213.
25. Castillo, V. E., Bell, J. E., Rose, W. J., Rodrigues, A. M.: Crowdsourcing Last Mile Delivery: Strategic Implications and Future Research Directions. Journal of Business Logistics 39(1), 7–25 (2018). doi: https://doi.org/10.1111/jbl.12173.
26. Pereira, M. M., Oliveira, D. L., Santos, P. P. P., Frazzon, E. M.: Predictive and Adaptive Management Approach for Omnichannel Retailing Supply Chains. In: IFAC-PapersOnLine, pp. 1707–1713. Elsevier B.V., UK (2018). doi: https://doi.org/10.1016/j.ifacol.2018.08.210.
27. Kharfan, M. V. W. K. C.: Forecasting Seasonal Footwear Demand Using Machine Learning. Massachusetts Institute of Technology, USA (2018).
28. Nuzzolo, A., Persia, L., Polimeni, A.: Agent-Based Simulation of urban goods distribution: a literature review. Transportation Research Procedia 30, 33–42 (2018). doi: https://doi.org/10.1016/j.trpro.2018.09.005.
29. Hübner, A., Wollenburg, J., Holzapfel, A.: Retail logistics in the transition from multi-channel to omni-channel. International Journal of Physical Distribution & Logistics Management 46(6/7), 562–583 (2016). doi: https://doi.org/10.1108/IJPDLM-08-2015-0179.
30. Melacini, M., Perotti, S., Rasini, M., Tappia, E.: E-fulfilment and distribution in omni-channel retailing: a systematic literature review. International Journal of Physical Distribution & Logistics Management 48(4), 391–414 (2018). doi: https://doi.org/10.1108/IJPDLM-02-2017-0101.
31. Berman, B.: Flatlined: Combatting the death of retail stores. Business Horizons 62(1), 75–82 (2019). doi: https://doi.org/10.1016/j.bushor.2018.08.006.
32. Rigby, D. K.: The Future of Shopping. Harvard Business Review (2011).
33. -33] Bell, D., Gallino, S., Moreno, A.: Showrooms and Information Provision in Omni-channel Retail. Production and Operations Management 24(3), 360–362 (2015). doi: https://doi.org/10.1111/poms.12258_2.
34. Fairchild, A. M.: Extending the Network: Defining Product Delivery Partnering Preferences for Omni-channel Commerce. Procedia Technology 16, 447–451 (2014). doi: https://doi.org/10.1016/j.protcy.2014.10.111.
35. Kumar, V., Rajan, B., Gupta, S., Pozza, I. D.: Customer engagement in service. Journal of the Academy of Marketing Science. Journal of the Academy of Marketing Science 47(1), 138–160 (2019). doi: https://doi.org/10.1007/s11747-017-0565-2.
36. Thobani, S.: Improving E-Commerce Sales Using Machine Learning, Massachusetts Institute of Technology. Massachusetts Institute of Technology (2018).
37. Carbonneau, R., Laframboise, K., Vahidov, R.: Application of machine learning techniques for supply chain demand forecasting. European Journal of Operational Research 184(3), 1140–1154 (2018). doi: https://doi.org/10.1016/j.ejor.2006.12.004.

38. Kilimci, Z. H., Akyuz, A. O., Uysal, M., Akyokus, S., Uysal, M. O., Bulbul, B. A., Ekmis, M. A.: An Improved Demand Forecasting Model Using Deep Learning Approach and Proposed Decision Integration Strategy for Supply Chain. Complexity, pp. 1–15 (2019). doi: https://doi.org/10.1155/2019/9067367.
39. Lagorio, A., Pinto, R., Golini, R.: Research in urban logistics: a systematic literature review. International Journal of Physical Distribution & Logistics Management 46(10), 908–931 (2016). doi: https://doi.org/10.1108/IJPDLM-01-2016-0008.
40. Denyer, D., Tranfield, D.: Producing a Systematic Review. The sage handbook of Organizational research Methods. Sage Publications, London, pp. 671–689 (2009).
41. Mayring, P.: Qualitative Inhaltsanalyse. In: Handbuch Qualitative Forschung in der Psychologie, pp. 601–613. (2019). doi: https://doi.org/10.1007/978-3-531-92052-8_42.
42. Papalambros, P. Y., Wilde, D. J.: Principles of Optimal Design, Principles of Optimal Design. Cambridge: Cambridge University Press (2000). doi: https://doi.org/10.1017/CBO9780511626418.
43. Freitag, C.: Modeling marketing effort in an omni channel world. In: Proceedings of the 8th International Conference on Management of Digital EcoSystems – MEDES, pp. 117–121. New York, New York, USA: ACM Pres (2016). doi: https://doi.org/10.1145/3012071.3012095.
44. Modak, N. M.: Exploring Omni-channel supply chain under price and delivery time sensitive stochastic demand. Supply Chain Forum 18(4), 218–230 (2019). doi: https://doi.org/10.1080/16258312.2017.1380499.
45. Zhou, J. J.: Pricing Timing Strategy of Dual-channel Retailer and Pure Online Retailer. Journal of Tongji University (Natural Science) 46(5), 709–714 (2018). doi: https://doi.org/10.11908/j.issn.0253-374x.2018.05.020.
46. Zhang, J., Xu, Q., He, Y.: Omnichannel retail operations with consumer returns and order cancellation. Transportation Research Part E: Logistics and Transportation Review 118(July), 308–324 (2018). doi: https://doi.org/10.1016/j.tre.2018.08.006.
47. Harsha, P., Subramanian, S., Uichanco, J.: Dynamic Pricing of Omnichannel Inventories. Manufacturing & Service Operations Management 21(1), 47–65 (2019). doi: https://doi.org/10.1287/msom.2018.0737.
48. Gallino, S., Moreno, A., Stamatopoulos, I.: Channel Integration, Sales Dispersion, and Inventory Management. Ssrn November, (2014). doi: https://doi.org/10.2139/ssrn.2494516.
49. Niranjan, T., Parthiban, P., Sundaram, K., Jeyaganesan, P. N.: Designing a omnichannel closed loop green supply chain network adapting preferences of rational customers. Sādhanā 44(3), 60 (2019). doi: https://doi.org/10.1007/s12046-018-1038-0.
50. Xu, X., Jackson, J. E.: Examining customer channel selection intention in the omni-channel retail environment. International Journal of Production Economics 208, 434–445 (2019). doi: https://doi.org/10.1016/j.ijpe.2018.12.009.
51. Gu, J. Z., Tayi, G. K.: Consumer Pseudo-Showrooming and Omni-Channel Product Placement Strategies. SSRN Electronic Journal 518, (2016). doi: https://doi.org/10.2139/ssrn.2811232.
52. Gao, F., Su, X.: Online and Offline Information for Omnichannel Retailing. Manufacturing & Service Operations Management 19(1), 84–98 (2017). doi: https://doi.org/10.1287/msom.2016.0593
53. Dzyabura, D., Jagabathula, S.: Offline assortment optimization in the presence of an online channel. Management Science 64(6), 2767–2786 (2018). doi: https://doi.org/10.1287/mnsc.2016.2708
54. Gupta, V. K., Ting, Q. U., Tiwari, M. K.: Multi-period price optimization problem for omnichannel retailers accounting for customer heterogeneity. International Journal of Production Economics 212, 155–167 (2019). doi: https://doi.org/10.1016/j.ijpe.2019.02.016.
55. Faugère, L., Montreuil, B.: Smart locker bank design optimization for urban omnichannel logistics: Assessing monolithic vs. modular configurations. Computers & Industrial Engineering, 105544 (2018). doi: https://doi.org/10.1016/j.cie.2018.11.054.
56. Chen, W., Goh, M., Zou, Y.: Logistics provider selection for omni-channel environment with fuzzy axiomatic design and extended regret theory. Applied Soft Computing 71, 353–363 (2018). doi: https://doi.org/10.1016/j.asoc.2018.07.019.

57. Abdulkader, M. M. S., Gajpal, Y., ElMekkawy, T. Y.: Vehicle routing problem in omni-channel retailing distribution systems. International Journal of Production Economics 196, 43–55 (2018). doi: https://doi.org/10.1016/j.ijpe.2017.11.011.
58. Millstein, M. A., Campbell, J. F.: Total Hockey optimizes omnichannel facility locations. Interfaces 48(4), 340–356 (2018). doi: https://doi.org/10.1287/inte.2018.0942.
59. Yadav, V. S., Tripathi, S., Singh, A. R.: Bi-objective optimization for sustainable supply chain network design in omnichannel. Journal of Manufacturing Technology Management 30(6), 972–986 (2019). doi: https://doi.org/10.1108/JMTM-06-2017-0118.
60. Ovezmyradov, B., Kurata, H.: Effects of customer response to fashion product stockout on holding costs, order sizes, and profitability in omnichannel retailing. International Transactions in Operational Research 26(1), 200–222 (2019). doi: https://doi.org/10.1111/itor.12511.
61. Hu, Q., Xu, B.: Differential game analysis of optimal strategies and cooperation in omni-channel organic agricultural supply chain. Sustainability 11(3), (2019). doi: https://doi.org/10.3390/su11030848.
62. Ilk, N., Brusco, M., & Goes, P.: Workforce management in omnichannel service centers with heterogeneous channel response urgencies. Decision Support Systems 105, 13–23 (2018). doi: https://doi.org/10.1016/j.dss.2017.10.008.
63. Wang, S. T.: Integrating KPSO and C5.0 to analyze the omnichannel solutions for optimizing telecommunication retail. Decision Support Systems 109, 39–49 (2018). doi: https://doi.org/10.1016/j.dss.2017.12.009.
64. Wu, Q., Hsu, W.-L., Xc, T., Liu, Z., Ma, G., Jacobson, G., Zhao, S.: Speaking with Actions - Learning Customer Journey Behavior. In: IEEE 13th International Conference on Semantic Computing (ICSC), pp. 279–286. IEEE (2019). doi: https://doi.org/10.1109/ICOSC.2019.8665577.
65. Shi, F., Ghedira Guegan, C.: Adapted Decision Support Service Based on the Prediction of Offline Consumers' Real-Time Intention and Devices Interactions. In: International Computer Software and Applications Conference, pp. 266–271. IEEE (2018). doi: https://doi.org/10.1109/COMPSAC.2018.10241.
66. Pondel, M., Korczak, J.: A view on the methodology of analysis and exploration of marketing data. In: Proceedings of the 2017 Federated Conference on Computer Science and Information Systems, pp. 1135–1143. (2017). doi: https://doi.org/10.15439/2017F442.
67. Zhang, S., Lee, C. K. M., Wu, K., Choy, K. L.: Multi-objective optimization for sustainable supply chain network design considering multiple distribution channels. Expert Systems with Applications 65, 87–99 (2016). doi: https://doi.org/10.1016/j.eswa.2016.08.037.
68. Lee, C. K. H.: A GA-based optimisation model for big data analytics supporting anticipatory shipping in Retail 4.0. International Journal of Production Research 55(2), 593–605 (2017). doi: https://doi.org/10.1080/00207543.2016.1221162.
69. Okada, T., Namatame, A., Sato, H.: An Agent-Based Model of Smart Supply Chain Networks. In: Proceedings in Adaptation, Learning and Optimization, pp. 373–384. Springer International Publishing, (2016). doi: https://doi.org/10.1007/978-3-319-27000-5_30.
70. Tao, Z., Zhang, Z., Wang, X., Shi, Y.: Simulation Analysis of Omni-channel Strategy Based on System Dynamics: A Case Study of Company X. In: IOP Conference Series: Materials Science and Engineering (2018). doi: https://doi.org/10.1088/1757-899X/439/3/032039.
71. Saghiri, S., Wilding, R., Mena, C., Bourlakis, M.: Toward a three-dimensional framework for omni-channel. Journal of Business Research 77(March), 53–67 (2017). doi: https://doi.org/10.1016/j.jbusres.2017.03.025.

Measuring the Effectiveness of a Scrum Training Session Using Psychological States of Flow

Walter A. Nagai, Rui M. Lima, and Diana Mesquita

Abstract In a globalized world and constantly updating economic and technological activities, engineers should develop competences related to their professional practice. Initial training in higher education institutions is the key to achieve that purpose. Project Management is one of the many necessary areas for engineering students, and Scrum is one of the most used project management frameworks. Lego4Scrum is a simulation with small blocks to build collaboratively and deliver products that use teamwork efforts. This work is an exploratory study with preliminary results focused the level of training participants' involvement. This paper is described a training with engineering students using Lego4Scrum framework, the psychological states of Flow and the first two levels of New Model Kirkpatrick Model. The results were the training experience chart and the training evaluation using Kirkpatrick levels' evaluations. Some results found were the level of participants' involvement to build the products permits the maximum capacity of people motivation with high attention and fully invested in the task, and the participants felt confident in apply the knowledge obtained in the workplace.

Keywords Experience · Involvement · Lego4scrum

W. A. Nagai (✉)
Technological Sciences Institute, Federal University of Itajubá, Itabira, MG, Brazil
e-mail: walternagai@unifei.edu.br

R. M. Lima
Centro Algoritmi, School of Engineering, University of Minho, Guimarães, Portugal
e-mail: rml@dps.uminho.pt

D. Mesquita
School of Engineering, CIEC–Research Centre on Child Studies/Centro Algoritmi, University of Minho, Braga, Portugal
e-mail: diana@dps.uminho.pt

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_42

1 Introduction

Training is a well-known activity that is widely used to train and support transformation of people into skilled labor for different organizations. In a globalized world and constantly updating economic and technological activities, it is necessary that future engineers will be efficient and effective in their jobs. Moreover, according to Lima et al. [1], Higher Education institutions are responsible to ensure conditions, resources and learning opportunities for students to develop the competences related to their professional practice, because initial training is a key moment to achieve that purpose.

According to Lima et al. [2], Industrial Engineering and Management (IEM) is based on specialized knowledge and competences from math, physics, and social sciences integrated with the concepts and methods of the engineering projects. Same authors present a list of the following professional practice areas integrated in IEM: Production Management, Automation, Quality, Economics Engineering, Marketing, Industrial Optimization, Ergonomics and Human Factors, Supply Chain Management, Maintenance, Project Management, and Product Design. It is important for engineers to experience the practice of their profession since their entry into higher education through interactions with the labor market. According to Lima et al. [3], this interaction can be promoted through visits to industries, seminars from professionals, internships, direct contact between students and professionals or with projects developed by students for solving real industrial/business problems. Moreover, it is known that Active Learning strategies are the most effective for competences development. Despite this knowledge, a lot of work as still to be done regarding the process of assessment of competences and evaluation of the education processes.

According to PMI [4], Project Management is an area of knowledge that mobilizes management concepts, tools and methods for planning, executing and closing projects in an efficient way. Being project management one of the areas of practice of IEM, it is important to select the most up-to-date content and develop and apply the best-known strategies for learning and assessment in order to improve IEM education.

Scrum is currently one of the most used project management frameworks, which is focused on managing projects with frequent changes driven by the client needs and desires. This frequent feedback cycles are the core of the management technique and are called sprints. According to Schwaber and Sutherland [5], the Scrum framework consists of Scrum teams associated with roles, events, artifacts and rules. Each component within the framework serves a specific purpose and is essential to the use and success of Scrum. Scrum rules integrate roles, events and artifacts, managing the relationships and interactions between them. Briefly, according to Sliger [6] Scrum is an agile method of quickly, iterative and incremental delivery of products that uses frequent feedback and collaborative decision making.

In the work of von Wangenheim [7] are described some teaching strategies of Scrum in undergraduate courses. All strategies are simulations of real situations and that involve the engineering students in a manual interaction. One interesting strategy is Lego4Scrum where the participants of simulation build a city using Lego blocks from user stories designed collaboratively between them. According to Krivitsky [8], Lego4Scrum has some characteristics: (a) collaborative team product backlog; (b) iterative and increment of product; (c) collaborative teams; (d) measures to assess the team's agility; and (e) continuous improvement.

As referred above, being able to assess competences' development is still an on-going need. According to Salas et al. [9], training is a systematic process that there is a right way to design, deliver, and implement a training program that greatly influence its effectiveness. Thus, measuring the training effectiveness is an important issue, in order to analyze the impact of the training for the learners and eventually for the learners' professional activities. There are mainly 4 questions to be answered when designing assessment methodologies: what should be assessed, who is going to assess, how will the assessment be implemented, and when is it going to happen. In this specific work, an innovative approach is going to be explored, where the assessment is going to be focused on the level of involvement that trainees are experiencing.

A high level of participant involvement can be considered a subjective state where people are completely involved in something to the point of losing awareness of time, fatigue and everything else, except the activity itself. This state of involvement is described as *Flow*, which according to Csikszentmihalyi et al. [10] is the intense experiential involvement in the moment-to-moment activity, in which the attention is fully invested in the task in question, and the person is at maximum capacity.

The objective of this work is to develop an exploratory process for measuring a training effectiveness based on the psychological states of Flow. The training activity was inspired in the Lego4Scrum and applied to engineering students. Additionally, the training session was also evaluated using two levels of the Kirkpatrick New World Model in order to observe other training's characteristics. In next sections, we described the training activity, the process of evaluation, some results and discussions about the findings.

2 Materials and Methods

This section describes the training activity, training assessment and evaluation of participant experience.

2.1 Training Inspired by Lego4Scrum

The training denoted "Training Scrum Teams with Lego Blocks" was inspired by Lego4Scrum version 2.0 described in [11]. The training was applied with duration of three hours, split in three sessions S1, S2, and S3 with fifty minutes each one and ten minutes of interval between them. Figure 1 shows the schedule of training, the

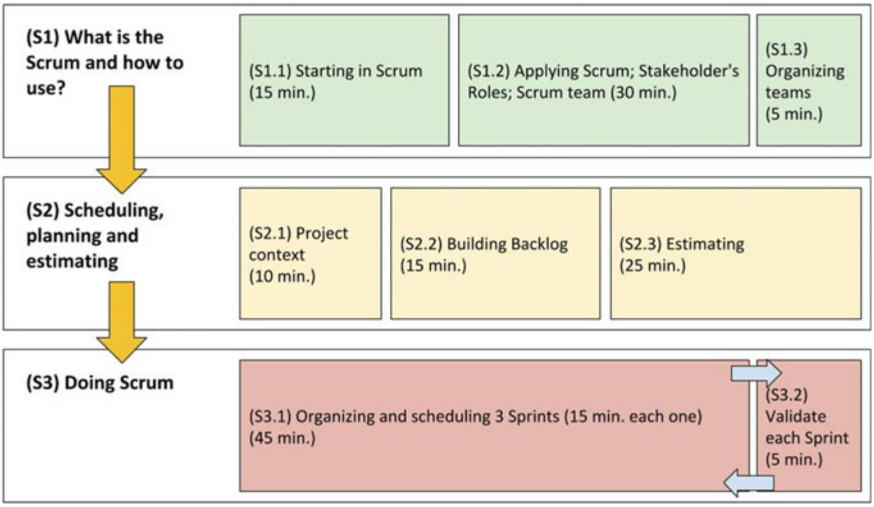


Fig. 1 Scrum training plan with three main sessions

activities' time for each session, and the description of the activities. The training objectives were that participants will identify and recognize user stories or use cases for the application of Scrum; analyze and identify tasks to perform Scrum Sprints; coordinate, organize and plan tasks in Scrum Sprints; evaluate, estimate and validate Scrum Sprints.

The training was realized with eighteen (18) students of engineering and average age of 23.67 years. Six (06) of these students are employed or developing supervised internships and two (02) use agile project management approaches in the workplace. The trainer acted as the Product Owner of product that was a city with many building types.

Session S1—"What is the Scrum and how to use?" had three activities to show the Scrum framework importance, adjust the participants knowledge levels about Scrum framework, and self-organize the teams. During session S2—"Scheduling, planning, and estimating", team members were presented with the problem context, had to collaboratively create the product backlog, and estimate the cost, or time, or importance of each product backlog's task. During the last session S3—"Doing Scrum", all teams decided which tasks to do during each Scrum Sprint. In the beginning of session S2, each team chooses a team member to represent the Scrum Master role. The members of each team decided to elect a member with Scrum Master's role to speak with the Product Owner. Thus, it was not necessary for everyone to ask the product owner and Scrum masters could discuss without interruption. In the last session S3—"Doing Scrum", the teams were collaboratively building the product in each Sprint with distinct tasks.

In the end of the training, there was a debriefing with the students. This debriefing follows a semi-structured questions available in Krivitsky [11].

2.2 Training Experience

To evaluate the experience was used the Experience Sampling Method (ESM) of Larson and Csikszentmihalyi [12], that is shortly, a method to ask to individuals what they do, feel and think daily. According to Cortina [13], when design an ESM questionnaire, the researcher can use three models: (i) based on signals; (b) restricted time intervals; (c) restricted event. During and ESM based on signals, the participants answer the questionnaires according to pre-selected timeline with or without random time choice, thus serving to capture a representative image throughout the participant's day. In an ESM based on restricted time interval, the participants are questioned at specific and predetermined points throughout the day. These points can be fixed in time or organized around specific daily occurrences. Finally, for the ESM based on restricted event, the participants measure themselves, when experiencing any important event or episode.

For this training, the ESM restricted event was chosen because the training was divided into sessions and activities. During the training, specifically after the activities S2.2, S2.3, and S3.1 (see Fig. 1), the participants were invited to respond two questions: (a) "How do you feel now?" and; (b) "How confident is your answer?". In the question (a), the participants choose one option: (i) anxiety (stressed, alert state); (ii) arousal (alert state and focused); (iii) worry (sad, stress); (iv) control (happy, confident); (v) apathy (sad, depressive, upset); (vi) boredom (depressive, little satisfied); (vii) relaxation (confident, satisfied) and; (viii) flow (happy, focused). In the question (b), the participants answer a value between one ("I'm not sure") to ten ("Absolutely sure").

The psychological states referred above are Flow states described in [10] and can be viewed in Fig. 2. According to Csikszentmihalyi et al. [10] for the state flow to happen, some preconditions are necessary: (a) the activity must have a clear set of objectives; (b) establishing a balance between the challenges and the perceived skills and; (c) clear and immediate feedback. Depending on the relationship between skills and challenges of each participant, the psychological state can be differentiated. In

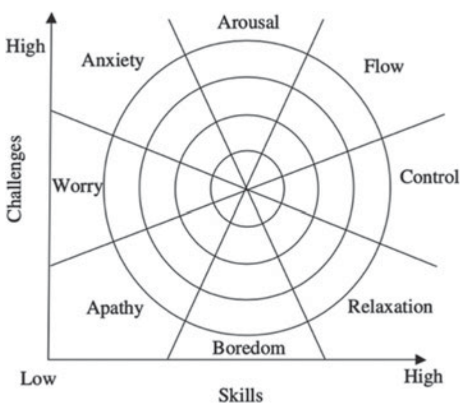


Fig. 2 Current model of the Flow psychological states between skills and challenges

Fig. 2, eight states are presented: apathy, worry, anxiety, boredom, arousal, relaxation, control and flow. The state flow is experienced when perceived challenges and skills are above the participant's average levels; when the levels are below, apathy is experienced.

2.3 Evaluate Training

According to Kirkpatrick and Kirkpatrick [14], a training could be assessed by four levels: (a) reaction; (b) learning; (c) behavior and (d) results. Briefly, the levels are described following: the reaction level considers relevant, involvement and training importance to participants. The learning level considers skills, attitudes, confidence and commitment of training's participants. The behavior level considers the application of the knowledge learned by participants in the organization or business. The last level considers the obtained results by participants in the organization or business after the training.

Evaluate training is very important for three reasons: (a) improve itself; (b) improve participants' learning to improve the organization's results; (c) show the training value to organization. Improving the training to become more effective, permits the participants better results and increase his/her confidence at work. Finally, when the main results of the organization are reached with performance improvements of training's participants, the training was effective.

In this study, training participants should answer some questions of two levels of [14]: (a) reaction and (b) learning. The questions about the reaction level were: (i) during the training session did something happen that interfered with your learning? If so, what?; (ii) describe any part/material of the training that would be most relevant to your work; (iii) describe any part/material of the training that was not relevant; (iv) describe/suggest/comment how the training could be improved and; (v) rating the characteristics following between a Likert scale (Strongly disagree; Partially disagree; Neutral; Partially agree; Strongly agree; No opinion): (1) the classroom environment helped me to learn; (2) my participation was encouraged by the facilitator/trainer/teacher; (3) the training topic interested me; (4) what I learned from this training will help in my work; (5) during the training, we discussed how to apply what we were learning; (6) I am confident of what is expected of me when I return to the work of my company/organization/department/institution; (7) I received prior information regarding the training and (8) I will recommend this training to my co-workers.

The questions about the learning level were: (a) What are the main concepts you learned during the training session?; (b) How important is it to apply what has been learned in your work?; (c) What support do you need to implement what has been learned?; (d) What barriers could limit the application of what has been learned?; (e) Could you comment on how confident you feel to apply in your work what has been learned?; (f) How do you plan to apply what has been learned in your work?; (g) What is the first thing you plan to apply from what you have learned today?

The rating follows a Likert scale considering the factors related to the question "My confidence in what I learned in training is not greater because…": (1) I do not have the necessary knowledge and skills; (2) I do not have a clear picture of what is expected of me; (3) I have other, higher priorities; (4) I do not have the necessary resources to apply what I learned; (5) I do not have the support to apply what I learned; (6) I don't think what I learned will work; (7) There is not an adequate system of accountability to ensure application of what I learned.

Another question related to learning was "According to the characteristics listed below, classify each one as contributing to learning in training" that should be scored on the same Likert scale as the previous level: (1) Knowledge was measured mainly with exercises training during the training session or with a questionnaire near the end; (2) I am very confident that I will apply what I have learned in my work; (3) I will receive the support necessary to successfully apply what I have learned and; (4) I am committed to applying what I have learned in my work.

3 Results of Training Experience and Evaluation

This section shows some results about the experience and training experience perceived by the participants during the training's sessions and activities.

3.1 Training Experience

Table 1 presents the participants' Flow states in each activity after realized it. The last column shows the total count of Flow states in all activities.

Considering the last column, the state flow was the psychological state more frequent during the activities. The second state more frequent was arousal, that means that students felt focused and alert state. The third state more frequent was relaxation,

Table 1 Flow states in the activities S2.2, S2.3, and S3.1

Flow state	S2.2	S2.3	S3.1 Sprint #1	S3.1 Sprint #2	S3.1 Sprint #3	Total count
Arousal	5	4	2	4	4	19
Flow	4	4	6	6	8	28
Control	2	2	9	1	0	14
Relaxation	1	4	1	6	6	18
Boredom	0	2	0	0	0	2
Apathy	0	0	0	0	0	0
Worry	1	0	0	0	0	1
Anxiety	5	2	0	1	0	8

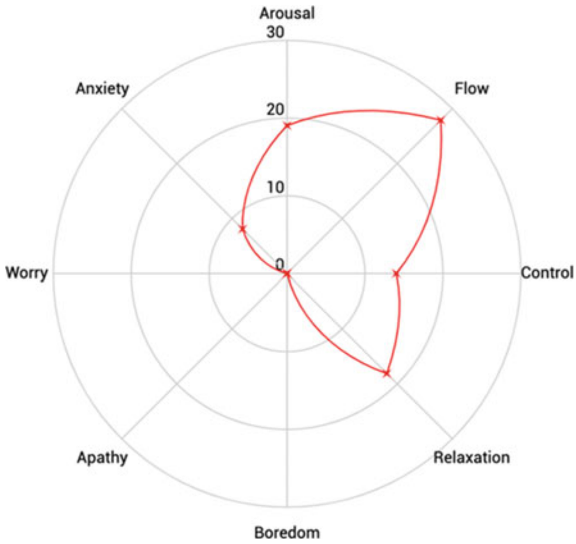


Fig. 3 Distribution of total Flow states in all training activities

that means the students felt confident and satisfied. On the other hand, the students never felt state of apathy during the sessions, but one student felt the state of worry in the S2.2 activity and two students felt state boredom in the S2.3 activity. Figure 3 illustrates the distribution of results presented above with the total psychological states during all activities analyzed. It can be seen that in the region described in the Fig. 3, students had skills consistent with the challenges that were presented during activities.

3.2 Training Evaluation

This section presents and discusses answers about the training levels reaction and learning collected with the students in the end of Session 3.

Table 2 present the answers to the question about what characteristics have higher contribution to training reaction level according to Kirkpatrick and Kirkpatrick [14]. The scale "Disagree" sums the scales Strongly disagree and Partially disagree, and "Agree" is the result of the sum of the scales Strongly agree and Partially agree.

Table 3 show the answers of all students related to the question "My confidence in what I learned in training is not greater because…".

Table 4 show the answers to this question "According to the characteristics listed below, classify each one as contributing to learning in training".

Table 2 Contribution characteristics of training reaction level

	Disagree	Neutral	Agree	No opinion
Classroom environment helped me to learn	1	1	15	0
My participation was encouraged by the facilitator/trainer/teacher	0	2	15	0
Training topic interested me	1	0	15	0
What I learned from this training will help in my work	0	0	17	0
During the training, we discussed how to apply what we were learning	1	2	14	0
I am confident of what is expected of me when I return to the work of my company/organization/department/institution	0	3	13	0
I received prior information regarding the training	3	4	10	0
I will recommend this training to my co-workers	0	0	16	0

Table 3 Answers about the question "My confidence in what I learned in training is not greater because… "

	Disagree	Neutral	Agree	No opinion
I do not have the knowledge and skills necessary	9	4	5	0
I do not have a clear perception of what is expected of me after training	13	4	1	0
I have other higher priorities	13	1	4	0
I do not have the necessary resources to apply what I learned in training	15	1	1	1
I do not have the necessary support to apply what I learned in training	12	4	1	1
What I learned will not work for me at work	15	2	0	1
I do not have a responsibility to implement what has been learned at work	13	1	3	1

Table 4 Answers to question "According to the characteristics listed below, classify each one as contributing to learning in training"

	Disagree	Neutral	Agree	No opinion
Knowledge was measured mainly with exercises training during the training session or with a questionnaire near the end	0	0	18	0
I am very confident that I will apply what I have learned in my work	0	1	17	0
I will receive the support necessary to successfully apply what I have learned	0	2	16	0
I am committed to applying what I have learned in my work	0	0	18	0

4 Discussions

At the end of the training, a debriefing was conducted with all participants. The use of Lego4Scrum offered a fun experience according to the students' opinion, offering an opportunity to communicate and adjust the pace of each group's activities. With the results obtained, some findings can be highlighted: a first finding about the training that an immersive experience and the participants remained stimulated or flow state (see Fig. 3) with the challenge presented according to the skills they have.

The second finding, there is a concordance between the experience and the students' responses to the Kirkpatrick model, regarding the characteristics that contributed to Kirkpatrick's reaction level in Table 2, it can be considered that the participants feel capable of applying what they have learned in their workplace. Analyzing the answers to the other questions for reaction level, such as "During the training session, did something happen that interfered with your learning? If so, what?", the participants realized that at the beginning, the training seemed disorganized, but that they felt more motivated during the training, as they were challenged to divide tasks and to fulfill Sprints' time, according to the practical application of Scrum. The answers to the question "Describe any part/training material that is most relevant to your work" were mostly directed to the organization, planning and estimates of the Sprints, in addition to organizing the Product Backlog and the division of tasks between the teams. Regarding the question "Describe any part/material of the training that is not relevant", the participants answered that no part was irrelevant. The last question of the reaction level was "Described/suggested/commented on how the training could be improved", the participants suggested improvements of the training room; reinforce Scrum concepts related to history, roles, organization of a Sprint and use of tools or materials available for training.

With the data presented at the learning level of Tables 3 and 4, there is a third finding, participants feel confident and able to use Scrum in the workplace. The answers to the question "What are the main concepts that you learned during the training session?" were directed to the scheduling and planning of Scrum; division of tasks between teams and; management of team members. For the question "How important is it to apply what has been learned in your work?", The answers were related to work improvement, time optimization, goals reach, project global vision, and teams motivated with the project subjects. The answers to the question "Comment on how confident you are in applying what has been learned in your work?" reinforces that participants feel confident in the learning obtained. For questions "How do you plan to apply what has been learned in your work?" and "What is the first thing you plan to apply to what you have learned today?", the answers were specifically to the workplace, but also to personal and academic life.

Considering all the findings, the students felt able to do well the Scrum framework in the workplace. Besides, they identified the missing abilities and improved them during the training. It means they became more effective to do the Scrum framework during the training sessions. The Lego4Scrum strategy permits the interaction and discussions that are very important to organize, schedule e estimate the sprints between teams, as that to undergraduate students, it is very important to practice this agile project management.

5 Conclusions

As referred before, the future IEM engineers should be more efficient and effective in their jobs, and the project management practice is important in their formation. Participate in a project management training session is important to engineers IEM formation in Higher Education. In this exploratory study, the participants were engineering students and they needed to be capacitated in the Scrum framework. To train in the Scrum framework, we used the Lego4Scrum to teach the main concepts and self-organized learning with Scrum team members.

In the context of undergraduate students, the goal is that they know to apply the learning after the training. With the findings founded, the students feel that capable and confident to able to use the Scrum in the workplace. Besides, the phycological states of Flow identified during the sessions with the participants permitted the involvement assessment of the training climate of them. These are the results of the first training of this exploratory study.

In the next steps of this study, we planned to use an ESM based on signals with a mobile app, develop a real-time dashboard to use during the training to see the Flow states, and apply to more engineering students.

Acknowledgements We would like to acknowledge the support of the Brazilian government, the staff of the Federal University of Itajubá—Campus Itabira, and the staff of the University of Minho. This work has been supported by FCT—Fundação para a Ciência e Tecnologia within the Project Scope UIDB/00319/2020.

References

1. Lima RM, Mesquita D, Amorim M, Jonker G, Flores MA (2012) An Analysis of Knowledge Areas in Industrial Engineering and Management Curriculum. International Journal of Industrial Engineering and Management (IJIEM) 3:75–82
2. Lima RM, Mesquita D, Rocha C, Rabelo M (2017) Defining the Industrial and Engineering Management Professional Profile: a longitudinal study based on job advertisements. Prod 27. https://doi.org/10.1590/0103-6513.229916
3. Lima RM, Dinis-Carvalho J, Sousa RM, Arezes P, Mesquita D (2017) Development of competences while solving real industrial interdisciplinary problems: a successful cooperation with industry. Prod 27. https://doi.org/10.1590/0103-6513.230016
4. Project Management Institute (2013) A guide to the project management body of knowledge (PMBOK guide), Fifth edition. Project Management Institute, Inc, Newtown Square, Pennsylvania
5. Schwaber K, Sutherland J (2017) The Scrum Guide

6. Sliger Mi (2011) Agile project management with Scrum. Newtown Square, North America, Dallas, TX
7. von Wangenheim CG, Savi R, Borgatto AF (2013) SCRUMIA—An educational game for teaching SCRUM in computing courses. Journal of Systems and Software 86:2675–2687. https://doi.org/10.1016/j.jss.2013.05.030
8. Krivitsky A (2019) Lego4Scrum 3.0: A complete guide to #lego4scrum-a great way to teach the Scrum framework and Agile thinking. LeanPub Publishing
9. Salas E, Tannenbaum SI, Kraiger K, Smith-Jentsch KA (2012) The Science of Training and Development in Organizations: What Matters in Practice. Psychol Sci Public Interest 13:74–101. https://doi.org/10.1177/1529100612436661
10. Csikszentmihalyi M, Abuhamdeh S, Nakamura J (2014) Flow. In: Flow and the Foundations of Positive Psychology. Springer Netherlands, Dordrecht, pp 227–238
11. Krivitsky A (2011) A Multi-Team, Full-Cycle, Product-Oriented Scrum Simulation with LEGO Bricks: The Small & Medium Business Edition
12. Larson R, Csikszentmihalyi M (2014) The Experience Sampling Method. In: Flow and the Foundations of Positive Psychology. Springer Netherlands, Dordrecht, pp 21–34
13. Cortina JM (2013) Modern Research Methods for the Study of Behavior in Organizations, 1st ed. Routledge
14. Kirkpatrick JD, Kirkpatrick WK (2016) Kirkpatricks' s four levels of training evaluation: results-behavior-learning-reaction. ATD Press, Alexandria, Va

Pedestrian Evacuation Plan on Fire Situations at a University

Lorena Mazia Enami and Márcia Marcondes Altimari Samed

Abstract The frequency of disasters has increased dramatically in recent years. This fact highlights the need for planning coordinated response actions to safeguard the greatest number of people in a vulnerable situation in a timely manner. In these cases, Humanitarian Logistics has established important concepts that contribute to decision making in situations of natural disasters or those caused by man. Fires are examples of a sudden-onset disaster, the main element of which is the planning of pedestrian evacuation. On the other hand, the literature has shown the effectiveness of applying mathematical models in the definition of disaster preparedness plans in Humanitarian Logistics. Based on this, the objective of this article is to define the evacuation coordination plan in case of fire in a university, using the mathematical model Set Covering Problem. Four scenarios were considered, based on the degree of risk of the buildings and the availability and characteristics of the gates for evacuation. As a result, there is a definition of which gates will cover the set of buildings for evacuation, in each scenario. Finally, the need to combine this study with evacuation training with the university community is evident.

Keywords Humanitarian logistics · Evacuation planning · Fire · Set covering problem

1 Introduction

Disasters may be natural geological, hydrological, climatological, meteorological and biological phenomena, or caused by men, such as complex conflicts, industrial accidents, environmental degradation, pollution, fires and traffic accidents [1]. In fire situations, it is necessary to carry out the assessment of the threat by decision-makers and to provide an evacuation plan [2].

L. M. Enami · M. M. A. Samed (✉)
State University of Maringá, Maringá, Brazil
e-mail: mmasamed@uem.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_43

In this scenario, an important problem is an evacuation plan, since most buildings have limitations capacity in cases of increased traffic at the time of large-scale emergency evacuation [3]. In addition, old buildings were built in other periods under more tolerant legislation and for this reason, they need studies about how to guarantee the safety of people [4]. Other adverse facts are panic situations and crowd behavior in situations that require evacuation. Thus, environments with large concentrations of people must be prepared and planned to ensure the safety of the occupants, improving the chances of survival in critical and emergency situations [5].

In such cases, it is essential to carry out evacuation planning [6] as a result of its positive influence on relief operations in response situations. Additionally, it is important to have a preparation stage to allow pedestrians to become aware of routes and destinations for evacuation from the site, effectively contributing to control and prevention of disaster [7].

The objective of this article is to define the coordination plan for the evacuation of pedestrians in the event of fire at a university, using the model of Set Covering Problem. In this way, we intend to answer the following research question: which gates will cover the set of buildings for evacuation?

The mathematical model for the Set Covering Problem considers the set of the location of the demand points (buildings), represented by a graph. A study, based on distances, helps to define the number and location of the gates needed to cover buildings, in case of fire evacuation.

For that, we consider four different scenarios: homogeneous risk for buildings; heterogeneous risk for buildings; heterogeneous risk for buildings and gates exclusive to pedestrian flows; all gates exclusive for pedestrian flow.

The next sections are organized as follows: Sect. 2 presents concepts related to the development of the work; Sect. 3 describes the university and definition of the mathematical model; Sect. 4 describes the application of the mathematical model for the Set Covering Problem, as well as the results; and, in Sect. 5, we present the final remarks.

2 Literature Review

The importance of the evacuation problem is related to the abandonment of the determined zone [3] and consists of the relocation of risk areas to safety areas [8], varying in scale, object of relocation and level of control by the authorities, which may be mandatory, recommended or voluntary [2].

To better manage disaster situations, decision-makers can benefit from evacuation plans for scenarios most likely to happen [9]. In addition, the evacuation plan is effective tool, being essential to know the dynamics of the crow, as well as, the main safety standards at the time of its elaboration [10].

In panic situations, people usually move in the same direction, using the same access used for entry as the exit, causing congestion and bottlenecks. Thus, places with large number of people are highly likely to experience panic attacks and evacuations must be completely planned [10].

Therefore, the relevance of evacuation planning must be emphasized due to its primary role in emergency situations. Planning must define the evacuation route or fixe destinations, even before disasters, which helps in emergency management [7].

It should also be considered that the availability of trained and prepared people to provide assistance and guidance to the public in the rapid identification of the evacuation plan, leading to significant benefits, such as a better distribution of the public in various exits, supported by differentiated paths, with less congestion and reduced evacuation times [10, 11].

In this context, disaster prevention and assistance has recently become a pillar for social development and the evacuation plan is a key tool to successfully prevent and provide assistance. Mainly due to the fact that by minimizing the evacuation time, each individual can choose the nearest exit yielding crowding. In this way, planning is necessary for each individual to choose the global optimum over the optimum location [11].

Some authors [11, 12], adapt the set coverage problem for confined spaces evacuation, while [13] applies the method to position sensors that should assist in attacks response. This brief review demonstrates a contemporary topic and the authors are unaware of the work of applying the pure method for evacuations plan to scenarios like this, demonstrating a simple use and application of it.

3 Case Study

The university where this study was carried out, occupies the current facility since 1973 and has 1,240,323.00 m^2. It is estimated that approximately 20 thousand people attend the university's campus daily, considering students, teachers and university agents.

Based on its extension, the university campus is divided into four (4) areas: A, B, C, and D. Figure 1 represents areas A and B.

These areas are characterized by constructions built in the 1970s, being some of them, built out of wood. In these areas there are facilities such as classrooms and laboratories, museum, music house, theater, workshop, ambulatory, pharmacy, publisher, sanitary buildings, sports courts, gym, bank agency, leisure areas, among others.

Thus, due to its structural vulnerability, old electrical installations and the large flow of people, areas A and B represent the portion of the university that is most prone to fires [14].

According to the Fig. 1, the buildings are represented by numbers (1, 2, 3,…) or preceded by the letter Q (QE5, Q03,…), while P1, P2, P3, P4, P5, P6, P7 and P8, represent the gates. Gates P3 and P4 are exclusive for vehicles entering and exiting and the others are exclusive for pedestrians entering and exiting.

This case study consists of applying the model of the Set Covering Problem to areas A and B of the university, considering its set of buildings (except the sports

Fig. 1 Areas A and B of the University campus

court) and the existing gates, in search of the answer to the following question: in situation of fire, which gates will cover the sets of buildings?

3.1 Set Covering Problem (SCP) Model

The SCP consists of a location model with aspects of maximum distance. In this case, we consider the maximum distance that separates the occupants of the buildings from the evacuation gates, as a crucial parameter. An upper limit of time or distance is defined to determine a physical arrangement that meets all regions at minimum cost [15]. Since the costs are the same, the objective of the problem becomes the minimization and the location of the gates necessary to attend all the occupants of the buildings, respecting the imposed restriction, based on [16].

We assume that buildings and gates are represented by a finite number of points, that the minimum distance "buildings-gates" is known, and that the sets of buildings and gates do not correspond to the same data set. Consequently, the problem is structured as binary, linear and integer programming.

If *s* is the established distance limit and d_{ij} is the distance from node *j* to node *i*, the set N_i can be defined as $N_i = \{j\ /d_{ij} \leq \mathrm{s}\}$. If there are *n* nodes that represent the buildings, there will be *n* sets of N_i, and each set will have at least one member, with d_{ji} being considered 0. Thus, at least one node *i*, will have the required distance to find node *j* [16]. The model is described according to the methodology presented by authors such as [8, 15, 17] and aims to minimize Z:

$$z = \sum_{j=1}^{n} x_j \tag{1}$$

Each building must be covered by at least one gate at a maximum distance, *s*, such as a restriction:

$$\sum_{jeNi} x_j \geq 1 \tag{2}$$

For all nodes *i*, where N_i is the set of eligible nodes to cover *i,* we have:

$$N_i = \left\{j | d_{ji} \leq s\right\} \tag{3}$$

$$x_j = (0, 1) \tag{4}$$

4 Development of SCP Model

After structuring the model, data collection started. The centroides of each building were represented by nodes *i*, and the centroides of the gates by nodes *j*. The *dji* variables, which are Euclideans distances, were measured from the centroid of the buildings to the centroid of the gates, using the AUTOCAD software. The parameter *s* was established by calculating the minimum-maximum distance between each building and the gates.

Then, the binary matrix was described according to the established set of restrictions. We assign value 1 if *xj* meets the building and, otherwise, we assign 0 (the binary matrix will be omitted in this article due to its large extension). The problem is solved by programming in Solver-Excel.

The evacuation scenarios consist of four (4) situations, considering: the studied area with homogeneous risk for buildings; the area studied with heterogeneous risk for buildings; only pedestrian flow gates; and the use of all pedestrian flow gates available.

Table 1 Allocation of buildings to the gates for homogeneous risks

Gates	Set of buildings									
P1	31	10	13	19	25	24	126	130	18	23	28
	38	104	17	40	41	22	27	30	16	26	29
P5	4	5	2	035	036	119	118	1	111	102	110
	109	11	12	15	117	123	113	120	108	124	Q02
	Q03	101	115	Q05	106						
P8	Q06	Q01	QE3	33	32	Q04	6	7	39	8	9
	42	QE5	3	103							

4.1 Homogeneous Risk for Buildings

After data collection in the field to define the distance matrix, we applied the maximum distance restriction to be covered as being 195.31 m^2, we obtained the binary matrix. With the execution of the SCP algorithm, we obtained, as a result, only three (3) gates giving coverage of the set of buildings for evacuation in case of fire, as showing in Table 1.

In this case, we noticed an imbalance in the number of buildings attributed to each gate, since P5 is responsible for approximately twice as many buildings in relation to P8. In addition, this scenario treats the risks as being homogeneous in all buildings, which disqualifies the result obtained.

4.2 Heterogeneous Risk for Buildings

In addition to the first scenario, we performed the insertion of weights, varying on a scale from 1 to 5, according to the functionalities of the buildings and the severity of the occurrence of a fire. Severity segmentation is performed as follows:

Risk 1. Buildings with sporadic flow of people;
Risk 2. Buildings exclusive for toilets;
Risk 3. Buildings for administrative services;
Risk 4. Buildings with big crowds, such as classrooms and fitness center;
Risk 5. Buildings with laboratory activities, such as chemistry laboratories.

For mixed buildings, we assign the highest corresponding value. Chemical laboratories are at risk 5 due to the flammable nature of the components, as well as places with service to the external community, due to the large flow of people in the place. With SCP model, we obtained a new configuration of buildings assigned to four (4) gates for evacuation in case of fire, considering a maximum distance of 145.78 m^2. The results are show in Table 2.

Heterogeneous risks express the need for an additional gate to cover buildings in case of fire, when compared to the first scenario. We can consider that this result represents greater safety in the evacuation of pedestrians, since the fire risks were

Table 2 Allocations of buildings to the gates for heterogeneous risk

Gates	Set of buildings									
P1	31	13	19	25	24	126	130	18	23	28	38
	17	22	27	30	29						
P4	104	40	41	110	109	11	12	16	15	26	123
	113	120	108	101	115	Q05	106				
P6	4	5	2	035	036	119	118	1	111	102	117
	124	Q02	Q03								
P7	Q06	Q01	QE3	33	32	Q04	6	7	39	8	9
	10	42	QE5	3	103						

considered according to the functionality of each building and according to the flow of people. However, the P4 gate covers the entry and exit of vehicles and, if used to evacuate pedestrians, it can cause a panic situation or lead to mistaken crowd behavior if pedestrians and drivers are not fully aware of the evacuation plan predetermined. In this way, a new scenario is proposed.

4.3 Exclusive Pedestrian Gate

In this scenario, we consider scenario 2 (heterogeneous risks), but with the elimination of vehicle entry and exit gates, keeping only pedestrian gates. In consequence, gates P3 and P4 were removed and the model was executed again.

The result obtained shows the coverage of the set of buildings for evacuation in the event of fire being carried out by means of three (3) gates, in which the maximum distance became 178.01 m^2. Table 3 shows the results.

The second and third scenarios can be compared, as both consider heterogeneous risks. The use of pedestrian-only gates may seem safer as they avoid panic situations, along with, avoiding to induce the mistaken behavior of crowds. However, there was a

Table 3 Allocation of buildings to pedestrian-only gates

Gates	Set of buildings										
P1	31	13	19	25	24	126	130	18	23	28	38
	104	17	40	41	22	27	30	16	26	29	
P5	118	111	102	110	109	11	12	15	117	123	113
	120	108	124	Q02	Q03	101	115	Q05	106		
P7	Q06	Q01	QE3	33	32	Q04	6	7	39	8	9
	10	42	QE5	3	103	4	5	2	035	036	119
	1										

small increase in the maximum distance to be covered in the evacuation path between the building and the gate, due to the reduction from four (4) to three (3) gates. In this case, we have an indication of the relevance of communicating the evacuation plan to students, teachers and university staff, as well as training evacuation coordination in case of fires.

4.4 All Pedestrian Gates Available

If we consider an ideal scenario, we would have all pedestrian gates being used for the evacuation of pedestrians in case of fire in areas A and B of that university. Based on this consideration, we add the following constraint to the model:

$$\sum_{j=1}^{n} x_j = p \tag{5}$$

where, p is the total number of gates to be used. Thus, we executed the PSC model for the six (6) gates, considering a maximum distance of 178.01 m^2.

This scenario has the same maximum distance considered in the third scenario. However, it minimizes the effective distance from the buildings to the gates, since the number of gates changes from three (3) to six (6). The results obtained are shown in Table 4.

Certainly, this scenario is the safest to be adopted in the university's fire evacuation coordination plan, as the largest number of gates maintains the coverage of all buildings and still ensures a lower number of pedestrians per gate.

Table 4 Allocations of buildings using all pedestrian gates

Gates	Set of buildings									
P1	31	13	19	25	24	126	130	18	23	28	38
	104	17	22	27	30						
P2	40	41	16	15	26	29	106				
P5	102	110	109	11	12	123	113	120	108	124	Q02
	Q03	101	115	Q05							
P6	4	5	2	035	036	119	118	1	111	117	
P7	Q04	6	7	39	8	9	10	42	QE5	3	103
P8	Q06	Q01	QE3	33	32						

5 Final Remarks

We carried out an adaptation of the SCP model to define a plan for the evacuation of pedestrians from the most susceptible areas to fires in a University. Four (4) scenarios were considered, according to the degree of risk of the buildings and the characteristics and availability of gates for evacuation.

In the first cycle of execution of the model, composed of two (2) scenarios, we demonstrated that the application of weights for different functionalities of buildings, according to the degree of risk, has a positive contribution. However, for the purpose of executing the model, all gates were considered for pedestrian evacuation in the event of fire, including gates for vehicles. In order to avoid panic situations and mistaken crowd behavior, we chose to create new scenarios in which vehicles gates are excluded from the model.

In the second cycle of execution of the model, also composed of two (2) scenarios, only gates exclusively for pedestrians were considered, in addition to the risks of buildings. Two situations were considered, the first in which the SCP defined the minimum number of gates for evacuation and the second, in which we defined the number of available gates as a fixed variable of the problem. According to the results obtained, the last scenario represents the safest and most viable solution for pedestrian evacuation, as it minimizes the effective distance traveled by pedestrians between buildings and gates and, due to the number of gates being fixed at six (6), it is estimated that the flow of pedestrians at each gate also decreases.

Based on the results, we suggest two contributions to improve this study. The first is to carry out simulations of removing one of the gates considered in the solution of the problem, in the event of a possible fire in its immediate vicinity, and to analyze the behavior of the new distribution of coverage of buildings by the remaining gates. The second is to propose a simulation of the flow of pedestrians at the evacuation gates in each scenario, based on the number of people occupying the buildings, adding to this, the analysis of the crowd behavior and panic factors. This study is an important contribution for the University to develop an evacuation coordination plan based on rigorous and accurate methodology. However, we note that the success of a pedestrian evacuation plan for fire situations, especially in places where people are very crowded, like this university, depends on the dissemination of the evacuation plan and the training of the entire university community.

References

1. IFRC: International Federation of Red Cross and Red Crescent Societies, https://media.ifrc.org/ifrc, last accessed 2020/01/09.
2. Stepanov, A., & Smith, J. M. Multi-objective evacuation routing in transportation networks. European Journal of Operational Research, 198(2), 435–446 (2009).
3. Han, L. D., Yuan, F., Chin, S. M., & Hwang, H. Global optimization of emergency evacuation assignments. Interfaces, 36(6), 502–513 (2006).

4. Lena, K., Kristin, A., Staffan, B., Sara, W., Elena, S. How do people with disabilities consider fire safety and evacuation possibilities in historical buildings?—A Swedish case study. Fire technology, 48(1), 27–41 (2012).
5. Souza, J. C., de Castro Brombilla, D. Humanitarian logistics principles for emergency evacuation of places with many people. Procedia-Social and Behavioral Sciences, 162, 24–33 (2014).
6. Apte, A. Humanitarian logistics: A new field of research and action. Foundations and trends® in technology, information and operations management, 3(1), 1–100 (2010).
7. Campos, V., Bandeira, R., Bandeira, A. A method for evacuation route planning in disaster situations. Procedia-Social and Behavioral Sciences, 54, 503–512 (2012).
8. Zelinsky, W., & Kosiński, L. A. The emergency evacuation of cities: A cross-national historical and geographical study. Rowman & Littlefield Pub Incorporated (1991).
9. Alexander, D. E. Principles of emergency planning and management. Oxford University Press on Demand, (2002).
10. Souza, J. C., Schumann, A. W., Nappi, M. L. The Importance of Architectural Design in Disaster Mitigation Involving Crowds. In International Conference on Production and Operations Management Society, pp. 87–95, Springer, Cham (2018).
11. Hong, Y., Li, D., Wu, Q., & Xu, H. Dynamic route network planning problem for emergency evacuation in restricted-space scenarios. Journal of Advanced Transportation, (2018).
12. Hong, Y., Li, D., Wu, Q., & Xu, H. 3D Path Network Planning: Using a Global Optimization Heuristic for Mine Water-Inrush Evacuation. In International Computing and Combinatorics Conference. Springer, Cham. p. 279–290 (2019).
13. Fontanini, A. D., Vaidya, U., & Ganapathysubramanian, B. A methodology for optimal placement of sensors in enclosed environments: A dynamical systems approach. Building and Environment, 100, 145–161 (2016).
14. D'Orazio, M., Bernardini, G., Tacconi, S., Arteconi, V., Quagliarini, E. Fire safety in Italian-style historical theatres: How photoluminescent wayfinding can improve occupants' evacuation with no architecture modifications. Journal of Cultural Heritage, 19, 492–501, (2016).
15. Crawford, B., Soto, R., Suárez, M. O., Paredes, F., Johnson, F. Binary firefly algorithm for the set covering problem. In 2014 9th Iberian Conference on Information Systems and Technologies (CISTI), pp. 1–5, IEEE (2014).
16. Toregas, C., Swain, R., ReVelle, C., & Bergman, L. The location of emergency service facilities. Operations research, 19(6), 1363–1373 (1971).
17. Larson, R. C., & Odoni, A. R. Urban operations research, 1st edn. Prentice-Hall, (1981).

Economic Production Quantity Model Considering Items with Distinct Levels of Imperfection

Sofia Miranda, João Vilela, and Adriana Leiras

Abstract Economic production quantity models are traditionally used in industries. From the original model, where the possibility of imperfect items in production is not considered, new developments and improvements were proposed over the years seeking to make the model as realistic as possible. However, many industries can benefit from selling these imperfect items at a differentiated value and thereby reducing their total cost of production. This paper presents an economic production quantity model that considers items with different degrees of imperfection, with their selling price varying according to this degree of defect. Thus, this work proposes an Imperfection-Price curve, relating the level of imperfection of a selected item to its cost of production, and consequently, to the profit it generates. This work also presents a numerical example and a sensitivity analysis, allowing for a better understanding of variable changes and their impact on the total production cost. This paper shows that an increase in the degree of imperfection leads an increase in total costs since the more imperfect the product, the lower sale value it will have.

Keywords Economic production quantity · Imperfect quality · Price-imperfection level curve

1 Introduction

Production management plays a vital role in the effective management of production industries such as extractive, intermediate and consumer goods industries. The classic Economic Production Quantity (EPQ) model, developed by Taft [1], originated as an extension of the Economic Order Quantity (EOQ) model, developed by Harris [2], to fill an existing gap and aid production industries in their development. Both models seek to minimize inventory-related expenses and are condensed to two primary costs: acquisition and inventory. Considered assumptions include

S. Miranda · J. Vilela · A. Leiras (✉)
Pontifical Catholic University of Rio de Janeiro, Rio de Janeiro, RJ 22451-900, Brazil
e-mail: adrianaleiras@puc-rio.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_44

constant and known demand, perfect item production and fixed and known costs. These assumptions are considered in order to simplify the solution of the problem when searching for an optimal solution.

However, in the real manufacturing process, production isn't always perfect. As a result, imperfect or defective products may also be produced. Imperfect products can be defined as items with a flaw that does not affect their ultimate functionality. Its imperfection may vary in intensity, affecting a product on different levels. Defective products, however, are unable to perform their functions as expected. Depending on the industry and the type of item being produced, an imperfect item may still be of interest to the final customer and even open the market to new customers looking for lower price ranges when purchasing a particular good. An example of this occurrence happens in the fashion industry, where multiple kinds of imperfections can occur, affecting products differently, such as: a clothes' pattern applied differently than specified, a scratch on the fabric, a pulled thread, and so on. Thus, the selling price may vary according to the degree of imperfection of the product. These items can be sold at outlets or through the company website for discounted rates.

Another example of imperfect items can be seen in electronics retailing companies, such as the American chain Best Buy. These companies often sell three versions of the same product, those being: (i) perfect version (closed box, never opened and being the first sale of the object), (ii) open box version (an item that was previously purchased, opened and returned to the store) and (iii) refurbished version (an item that was previously purchased and returned due to a found defect. The item is then repaired by the store's technology team and put back on sale). Thus, one can define three states of the same product, each with a distinct degree of imperfection. As a result, the price of the same product will vary depending on both the current state and the past history of the item.

Thereby, the motivation of this study is to apply a variable related to the cost of imperfection in the production process in order to reduce the total cost of an industry's production. Thus, we seek to explore the effects of different degrees of imperfections of a product on its final selling price and total production cost in the EPQ model. Up to our knowledge, this is the first study to consider different levels of imperfections in an EPQ model. Thus, this paper fills an existent literature gap by creating a price curve that is influenced by the imperfection level of the item. This imperfection-price curve is then applied to the model created by Cunha et al. [3], which already considers backordering. As a result, the present study displays the effects of cost changes on the total cost function in an environment where backordering is allowed, enabling a better understanding of this type of production problem and strategy, while facilitating the application of the EPQ model in industries with new production characteristics.

2 Literature Review

Literature shows a great effort over the years to have [2] premise of perfect items revised and refined, as presented by Khan et al. [4] and Hsu and Hsu [5]. The first work to include discounts on imperfect items in an extended economic order quantity model was suggested by Salameh and Jaber [6]. The authors considered that the lots would always have a random fraction of imperfect items, which would be represented in the model by a known random distribution variable, and that after a complete lot check, these imperfect items should be removed and sold at a discounted price.

From the model of Salameh and Jaber [6], several works emerged proposing simplifications, extensions and improvements. Both Chiu [7] and Chan et al. [8] considered the possibility to repair items in an economic production quantity model. However, Chen et al. [8] argue that part of these imperfect items could still be sold at a discount and defective items could be repaired or discarded, while Chiu [7] advocates repairs to all imperfect items.

Eroglu and Ozdemir [9] and Wee et al. [10] also considered the sale of defective and imperfect items, respectively, at a discounted price and proposed to add total backordering to the model. Yu et al. [11] researched the incorporation of partial backordering with item deterioration and Wee et al. [10] contemplated the option of partial backordering with lost sales.

The works of Wee et al. [12] and Taleizadeh and Pentico [13], two independent procedures were developed to obtain the solution of the economic production and order quantity model, respectively.

Considering stochastic parameters, Roy et al. [14] proposed assigning the demand as stochastic, in repair of defective items with backlogging. While in Salehi et al. [15], an economic order model that allows shortages due to stochastic occurrences of defects was studied. Finally, in Cunha et al. [3], the authors proposed an economic production quantity model with partial backordering and discount for imperfect items, where the production time of imperfect batches is stochastic.

This paper seeks to fill a gap in the literature by exploring the effects of varying the degree of imperfections on a product's final selling price and total production cost. This will be applied to the model of Cunha et al. [3] and will follow the same methodology presented in the work of Salehi and Taleizadeh [15]. Thus, it will be possible to study the application of a variable discount for products with different degrees of imperfection in several problems, seeking to bring the state of the art closer to the reality of production.

3 Problem Description and Mathematical Modelling

The studied production system contemplates two central dynamics: the imperfection of batch production and the possibility of backordering. The first concerns about the impact of the degree of imperfection has on the sales price of a product and consequently, how this is reflected in the total cost of production. In this study, the production of successive imperfect batches is described by a random variable X and can increase the total cycle time to $T' = T(X + 1)$. This is because the production cycle time only ends after the production of a perfect batch T [3]. In addition, an n parameter was added to represent the degree of imperfection that occurred for a given buyer.

Table 1 Parameters applied

Parameters	
D	Demand rate [units per planning period]
C_0	Setup cost [cost per time unit]
C_h	Cost of stocking a unit [cost per time unit]
C_b	Backorder cost of one unit of time [cost per time unit]
C_i	Cost of keeping an item backordered per unit of time [cost per time unit]
C_l	Cost of losing customer satisfaction from unmet demand
N	Degree of imperfection [$0 \leq n \leq 1$]
B	Out-of-stock fraction that will be backordered [$0 < \beta < 1$]]
X	Number of consecutive imperfect batches produced [units per time unit]
P	Production rate [production per constant production time unit, $0 < D < P$]

Table 2 Decision Variables applied

Decision variables	
T	Time between two successive productions
T'	Time between two successive perfect productions [$T' = (X + 1)\ T$]
F	Fraction of cycle size where stock level is positive [$0 < F < 1$]

From the perspective of production delays, there are two possible scenarios depending on the fraction of backorder batches defined by the β parameter and are mentioned as follows. This entails the formation of two cost portions to include the costs of sales lost due to the delay, and the costs of the backorder itself, associated with additional production operations due to the delay. Parameters and decision variables used in this study are described in Tables 1 and 2.

The main assumptions applied to the model are presented below. Assumptions 1–6 come from the model presented by Cunha et al. [3] and assumption 7 is added in this work.

1. The planning horizon is finite.
2. The demand rate is known, constant and lower than the production rate.
3. Product shortages are allowed and partially backordered.
4. There is a fixed production schedule where batches are produced at equally spaced times in terms of T.
5. The probability of each batch being below quality standards (imperfect item) is independent and random.
6. There is no rework of imperfect items.
7. Every imperfect item can be sold for a discounted amount.

The cost function make-up can be divided into the costs of configuration, storage, lost sales, backorder, and imperfection. This function is described in Eq. (1) and varies according to the period between productions T, the time fraction in which the stock is positive F, and the number of consecutively produced imperfect batches X.

$$\begin{aligned} C(F,T,X) =& C_0 + \frac{C_h \cdot D \cdot T^2 \cdot F^2}{2}\left(1 - \frac{D}{P}\right) + C_l \cdot D \cdot T \cdot (1-\beta) \times (1-F) \\ &+ \frac{C_b \cdot \beta \cdot D \cdot T^2 \cdot (1-F)^2}{2}\left(1 - \frac{D}{P}\cdot\beta\right) + m \cdot log_{10}(n+1) \cdot X \cdot C_i \end{aligned} \tag{1}$$

To best represent the cost of imperfection, there was a need for a function that would show as accurately as possible the results that imperfections have in the price of a product and, consequently, in its cost of production. Thereby, a function was created that, when applied to the degree of imperfection of an item, would lead to a price conversion factor that could vary between 0 and 1. The chosen function was a logarithm because it represents how much a customer would be willing to pay for products with different degrees of imperfection. This curve was inspired by the behavior of a risk-averse consumer in a scenario of uncertainty. These behaviors have been studied in several areas such as psychology [16] and microeconomics [17], and try to represent an individual's view of the possibility of experiencing a financially unfavorable event, usually linked to loss of equity. Similarly, the unfavorable event studied in this paper is precisely the level of imperfection that a consumer encounters in the desired product.

Small degrees of imperfection are expected to lead to a significant variation in customer price perception, while changes in the level of defect in a highly defective product will lead to minor variations. An example of this behavior would be the perception of the value of a jacket where the zipper gets stuck for a 30% discount *vs.* a jacket containing either one or two rips, both of which would come out at a similar 80% discount as both have a high degree of imperfection.

This log function is applied to the degree of imperfection n to generate this behavior, and it is then necessary to analyze the extreme cases of a perfect product and a completely imperfect product in order to adjust this curve. Considering the perfect product case, we want the part of the cost equation related to the defect to be nullified, that is, we want this logarithm to be zero since there is no imperfection cost linked to it. For this to occur, the logarithm must be applied to $(n+1)$, so that when n is zero, we have a logarithm of 1, which is equal to 0. In the case of the completely imperfect product, we want the conversion factor of price to be 1, so we need a multiplier factor that, when applied to the $log(1+1)$, would give us a unit value. Thus, this multiplier factor must be $\frac{1}{log(1+1)}$, which is $\frac{1}{log(2)}$ (Fig. 1).

The uncertainty of the model is represented by the stochastic parameter X. In this study, X was defined as a random geometric probability distribution variable, having ξ [15, 18] as the probability of producing an imperfect batch. The properties of this distribution are as follows:

$$X \sim Geo(\xi) \tag{2}$$

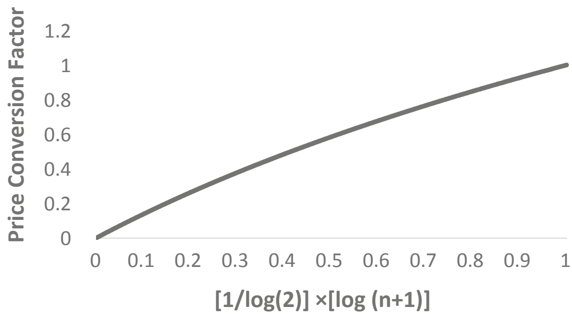


Fig. 1 Proposed imperfection-cost curve

$$X = \xi^x \cdot (1 - \xi) \tag{3}$$

$$E[X] = \frac{\xi}{1 - \xi} \tag{4}$$

$$E\left[X^2\right] = \frac{\xi \cdot (1 - \xi)}{(1 - \xi)^2} \tag{5}$$

Using these properties (2–5), it is possible to calculate the expected cost for a given cycle. Since only the cost of imperfection depends on X, the same structure of Eq. (1) can be kept, with only X being substituted for its expected value, arriving at Eq. (6)

$$\begin{aligned} CC(F,T) = & C_0 + \frac{C_h \cdot D \cdot T^2 \cdot F^2}{2}\left(1 - \frac{D}{P}\right) + C_l \cdot D \cdot T \cdot (1 - \beta) \cdot (1 - F) \\ & + \frac{C_b \cdot \beta \cdot D \cdot T^2 \cdot (1 - F)^2}{2}\left(1 - \frac{D}{P} \cdot \beta\right) + m \cdot log_{10}(n + 1) \cdot \frac{\xi}{1 - \xi} \cdot C_i \end{aligned} \tag{6}$$

Finally, the total production cost can be described by:

$$\begin{aligned} TC(F,T) = & \frac{CC(F,T)}{E[T']} \\ = & (1 - \xi)\left[\begin{array}{l} \frac{C_0}{T} + \frac{C_h \cdot D \cdot T \cdot F^2}{2}\left(1 - \frac{D}{P}\right) + C_l \cdot D \cdot (1 - \beta) \cdot (1 - F) \\ + \frac{C_b \cdot \beta \cdot D \cdot T \cdot (1 - F)^2}{2}\left(1 - \frac{D}{P} \cdot \beta\right) + \frac{m \cdot log_{10}(n + 1) \cdot \frac{\xi}{1 - \xi} \cdot C_i}{T} \end{array}\right] \end{aligned} \tag{7}$$

With the expected time for a cycle being:

$$E[T'] = E[(X + 1)T] = \left(\frac{\xi}{1 - \xi} + 1\right)T = \frac{T}{1 - \xi} \tag{8}$$

4 Mathematical Model Optimization

According to the methodology presented by Taleizadeh [18], it is possible to simplify the model's equation through the use of artificial variables to aid the mathematical development of the equations. Thus, (7) can be rewritten as:

$$TC(F,T) = s_0\left[\frac{s_1}{T} + s_2 \cdot T \cdot F^2 + s_3 \cdot (1-F) + s_4 \cdot T \cdot (1-F)^2 + \frac{s_5}{T}\right] \quad (9)$$

where:

$$s_0 = (1-\xi) \quad (10)$$

$$s_1 = C_0 \quad (11)$$

$$s_2 = \frac{C_h \cdot D}{2} \cdot \left(1 - \frac{D}{P}\right) \quad (12)$$

$$s_3 = C_l \cdot D \cdot (1-\beta) \quad (13)$$

$$s_4 = \frac{C_b \cdot \beta \cdot D}{2} \quad (14)$$

$$s_5 = \frac{1}{log_{10}2} \cdot log_{10}(n+1) \cdot \left(\frac{\xi}{1-\xi}\right) \cdot C_i \quad (15)$$

The first partial derivatives for T and F are used to minimize the total cost [15, 18], as observed in (16) and (17):

$$F^*(T) = \frac{\partial TC}{\partial F} = \frac{s_3 + 2 \cdot s_4 \cdot T}{2 \cdot s_2 \cdot T + 2 \cdot s_4 \cdot T} \quad (16)$$

$$T^*(F) = \frac{\partial TC}{\partial T} = \sqrt{\frac{s_1 + s_5}{s_2 \cdot F^2 + s_4 \cdot (1-F)^2}} \quad (17)$$

To ensure both these equations will have viable results, it is necessary to ensure that their denominators will not be null. For that to be the case in (16), $(s_2 + s_4)$, and T must assume non-null values for the solution to be viable. The former will not pose an issue since $D < P$, and C_h, C_b, β, D and P are all positive, which means s_2 and s_4 will always be positive. And the latter is avoided by the fact that T is always positive as well. In (17), since the denominator is a quadratic equation, it is necessary to ensure that there are no possible values of F that could cause it to be null, which means its discriminant (18) must always be negative:

$$\Delta = -4 \cdot s_2 \cdot s_4 \quad (18)$$

Using the previous analysis, it is possible to conclude that it always will be negative. Substituting (16) in (17), the following equation is obtained:

$$T^* = \sqrt{\frac{4 \cdot s_1 \cdot s_2 + 4 \cdot s_1 \cdot s_4 + 4 \cdot s_2 \cdot s_5 - s_3^2 + 4 \cdot s_4 \cdot s_5}{4 \cdot s_2 \cdot s_4}} \tag{19}$$

Finally, having proved the optimality conditions for the derivatives of (9), it is possible to guarantee that any F applied to (17) minimizes (9) with a resulting T*. Thereby, it is possible to substitute (17) in (9) to obtain:

$$TC(F) = s_0 \cdot \left(\begin{array}{l} \dfrac{s_1 + s_5}{\sqrt{\frac{s_1 + s_5}{s_2 \cdot F^2 + s_4 \cdot (1-F)^2}}} + \left(s_2 \cdot F^2 + s_4 \cdot (1 - F)^2\right) \\ \cdot \sqrt{\dfrac{s_1 \ + \ s_5}{s_2 \cdot F^2 \ + \ s_4 \cdot (1 - F)^2}} + s_3 \cdot (1 - F) \end{array} \right) \tag{20}$$

As previously proven, $s_2 \cdot \mathrm{F}^2 + s_4 \cdot (1 - \mathrm{F})^2$ has a negative discriminant, meaning it will never be null, which, coupled with the fact that $s_1 + s_5$ is always positive, guarantees the viability of (20). Thus, it is possible to search for the problem's global optimum through the first and second-order derivatives presented in the Eqs. (21) and (22).

$$\frac{\partial TC(T^*)}{\partial F} = -s_0 \cdot \left(s_3 - (2 \cdot s_2 \cdot F + s_4 \cdot (2 \cdot F - 2) \cdot \sqrt{\frac{s_1 + s_5}{s_2 \cdot F^2 + s_4 \cdot (1 - F)^2}} \right) \tag{21}$$

$$\frac{\partial^2 TC(T^*(F))}{\partial F^2} = \frac{\left(2 \cdot s_0 \cdot s_2 \cdot s_4 \cdot \left(\frac{s_1 + s_5}{s_2 \cdot F^2 + s_4 \cdot (F-1)^2}\right)^{\frac{3}{2}}\right)}{s_1 \ + \ s_5} \tag{22}$$

5 Procedure for Finding Optimal Values for T, F and TC

The procedure for finding the optimal values of T, F and TC is described below, as defined by Salehi et al. [15]. This procedure must be done for each specific case and will be exemplified in the following example:

8. Calculate the first derivative of TC(F = 1) using (21).
9. If TC′(F = 1) < 0, proceed to the third step. If TC′(F = 1) ≥ 0, proceed to the fourth step.

10. Set F = 1 and replace it in (17) to calculate T and then use it to calculate TC by (7), comparing it to the value of $C_l \cdot D$. If $C_l \cdot D <$ TC, the optimal values will be F* = 0 and T* = ∞; if not, F* = 1 and T* is calculated using (17).
11. Determine T* using (19).
12. Replace T* in (16) and find F*.
13. Calculate TC* using (20).

6 Experimental/Numerical Setting

To illustrate the model descripted in Sect. 3, a numerical example and a sensitivity analysis is presented below, which was developed on Excel 2019. Considering the following parameters: D = 1500; C_0 = 400; C_h = 2; C_b = 4; C_l = 1; C_i = 405; P = 8000; $\beta = 0.60$; $\xi = 0.20$; n = 0.50

1. Applying Eq. (21) we obtain $TC'(F = 1) = 1196.99 > 0$.
2. Thus, we go to step 4.
3. By Eq. (19), we find $T^* = 0.79$.
4. Applying Eq. (16), we have $F^*(T) = 0.70$.
5. Finally, by Eq. (20), we obtain $TC^* = 1077.31$.

To better understand the algorithm's applicability, a sensitivity analysis was made using the example above. This analysis illustrates the impact in T^*, F^* e TC^* when changing parameters and its results are presented below (Table 3).

Analyzing Table 3, we can observe that by increasing the imperfection level of an item, the related cost also increases, showing a direct correlation between the imperfection level and its production cost.

Table 3 Sensitivity Analysis for the Imperfection Level

			Optimal values			Percentage differences		
Variable	Change (%)	Value	T*	F*	TC*	T* (%)	F* (%)	TC* (%)
n	−75	0.125	0.746	0.710	1033.442	−5	1	−4
n	−60	0.2	0.756	0.708	1043.484	−4	1	−3
n	−45	0.275	0.764	0.707	1052.808	−3	1	−2
n	−30	0.35	0.772	0.705	1061.506	−2	0	−1
n	−15	0.425	0.779	0.704	1069.652	−1	0	−1
n	0	0.5	0.786	0.703	1077.311	0	0	0
n	15	0.575	0.793	0.702	1084.533	1	0	1
n	30	0.65	0.799	0.701	1091.365	2	0	1
n	45	0.725	0.805	0.700	1097.843	2	0	2
n	60	0.8	0.810	0.699	1104.002	3	−1	2
n	75	0.875	0.816	0.698	1109.870	4	−1	3
n	90	0.95	0.821	0.697	1115.472	4	−1	4

7 Conclusions and Future Research

This paper proposed an extension of the EPQ model by Cunha et al. [3], developing an economic production lot model that considers partial backordering and a discounted price relation according to the degree of imperfection of a specific item. A relationship curve between the imperfection level and a cost conversion factor has been proposed. This allows for the flexibility of the discount, which varies for each product and its imperfection level. This model assumes that all imperfect items can be sold, changing only the discount linked to it, depending on their degree of imperfection. The model also considered that backorder and the demand rate are deterministic.

For the solution of this model, the total cost was minimized and the framework of Salehi et al. [15] was applied to find: the optimal time period values between two successive productions (T*), the optimal fraction of the size cycle where the stock level is positive (F*) and total production cost (TC*). Additionally, a numerical example and a sensitivity analysis were performed, varying the parameter values to analyze their impact on the results.

The degree of imperfection (n) leads to an increase in total costs because the more imperfect the product, the lower the sale value it will have. It is important to highlight that while all these parameters increase the total cost, this does not mean that they all decrease profits.

New approaches and studies can be applied to this work making it more realistic and are listed below as suggestions for future research. An example would be to analyze the possibility of fixing imperfect products vs. simply selling them at a discounted value. Also, an analysis could be performed to better calibrate the proposed price-imperfection level curve to further resemble expected consumer behavior. Another compatible study topic would be to perform a sensitivity analysis of the proposed model against different price-imperfection curves of varying natures, according to different characteristics of consumer imperfection aversion.

Acknowledgements This study was financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brazil (CAPES)—Finance Code 001.

References

1. Taft, E. W.: The most economical production lot. Iron Age, 101(18), 1410–1412 (1918).
2. Harris, F. W.: How many parts to make at once (1913).
3. Cunha, L. R. A., Delfino, A. P. S., dos Reis, K. A., Leiras, A.: Economic production quantity (EPQ) model with partial backordering and a discount for imperfect quality batches. International Journal of Production Research, 56(18), 6279–6293 (2018).
4. Khan, M., Jaber, M. Y., Guiffrida, A. L., Zolfaghari, S.: A review of the extensions of a modified EOQ model for imperfect quality items. International Journal of Production Economics, 132(1), 1–12 (2011).

5. Hsu, L. F., Hsu, J. T.: Economic production quantity (EPQ) models under an imperfect production process with shortages backordered. International Journal of Systems Science, 47(4), 852–867 (2016).
6. Salameh, M. K., Jaber, M. Y.: Economic production quantity model for items with imperfect quality. International journal of production economics, 64(1–3), 59–64 (2000).
7. Chiu, Y. P.: Determining the optimal lot size for the finite production model with random defective rate, the rework process, and backlogging. Engineering optimization, 35(4), 427–437 (2003).
8. Chan, W. M., Ibrahim, R. N., Lochert, P. B.: A new EPQ model: integrating lower pricing, rework and reject situations. Production Planning & Control, 14(7), 588–595 (2003).
9. Eroglu, A., Ozdemir, G.: An economic order quantity model with defective items and shortages. International journal of production economics, 106(2), 544–549 (2007).
10. Wee, H. M., Yu, J., Chen, M. C.: Optimal inventory model for items with imperfect quality and shortage backordering. Omega, 35(1), 7–11 (2007).
11. Yu, J. C., Wee, H. M., Chen, J. M.: Optimal ordering policy for a deteriorating item with imperfect quality and partial backordering. Journal of the Chinese institute of industrial engineers, 22(6), 509–520 (2005).
12. Wee, H. M., Huang, Y. D., Wang, W. T., Cheng, Y. L.: An EPQ model with partial backorders considering two backordering costs. Applied Mathematics and Computation, 232, 898–907 (2014).
13. Taleizadeh, A. A., Pentico, D. W.: An economic order quantity model with partial backordering and all-units discount. International Journal of Production Economics, 155, 172–184 (2014).
14. Roy, M. D., Sana, S. S., Chaudhuri, K.: An economic production lot size model for defective items with stochastic demand, backlogging and rework. IMA Journal of Management Mathematics, 25(2), 159–183 (2014).
15. Salehi, H., Taleizadeh, A. A., Tavakkoli-Moghaddam, R.: An EOQ model with random disruption and partial backordering. International Journal of Production Research, 54(9), 2600–2609 (2016).
16. Lopes, L. L.: Between hope and fear: The psychology of risk. In Advances in experimental social psychology, vol. 20, pp. 255–295. Academic Press (1987).
17. Friedman, M., Savage, L. J.: The utility analysis of choices involving risk. Journal of political Economy, 56(4), 279–304 (1948).
18. Taleizadeh, A. A.: Lot-sizing model with advance payment pricing and disruption in supply under planned partial backordering. International Transactions in Operational Research, 24(4), 783–800 (2017).

Food Security: Location of Assistance Entities in Poverty Zones

Nathalia Holanda Assumpção and Márcia Marcondes Altimari Samed

Abstract Humanitarian logistics has the essential function of managing responses in the supply chain of critical materials and services, including demand variation, uncertain supplies, in a short time and wide scope. The problem of starvation can be triggered by social inequality, wars, natural events such as drought, economic policies, among others. Thus, starvation is a humanitarian problem that can affect people in poverty situations, including death. In Brazil, social inequality means that on the one hand there is food waste, whose destination is usually garbage. On the other hand, there is a shortage of food on the table of a large portion of the population. In this context, food banks have a key role to decrease starvation for people in poverty situations. This article aims to define a set of entities and their respective locations, to contribute and promoting food security in poverty zones. For this, we set a location model based on the Set Covering Problem. The results demonstrate which entities must cover the poverty zones, given the 5 km distance restriction between the distance of demands and the suppliers. Under these circumstances, this study has the potential to contribute to increasing the availability, stability, utilization, and access to food security for people in the poverty situation and, consequently, contributes to the reduction of food waste.

Keywords Humanitarian logistics · Food bank · Food security · Location problem · Set covering problem

1 Introduction

The assistance food system is a complex ecosystem that has as a central role: the food bank, which undertakes the main function of attaining food for agencies and partner programs such as assistance entities and shelters. In this article we will describe the study carried out at the food bank suited in a city of the south of Brazil, Maringá.

N. H. Assumpção · M. M. A. Samed (✉)
State University of Maringá, Maringá, Brazil
e-mail: mmasamed@uem.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_45

The Maringá food bank was funded by the state government in association with the private initiative, under regulation by the Federal Social Development Office. The most fundamental task of the food bank is to integrate the food donors of a supply center (CEASA) to the assistance entities. The entities redirect the acquired resources to people that are in a food insecurity situation. Yearly, 1,400 tons of food is destined to this food bank, where it undergoes a strict selection process, which guarantees safety. This process results in a 63% harnessing of the gross amount, which benefits, weekly, more than 8 thousand of people in a state of social and nutritional vulnerability.

The food bank intends on expanding its reach among people in a vulnerable situation and it already possesses a set of assistance entities that have applied to receive donated food. However, the food bank requires a strict study to define which entities should receive donated foods.

The poverty zones of the city were mapped out and established as a starting point. Based on this map and with accordance to the location of the candidate entities, this article intends to answer the following question: which assistance entities will give coverage to the main poverty zones of Maringá, consequently, benefitting social and nutritional vulnerability people?

In this context, the general objective of this article consists into apply the Set Covering Problem model to determine which entities (how many and their location) should be associated with the food bank, as to give coverage to the population in a vulnerable situation, based on the poverty map of Maringá.

The specific objectives are defined as: to identify candidate entities as well as the volunteered organizations; to study the map that represents the poverty zone of Maringá; to model the coverage problem; to develop a coverage model that assures food distribution to people socially and nutritionally vulnerable.

The present study is structured as follows: Introduction, Literature Review, Methodology, Results, and Final Remarks.

2 Literature Review

Food security is a concept established when we consider that all people, have physical and economic access to food that is safe, sufficient, and nutritious to meet their needs and preferences to have an active and healthy life [1]. We may list four main food security elements: availability, stability, utilization, and access [2, 3]. On the other hand, food insecurity occurs when any of these elements are at fault, resulting in poor nutrition or even in large scale starvation [4]. Food crisis begins when starvation and malnutrition rates increase sharply, be it at a local, national or global scale by effects of a disruption in food demand as well as in its offer, which generally involves abrupt price surges [5]. In this context, humanitarian logistics aims to ensure the efficiency and functionality of the flow of supplies and people, with the primary intent of saving lives and relieving the vulnerable's suffering [6].

Despite all efforts made against poverty and famine, there is still an unacceptable number of people who have no access to the necessary food required to live actively and healthily [7]. According to Jones et al. [8], 870 million people worldwide present a caloric intake below what is deemed necessary, directly interfering with mental and physical health. Meanwhile, about 1.3 billion tons of food are wasted yearly on the planet, about 30% of the gross production [9].

Thus, an unbalanced throughout the food waste present in the global supply chain may be observed, food that could otherwise be used in the nutrition of millions of people [10]. Various recent studies have directed their focus onto food waste levels, therefore, bringing to light their causes and complexity according to specific conditions, local context and various regions [11–14].

In 2015, amidst the pursuit of a global solution, the United Nations (UN) accorded on the Sustainable Development Goals (SDG), which include two goals that are entirely related to this article, which concerns food waste and world hunger. The first objective consists in, until 2030, reducing by half food waste per capita at retail and consumer levels as well as reducing food losses along production and supply chains, including post-harvest losses [15]. The second objective consists of eradicating hunger, achieving food security and improvement nutrition and promoting sustainable agriculture, until 2030 [16].

In this scenario, it is possible to verify the initiative of many social programs funded by public entities as well as non-governmental organizations (NGOs). As an example, we have the food bank model, which concept first appeared in the United States of America, in the decade of 1960. This concept expanded to many countries throughout the world, intensifying a wide variety of humanitarian relief organizations [17, 18].

According to Bacon [19], the rise in the number of food banks in important countries suggests the attention on how food insecurity needs can be quickly measured, mapped and matched with access to food assistance.

Food bank operations, originating from retrieval and redistribution of food has its composition as depicted in Fig. 1.

Food bank supply chain network shares several characteristics with its industrial counterpart. In fact, multiple relevant location and transportation problems encountered in the context of food distribution are defined on networks and share a common

Fig. 1 Food bank operations. *Source* Adapted from Wetherill [24]

structure with classical supply chain planning problems. This is possibly explained by the social purpose of this type of networks can be serve and the specific characteristics of the numerous organizations that interact with food banks [20].

3 Methodology

According to Voss et al. [21], this article can be characterized as a case study, in which it is intended to investigate a phenomenon within the context of real life. Thus, a combined methodology approach between qualitative and quantitative analysis is established, this combination allows a better comprehension of the research problems that each approach would make possible in isolation being complementary ideas [22].

In this way, we established a planning for conducting the case study, as illustrated in Fig. 2.

- Step 1: Develop a map that represents the poverty zones in the city of Maringá.
- Step 2: Define the centroids that represent the points of demand (poverty).
- Step 3: Define the centroids that represent the points of suppliers (assistance entities).
- Step 4: Calculate the distance matrix between supply and demand points.
- Step 5: Apply the SCP, as described below.

SCP consists of a coverage method with maximum distance parameters. In this case, we consider the maximum distance that separates the assistance entities and the poverty zones as a fundamental parameter.

We assume that assistance entities and poverty zones are represented, as a finite number of points, of which the maximum distance, s, is known moreover the data sets concerning assistance entities and poverty zones are distinct. Thus, the problem was structured as a binary, linear, and integer program.

If s is the threshold distance established and d_{ij} is the distance between a given j node and an i node, the set N_i may be defined as:

$$N_i = \left\{ j / d_{ij} \leq s \right\} \tag{1}$$

If there are n nodes that represent the poverty zones, there will be n sets of N_i, and each set will have at least one element, with d_{ij} considered as 0. Thus, at least one node i will be of the required distance to find node j. The model has as its objective

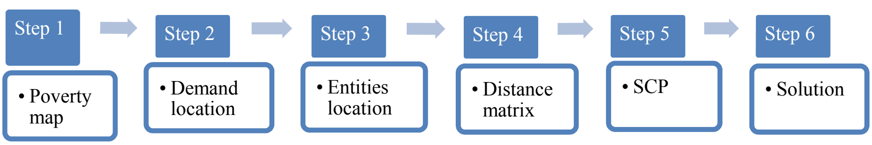


Fig. 2 Methodology

to minimize Z:

$$z = \sum_{i=1}^{n} x_j \tag{2}$$

Each poverty zone needs to be covered for, by at least, one social entity at a given maximum distance s. As a constraint condition:

$$\sum_{j \in N_i} x_j \geq 1 \tag{3}$$

For every node i, where N_i is the set of nodes that are eligible to cover i, hence:

$$N_i = \{j / d_{ji} \leq s\}, \tag{4}$$

$$x_j = (0, 1) \tag{5}$$

- Step 6: Obtain the solution that represents which entities will cover the poverty zones and will be able to receive donations from the food bank.

4 Results

First, we considered a social parameter available in CENSO/IBGE [23] and selected the poverty zones ranked as the more precarious ones. Thereupon, we obtained zones A, D, E, G, H, K, N, O, as shown in Fig. 3.

Afterward, by means of ArcGIS software, we defined the centroid of the areas selected for the study. The centroids of the poverty zones were defined as demand points whereas the centroids of the candidate entities were considered as supply points. Therefore, this resulted in 13 centroids concerning the entities, as the social entities considered were the candidates and those, which are already set up in these zones.

Based on the centroids that represent demand (CA, CG, CD, …, CH) and supply points (E1, E2, E3, …, E13), we calculated the effective distance between each centroid and, thereby, we attained a distance matrix, which is represented in Table 1.

To transform the distance matrix into a binary matrix, we established a maximum coverage distance of 5 km, with the support of food bank experts using brainstorming. Distances under or equal to 5 km were replaced by 1, otherwise, distances higher than 5 km were replaced by 0.

Accordingly, we applied the successive reduction algorithm of the SCP binary matrix and acquired supply points that will give coverage to the demand, as to maximize the service provided. The results are shown in Table 2.

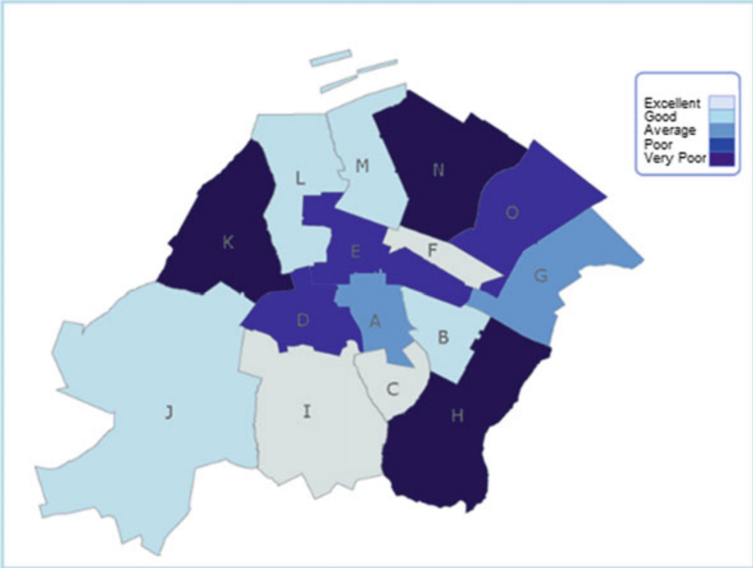


Fig. 3 Poverty map of Maringá. *Source* Adapted from CENSO/IBGE [23]

Table 1 Distance between supply and demand points (km)

	CA	CG	CD	CE	CO	CN	CK	CH
E1	4.88	9.63	5.7	7.59	10.26	11.53	10.18	4.29
E2	1.73	8.45	2.91	4.38	8.32	8.12	7.09	6.16
E3	10.28	3.62	13.04	10.25	4.59	8.01	15.56	9.7
E4	8.84	3.04	11.72	9.76	5.45	9.21	15.02	6.85
E5	11.15	4.42	13.96	11.38	5.86	9.37	16.74	9.91
E6	5.41	6.29	7.91	7.79	7.67	10.15	12.15	1.66
E7	3.88	4.47	6.74	4.91	4.61	6.56	10.04	5.21
E8	6.6	10.92	5.69	4.16	9.14	6.52	3.86	11.57
E9	7.67	10.14	7.65	4.87	7.98	4.63	6.27	12.27
E10	9.81	3.32	12.52	9.63	3.92	7.3	14.88	9.58
E11	2.46	5.97	5.35	4.32	5.96	7.24	9.02	4.89
E12	8.16	13.68	6.94	6.75	11.93	9.13	2.75	13.76
E13	9.5	2.86	12.26	9.54	3.97	7.54	14.88	9.01

Table 2 Entities that cover poverty zones

E11	E4	E2	E8	E3	E9	E8	E1
CA	CG	CD	CE	CO	CN	CK	CH

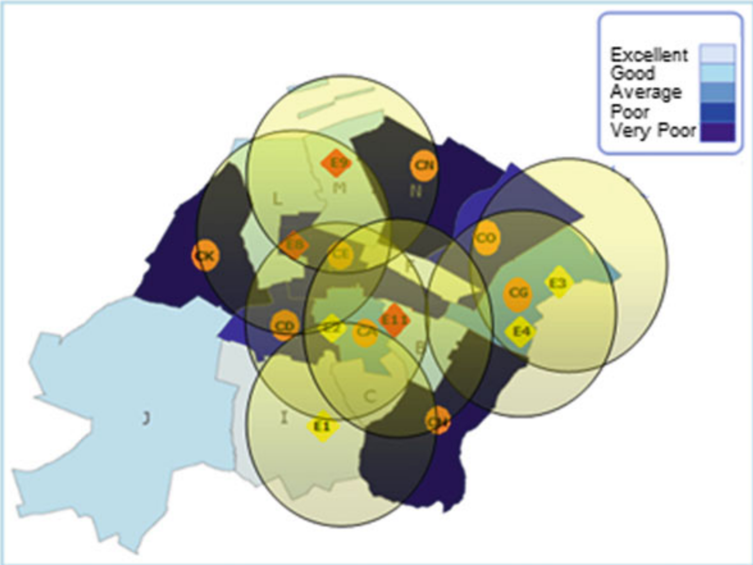


Fig. 4 Coverage map

The results indicate which active social entities will continue providing relief, as well as which candidate entity will begin to act as to contribute with food supply to people located in these poverty zones in a food insecurity situation. As a result, we developed a map that provides an overview of supply coverage performed by this set of social entities, as shown in Fig. 4.

According to Fig. 4, it is possible to verify the coverage configuration of the poverty zones, where the circles represent the radius of 5 km around the centroid of the entities. It is clear there is an overlap of influence of entities in poverty zones, however, we can assure that all poverty zones are covered, at least, by one entity.

Herewith, food supply originating from the food bank to the poverty zones can be achieved by the set of candidate entities E1, E2, E3, and E4 as well as the currently operating entities, E8, E9, and E11.

5 Final Remarks

This article aimed to define a set of entities and their respective locations, to contribute to promoting food security in poverty zones. The problem was modeled considering the map that represents poverty zones in the city of Maringá. A distance matrix was built with the aid of a geographic positioning tool, based on the location of the entities, which are already integrated into the food bank as well as a set of candidate entities. From the distance matrix, we applied SCP, which resulted in a minimal set of entities that will cover the main poverty zones of Maringá.

The contribution of this article to the food bank consists of the adoption of a methodology to select of assistance entities, benefiting people in a social and nutritional vulnerability situation. This article also contributes to people that lives in poverty zones, who does not have suitable access to food assistance.

The immediate consequence of this study regards the formulation of strategies that aim at contributing directly with the objectives of the Sustainable Development Goals, attaining a greater reach of food security through assurance the access to nourishing food, reducing food waste and, thus, effectively diminishing starvation in the poverty zones of Maringá.

To complement this study, we intend to investigate the best method to promote food distribution, considering each entity and the beneficiaries in their respective coverage areas. A qualitative study will also be carried out to verify if the entities are assuring the four main elements of food security: availability, stability, utilization, and access.

References

1. Owusu, V., Abdulai, A., Abdulai, Abdul-Rahman, S. Non-Farm Work and Food Security Among Farm Households in Northern Ghana. Food Policy, 36(2), 108–118, (2011).
2. Anríquez, G., Daidone, S., Mane, E. Rising Food Prices and Undernourishment: A Cross-Country Inquiry. Food Policy, 38, 190–202, (2013).
3. Carletto, C., Zezza, A., Banerjee R. Towards Better Measurement of Household Food Security: Harmonizing Indicators and the Role of Household Surveys. Global Food Security, 2(1), 30–40, (2013).
4. Seligman H.K., Laraia, B.A., Kushel, M.B. Food Insecurity is Associated with Chronic Disease Among Low-Income NHANES Participants. J. Nutr.140, 304–310, (2010).
5. Timmer, C. P. Preventing Food Crises Using a Food Policy Approach. Journal of Nutrition, 140(1), 224S-228, (2010).
6. Thomas, A. Elevating Humanitarian Logistics. International Aid&Trade Review; IA&T Europe. (2004).
7. Hosseini, S. S., Pakravan, C, M.R., Salamia, H., Flora, C. The Impact of the Targeted Subsidies Policy on Household Food Security in Urban Areas in Iran. Cities, 63,110–117, (2017).
8. Jones, A. D., Ngure, F. M., Pelto, G., Young, S.L. What Are We Assessing When We Measure Food Security? A Compendium and Review of Current Metrics. Advances in Nutrition, 4(5), 481–505, (2013).
9. Curry, N., Pillay, P. Biogas Prediction and Design of a Food Waste to Energy System for the Urban Environment. Renewable Energy, 41(C), 200–209, (2012).
10. Stuart, T. Waste. Uncovering the Global Food Scandal. Penguin, London (2009).
11. Leverenz, D., Moussawel, S., Maurer, C., Hafner, G., Schneider, F., Schmidt, T., Kranert, M. Quantifying the Prevention Potential of Avoidable Food Waste in Households Using a self-reporting Approach. Resources, Conservation and Recycling, 150, (2019).
12. Caldeira, C., De Laurentiis, V., Corrado, S., Van Holsteijn, F., Sala, S. Quantification of Food Waste per Product Group Along the Food Supply Chain in the European union: A Mass Flow Analysis. Resources, Conservation and Recycling, 149, 479–488, (2019).
13. Muth, M. K., Birney, C., Cuéllar, A., Finn, S. M., Freeman, M., Galloway, J. N., Zoubek, S. A Systems Approach to Assessing Environmental and Economic Effects of Food Loss and Waste Interventions in the United States. Science of the Total Environment, 685,1240–1254, (2019).

14. Henz, G. P., Porpino, G. Food Losses and Waste: How Brazil is Facing this Global Challenge? Horticultura Brasileira, 35(4), 472–482, (2017).
15. Philippidis, G., Sartori, M., Ferrari, E., M'barek, R. Waste Not, Want Not: A Bio-Economic Impact Assessment of Household Food Waste Reductions in the EU. Resources, Conservation and Recycling, 146,514–522, (2019).
16. Thilsted, S. H., Thorne-Lyman, A., Webb, P., Bogard, J. R., Subasinghe, R., Phillips, M. J.,Allison, E. H. Sustaining Healthy Diets: The Role of Capture Fisheries and Aquaculture for Improving Nutrition in the Post-2015 Era. Food Policy, 61,126–131, (2016).
17. Cotugna, N.; Vickery, C.E.; Glick, M. An Outcome Evaluation of a Food Bank Program. J. Am Diet. Assoc., 94, 888–890, (1994).
18. Handforth, B.; Henkick, M.; Schwartz, M.B. A Qualitative Study of Nutrition-Based Initiatives at Selected Food Banks in The Feeding America Network. J. Acad. Nutr. Diet. 113, 411–415, (2013).
19. Bacon, C. M. & Baker, G. A., The rise of food bank and the challenge of matching food assistance with potential need: toward a spatially specific, rapid assessment approach.34, 899–919, (2017).
20. Martins, C. L., Melo, M. T., Pato, M. V. Redesign a food bank supply chain network. Part I: Background and mathematical formulation. Technical reports on Logistics of the Saarland Business School. N (10), (2016).
21. Voss, C., Tsikriktsis, N., & Frohlich, M. Operations management case research. International Journal of Operations & Production Management, 22 (2), 195–219, (2002).
22. Amaratunga, D., Baldry, D., Sarshar, M., & Newton, R. Qualitative and quantitative research in the built environment application of "mixed' research approach: a conceptual framework to measure FM performance. Work Study, 51(1), 17–31, (2002).
23. CENSO/IBGE (2010). Homepage: http://www2.maringa.pr.gov.br/diagnosticosocial, last accessed: 2019/06/20.
24. Wetherill, M. S., White, K. C., Rivera, C., & Seligman, H. K. Challenges and Opportunities to Increasing Fruit and Vegetable Distribution Through the US Charitable Feeding Network: Increasing Food Systems Recovery of Edible Fresh Produce to Build Healthy Food Access. Journal of Hunger and Environmental Nutrition, 14(5), 593–612, (2019).

Emotions and the Purchase Decision Processes of Green Products: An Exploratory Study with Consumption Emotions Set Scale (CES)

Camila Kolling, Janine Fleith de Medeiros, José Luis Duarte Ribeiro, Marleen Onwezen, and Arthur Marcon

Abstract The present study focuses on the emotional factors and their influence in the decision-making process for the purchase of green products. To provide theoretical and practical support to existing literature, we evaluating individually the role of emotions that are part of the Consumption Emotions Set Scale (CES). The majority of the sample studied preferred to position themselves closer to positive emotions rather than negative when evaluating purchase decision processes for environmentally sustainable products. Emotions most triggered concerning green products were sympathy (for people who buy green products), pride (by buying green products), and joy (by knowing that green products are available). Furthermore, according to our results, women feel more peacefulness, pride, enthusiasm, surprise, relief, and serenity in the green product purchase process and less educated respondents showed more comfort in the process of green product purchase. Regarding the practical implications of the study, the information provided can be used to develop advertising campaigns, both for environmental awareness and for the promotion of environmentally sustainable products.

Keywords Green Product Purchase · Pro-Environmental Consumer Behavior · Emotions

---

C. Kolling (✉) · J. F. de Medeiros
Universidade de Passo Fundo, Passo Fundo, Brazil
e-mail: camila_kolling@hotmail.com

J. F. de Medeiros
e-mail: janine@upf.br

J. L. D. Ribeiro · A. Marcon
Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil
e-mail: ribeiro@producao.ufrgs.br

A. Marcon
e-mail: marcon.arthur@hotmail.com

M. Onwezen
Wageningen University and Research, Wageningen, Netherlands
e-mail: marleen.onwezen@wur.nl

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_46

1 Introduction

Theories in neuroscience, psychology and sociology recognize the central role of emotions in human behavior [1, 2]. However, the meaning of emotions has been neglected in the economic literature in general and, in more recent times, in environmental valuation [3, 4]. Besides that, a common aspect of most economic models that tend to incorporate emotions focuses on the implicit assumption that the cognitive and emotional dimensions are independent [3, 5].

Scientifically, for a long time, reason and emotion were opposing forces [6]. Nevertheless, researches developed in the fields of psychology and neuroscience show that the emotional and the cognitive systems are closely interconnected, communicating with each other and, together, affecting human behavior [1]. Therfore, it can be said that emotions are not irrational and disruptive for decision-making [4].

In this context, although studies have been performed to investigate the influence of emotional factors on decision-making processes for the purchase of environmentally sustainable products, there is a need for more research [2, 7, 8]. This perception is justified since many of the work carried out has focused on one or two self-conscious emotions [9–13]. Despite self-conscious emotions are ideal predictors of moral behavior, basic emotions can also affect green purchase decision process [14].

2 Objective

The present study aims to investigate the influence of emotional factors in the decision-making process for the purchase of green products, having as theoretical support the cognitive theory of emotions. Specifically, the present study wish provide theoretical and practical support to existing literature, evaluating individually the role of emotions that are part of the Consumption Emotions Set Scale (CES), proposed by Richins [15]. Still, since personal factors tend to influence emotions during decision making processes [16, 17], variables such as sex, age and level of education have their interference verified regarding the emotions experienced in purchase processes of environmentally sustainable products.

3 The CES Scale, Factors and Descriptors

Richins [15] developed a specific scale to measure consumption-related emotions. The scale named Consumption Emotions Set (CES) is composed of 47 emotion descriptors, distributed in 17 factors. Although other scales have been developed afterwards [18–20]. CES presents the most comprehensive structure to measure emotions throughout the purchase and consumption experiences [21, 22].

This conclusion is justified on the requirements that oriented the scale's elaboration: (i) the construction of a scale with measures concise enough to be used in surveys and field studies; (ii) the identification of emotion descriptors that are familiar and readily understood by consumers; and (iii) applicability range that covers distinct purchasing processes.

The CES list of factors and descriptors contemplates both positive and negative emotions (see Fig. 1). In fact, in studies regarding the structure of feelings, the distinction between positive and negative emotions constantly emerges as the two dominant and relatively independent dimensions [23, 24].

4 Method

In light of this study's objective, we chose to carry out a descriptive research with quantitative approach. As for the sample and population, we considered the research universe to be the economically active inhabitants of southern Brazil, selected through a non-probabilistic quota sample, totaling 138 respondents. In this type of sampling the interviewer's judgment is decisive, choosing the respondents in locations considered relevant for finding the studied public [56].

As for the quota, we considered the variables of gender, age and education. We sampled, in a balanced way, male and female respondents, in three age intervals (under 24 years old, between 24 and 35 and over 35 years old), and respondents with high school, higher education and post graduate education. The data collection instrument used was a structured questionnaire. To design the questionnaire, after the reverse translation of the CES, we conducted a linguistic analysis of the expressions in the scale for the Brazilian context. As a result, some factors were substituted by descriptors. Still, due to the instrument design strategy, which encompassed bipolarity of emotions, some antonyms were added.

Regarding the data collection procedures, we used both non-personal data collection (sending the survey via e-mail to people that fit the study's objective), and personal (physically approaching people in colleges and shopping malls). Finally, for the data analysis, initially we performed a general description of frequency, followed by a bivariate analysis. As for the bivariate analysis, it was possible to verify whether the demographic variables of sex, age and schooling influenced the answers (significance of the correlation $p > 0.05$). Additionally, since we used a discrete scale (non-normal data), we used a Monte Carlo simulation to identify the appropriated decision limits in the evaluation of the factors' significance.

Factors	Descriptors	Relevant conceptual issues
Anger	Frustrated Angry Irritated	When consumers feel anger, the probability of their acting to change from this state is high [25-27]. Anger can positively influence the purchase of environmentally sustainable products [7, 28], and be one of the resulting feelings towards irresponsible corporative behavior [17, 29, 30].
Discontent	Unfulfilled Discontented	According to Oliver et al. [31], consumers undergo two cognitive-emotional processes when purchasing a product: (i) performance-related formation of expectations; and (ii) confirmation or disconfirmation of these expectations. If the negative disconfirmation occurs, the authors highlight that the consumer will feel unfulfilled.
Worry	Nervous Worried Tense	In consumption, worry is directly related to purchase perceived risk. Conceptually, perceived risks encompass two main issues: uncertainty and consequences [32]. Therefore, the risk concept requires the existence of uncertainty regarding the results of all possible actions [33]. Uncertainty measures the subjective probability that a purchase will result in undesirable consequences to consumers [34].
Sadness	Depressed Sad Miserable	Bauman [35] state that sadness and depression are emotions stemming from the consumer society, characterized by the culture of the ephemeral and indebtedness. At the same time, Araña and León [5] found that sadness can influence the rule decision type that will be used by consumers (whether compensatory or no compensatory).
Fear	Scared Afraid Panicky	As it happens with the worry factor, fear also presents strong relation with the perceived risk in a given purchase. According to Schiffman and Kanuk [36], although researchers have not reached a consensus, there are generally six types of perceived risks addressed in the literature (financial, physical, safety, social, performance and psychological). Risks' degree of importance varies depending on the type of product being purchased and depending on demographic and behavioral characteristics of a given group of consumers. Regarding sustainable product consumption, Singh et al. [30] found that fear can inhibit the purchase intention.
Shame	Embarrassed Ashamed Humiliated	According to Brennan and Binney [37], shame encompasses a wide spectrum of distressing emotions such as humiliation and mortification, which accompany the feeling of being rejected, ridiculed, exposed, or losing the respect of others. In consumption, shame can accelerate purchase decision process [27].
Envy	Envious Jealous	Envy is characterized by feelings of superiority, desire, resentment, and disapproval of emotions, whereas jealousy is characterized by the fear of losing, distrust, and anger.
Loneliness	Lonely Homesick	Bauman [35] highlights that loneliness is greatly present in a consumer society, in which the relationships are superfluous and temporary, and material goods are often purchased in order to fulfill an existential emptiness.
Romantic Love	Sexy Romantic Passionate	Romantic love emphasizes a controlling perspective of passion, which can be related to rationality loss and to the lack of emotional control [38, 39]. In consumption, passion and romance are directly related to attention, selection and selective retention [40].
Love	Loving Sentimental Warm hearted	Commonly ignored in the scales normally used, love was the second most cited emotion in a study that aimed to list the feelings experienced when consumers thought of meaningful objects to them, only behind happiness [41]. Actually, consumers often use objects they claim to "love" as an extension of their personality, that is, these objects (which are few) play an important role for consumers to understand and describe who they are as persons [42].

Fig. 1 CES scale factors and descriptors

Peacefulness	Calm Peaceful	Peacefulness is directly related to the absence of cognitive dissonance after the purchase. That is, when consumers feel they have made the best decision [43].
Contentment	Contented Fulfilled	In consumer behavior research, when supply meets or positively exceeds consumer expectation, consumers feel fulfilled [31].
Optimism	Optimistic Encouraged Hopeful	Studies indicate that optimism is a personal trait of hopeful people [44, 45]. Hope is related to people's belief in better future results. It is detached from the so-called biological emotions [46]. Therefore, hope is constituted of a dimension that addresses the perceived probability of achieving a desired goal [45].
Joy	Happy Pleased Joyful	Joy and pleasantness comprise an affective potential that is greater than satisfaction [47]. Pleasantness is characterized by a combination of high pleasure (joy) and high surprise activation [23]. Hwang and Kim [14] found that joy can motivate environmentally friendly product purchase and repurchase, not out of empathy, but for narcissism.
Excitement	Excited Thrilled Enthusiastic	Excitement is directly related to the feeling of pleasure. Purchase and consumption excitement are related to success, possession, and achievement [48].
Surprise	Surprised Amazed Astonished	Vanhamme [49] describes surprise as a syndrome of reactions characterized by its unobservable manifestations at three levels: behavioral, physiological, and subjective level. According to Kumar [50], surprise has an important function of memory expansion. Vanhamme [51] emphasizes that surprise can exert the function of amplifying subsequent emotions (having a neutral valence).
Other items	Guilty Proud Eager Reeved	Guilt is an emotion that is related both to post-purchase regret and to motivate more socially appropriate behaviors [43]. It has a stronger effect on reparative behaviors when compared to shame [52]. Studies that analyze the choice for sustainable products found that liguilt, just as pride, can be very efficient in motivating the choice for such products [9-12, 28, 53]. Eagerness refers to the uncertainty of the success, to the imagined obstacles, to the idealization of the pleasure to be experienced, and to the amount of time necessary to reach the goal [46, 54]. Relief can be understood as an emotion that follows the satisfaction of expectations. It can also be understood as the elimination of motives that could cause worry or fear [55].

Fig. 1 (continued)

5 Results

The sample can be characterized as follows: 66 women and 72 men; 44 people under 24 years old, 49 with ages between 24 and 35, and 45 subjects over 35 years old; 15 have high school, 51 are graduated and 72 post-graduated.

According to the data presented in Table 1, the majority of consumers preferred to position themselves closer to positive emotions rather than negative, except for the variables "loneliness/welcomeness" and "eagerness/serenity", which presented dichotomy.

This means that a great share of the sample understands that the purchase of a green product can enable attraction, and approximation [57, 58]. Table 1 also shows that the emotions most triggered concerning green products were sympathy (for people

Table 1 Consumer's emotional positioning toward green products

A	-3	-2	-1	0	1	2	3	B
I feel angry in the green product purchase process	1	1	3	28	27	43	35	I feel peacefulness in green product purchase process
Green products make me discontent	1	1	4	26	30	37	39	Green products make me feel contentment
I feel worried when I buy and use green products	1	1	8	36	28	36	28	I feel unconcerned when I buy and use green products
I feel sad when I realize the products I desire are green	0	0	4	20	29	41	44	I feel joy to know that green products are marketed
I fear buying green products	1	4	7	17	33	54	22	I trust the performance of green products
I feel ashamed when I buy green products	0	0	2	26	27	38	45	I feel pride when buying green products
I envy who buys green products	0	0	0	28	13	38	59	I sympathize with people who buy green products
I feel lonely when I look for green products	1	4	8	56	27	25	17	I feel welcomed when I search for green products
I hate green products	0	0	4	32	53	21	28	I love to find green products in the market
I am pessimist about the green products market	1	3	8	19	26	49	32	I am optimist about the green products market
I feel disappointed in purchases that involve green products	0	2	4	32	43	33	24	I feel enthusiasm in purchases that involve green products
I feel frustrated when searching for and buying green products	0	4	5	33	44	33	19	I am positively surprised to find green products
I have contempt for green products	0	2	1	43	52	29	11	I have a passion for green products
I feel guilty when I buy green products	0	0	2	31	49	34	22	I feel relieved when I buy green products
The process of purchasing and using green products makes me feel eager	0	1	2	50	37	28	20	The process of purchasing and using green products brings me serenity

who buy green products), pride (by buying green products), and joy (by knowing that green products are available).

According to the bivariate analysis, women feel more peacefulness, pride, enthusiasm, surprise, relief, and serenity in the green product purchase process. They also manifest greater love and passion in the purchase of environmentally sustainable products and greater support for those who buy products with such characteristics (Table 2). About education level, our results demonstrate that the less educated

Table 2 Bivariate analysis between gender and emotions

Emotions	**Gender**	**Deviation Fem**	**Deviation Male**	**Average Fem**	**Average Male**	**Difference**	**Significance**	**1,96**
I feel peacefulness in green product purchase process		1,17	1,20	1,86	1,21	-0,66	-3,25	Signif.
Green products make me feel contentment		1,38	1,12	1,70	1,39	-0,31	-1,43	
I feel unconcerned when I buy and use green products		1,34	1,17	1,59	0,92	-0,67	-3,13	Signif.
I feel joy to know that green products are marketed		1,10	1,12	1,94	1,54	-0,40	-2,11	Signif.
I trust the performance of green products		1,21	1,27	1,61	1,15	-0,45	-2,15	Signif.
I feel pride when buying green products		1,01	1,16	2,05	1,40	-0,64	-3,48	Signif.
I sympathize with people who buy green products		0,96	1,18	2,29	1,60	-0,69	-3,78	Signif.
I feel welcomed when I search for green products		1,50	1,03	0,94	0,65	-0,29	-1,29	
I love to find green products in the market		1,11	1,04	1,56	1,00	-0,56	-3,06	Signif.
I am optimist about the green products market		1,40	1,20	1,68	1,28	-0,40	-1,81	
I feel enthusiasm in purchases that involve green products		1,15	1,11	1,53	1,00	-0,53	-2,75	Signif.
I am positively surprised to find green products		1,28	1,03	1,42	0,83	-0,59	-2,97	Signif.
I have a passion for green products		0,89	1,04	1,23	0,79	-0,44	-2,64	Signif.
I feel relieved when I buy green products		1,02	0,92	1,67	0,99	-0,68	-4,10	Signif.
The process of purchasing and using green products brings me serenity		1,17	0,95	1,47	0,72	-0,75	-4,11	Signif.

respondents showed more comfort in the process of green product purchase. Specifically, regarding the statistically significant aspects, the respondents with lower education level presented greater peacefulness, confidence, pride, and relief in the process of green product purchase. They also show greater optimism in the development of green product trade and greater support for those who buy green products (Table 3). Age is not statistically significant.

Through an adaptation of Richin's [15] CES Scale, we can affirm that consumers perceive a greater number of benefits rather than harms when buying green products. Additionally, despite the self-conscious emotions are ideal predictors of moral behavior (such as environmentally sustainable purchasing) [7], basic emotions, such as joy, also tends to influence pro-environmental attitudes and behavior. When we compare the results found in this study with other studies that investigate emotions, we

Table 3 Bivariate analysis between education and emotions

Emotion	Education	Deviation Basic	Deviation Grad	Deviation Postgrad	Average Basic	Average Grad	Average Postgrade	Difference	Significance	1,96
I feel peacefulness in green product purchase process		0,99	1,05	1,34	2,00	1,61	1,36	0,64	2,13	Signif.
Green products make me feel contentment		1,70	1,15	1,22	1,67	1,53	1,51	0,15	0,33	
I feel unconcerned when I buy and use green products		1,50	1,35	1,21	1,47	1,14	1,26	0,33	0,80	
I feel joy to know that green products are marketed		1,12	1,12	1,11	2,00	1,65	1,74	0,35	1,11	
I trust the performance of green products		0,93	1,19	1,33	1,87	1,29	1,32	0,57	2,00	Signif.
I feel pride when buying green products		0,86	1,12	1,15	2,07	1,49	1,79	0,58	2,21	Signif.
I sympathize with people who buy green products		0,41	1,17	1,13	2,60	1,76	1,90	0,84	4,91	Signif.
I feel welcomed when I search for green products		1,23	1,26	1,30	0,33	0,78	0,89	0,56	1,57	
I love to find green products in the market		1,12	0,98	1,18	1,40	1,18	1,31	0,22	0,70	
I am optimist about the green products market		0,91	1,10	1,45	2,00	1,65	1,24	0,76	2,62	Signif.
I feel enthusiasm in purchases that involve green products		1,18	0,96	1,27	1,40	1,25	1,22	0,18	0,52	
I am positively surprised to find green products		1,45	1,09	1,20	1,33	1,10	1,08	0,25	0,62	
I have a passion for green products		0,86	0,91	1,07	0,73	1,06	1,01	0,33	1,27	
I feel relieved when I buy green products		0,88	1,03	1,01	1,80	1,16	1,32	0,64	2,50	Signif.
The process of purchasing and using green products brings me serenity		1,29	1,04	1,13	1,33	0,98	1,10	0,35	0,98	

find, in general lines, that emotions not previously investigated in purchase scenario associated with environmentally sustainable products (such as contentment, peacefulness, love, optimism, enthusiasm, surprise, passion, relief, unconcern, sympathy and trust), may happen, positively stimulating decision-making processes.

In addition, inferences can be drawn from the results of the present study and from other researches developed. The association with anger, for example, occurred, fundamentally, when consumers were exposed to irresponsible corporate behaviors [17, 29, 30]. Since when consumers experience anger they are significantly more likely to act to change from this state than when they experience sadness [25–27], it is clear why the studies conducted by Harth et al. [28] and Wang and Wu [7] confirmed that anger can positively influence the purchase of green products.

Additionally, since guilt can induce more appropriate socially behaviors, it is possible to understand why studies that analyzed the choice for sustainable products confirmed that guilt can be a motivating emotion [9–12, 28, 53]. Actions directed/controlled by organizations strongly stimulate guilt in subjects and, consequently, stimulate the desired action in terms of sustainability [59].

With reference to personal factors, the results obtained, grouped with those of other studies already carried out, make it possible to generalize that men tend to have a greater knowledge on environmental issues when compared to women [60–62]. However, women are more likely to purchase green products and more often participate in actions that demand behavior change (for example, recycling and energy and resource conservation) [63, 64]. Comparing the data observed in the present study with data verified in other studies that related the variable age with the purchase of green products, we can affirm that there is no consensus on the age of more ecologically conscious consumers [65, 66]. Finally, about education level, the contrast of our study with others follows the fact that the majority of the people with low levels of education in this study were younger, that is, they are still studying, and thus, have developed ecological awareness and knowledge since early stages of life [67, 68].

6 Conclusions

Regarding the practical implications of the study, the information provided can be used to develop advertising campaigns, both for environmental awareness and for the promotion of environmentally sustainable products (sympathy, pride and joy are examples of factors to be considered in communication). Emotional factors should also be considered in the planning of the quality attributes to be inserted in green offerings, especially regarding the peacefulness, contentment, unconcern, joy, and trust emotions. Still, factors such as unconcern and relief can be used as motivators for a proper disposal.

As future research, it is suggested to evaluate the influence of CES emotions factors in green purchasing decision processes for different types of products, that is, convenience, comparative shopping and specialty goods. Also, due to the existence of research that seeks to integrate emotion and cognition in the buying behavior, future studies can incorporate affective states to the cognitive basis models, a fact that would increase the analytical capacity, allowing a more consistent and reliable behavior description.

References

1. Rustichini, A.: Emotion and reason in making decisions, Science. 310, 1624–1625 (2005).
2. Menzel, S.: Are emotions to blame?-The impact of non-analytical information processing on decision-making and implications for fostering sustainability. Ecological Economics. 96, 71–78 (2013).
3. Araña, J. E., León, C. J.: Do emotions matter? Coherent preferences under anchoring and emotional effects. Ecological Economics 66(4), 700–711 (2008).
4. Sleenhoff, S., Landeweerd, L., Osseweijer, P.: Bio-basing society by including emotions. Ecological Economics. 116, 78–83 (2015).
5. Araña, J. E., León, C. J.: Understanding the use of non-compensatory decision rules in discrete choice experiments: the role of emotions. Ecological Economics 68(8), 2316–2326 (2009).
6. Dolan, R. J.: Emotion, Cognition, and Behavior. Science. 298 (5596), 1191–1194 (2002).
7. Wang, J., Wu, L.: The impact of emotions on the intention of sustainable consumption choices: evidence from a big city in an emerging country. Journal of Cleaner Production. 126, 325–336 (2016).
8. Kao, T. F., & Du, Y. Z. A study on the influence of green advertising design and environmental emotion on advertising effect. Journal of Cleaner Production, 242, 118294 (2020).
9. Onwezen, M.C., Antonides, G., Bartels, J.: The norm activation model: an exploration of the functions of anticipated pride and guilt in pro-environmental behaviour. J. Econ. Psychol. 39, 141–153 (2013).
10. Onwezen, M.C., Bartels, J., Antonides, G.: Environmentally friendly consumer choices: cultural differences in the self-regulatory function of anticipated pride and guilt. J. Environ. Psychol. 40, 239–248 (2014).
11. Antonetti, P., Maklan, S.: Exploring postconsumption guilt and pride in the context of sustainability. Psychology & Marketing 31(9), 717–735 (2014b).
12. Antonetti, P., Maklan, S.: Feelings that make a difference: how guilt and pride convince consumers of the effectiveness of sustainable consumption choices. Journal of Business Ethics 124 (1), 117–134 (2014a).
13. Brick, C., Sherman, D. K., Kim, H. S.: "Green to be seen" and "brown to keep down": Visibility moderates the effect of identity on pro-environmental behavior. Journal of Environmental Psychology 51, 226–238 (2017).
14. Hwang, K., Kim, H.: Are Ethical Consumers Happy? Effects of Ethical Consumers' Motivations Based on Empathy Versus Self-orientation on Their Happiness. Journal of Business Ethics. 1–20 (2018).
15. Richins, M.L.: Measuring Emotions in the Consumption Experience, Journal of Consumer Research. 24, 127–146 (1997).
16. Babin, B. J., Griffin, M., Borges, A., Boles, J. S.: Negative emotions, value and relationships: differences between women and men. Journal of Retailing and Consumer Services 20(5), 471–478 (2013).
17. Xie, C., Bagozzi, R. P., Grønhaug, K.: The role of moral emotions and individual differences in consumer responses to corporate green and non-green actions. Journal of the Academy of Marketing Science. 43(3), 333–356 (2015).
18. Honea, H., Dahl, D. W.: The promotion affect scale: defining the affective dimensions of promotion. Journal of Business Research. 58(4), 543–551 (2005).
19. King, S. C., Meiselman, H. L., Carr, B. T.: Measuring emotions associated with foods in consumer testing. Food Quality and Preference. 21(8), 1114–1116 (2010).

20. Lichtlé, M. C., Plichon, V.: Les émotions ressenties dans un point de vente: Proposition d'une échelle de mesure. Recherche et Applications en Marketing (French Edition). 29(1), 3–26 (2014).
21. Laros, F. J., Steenkamp, J. B. E.: Emotions in consumer behavior: a hierarchical approach. Journal of business Research. 58(1), 1437–1445 (2005).
22. De Medeiros, J. F., Sampaio, C. H., Perin, M. G.: Fatores emocionais no processo de tomada de decisão de compra. Psico 41(4), 439–446 (2010).
23. Watson, L., Spence, M. T.: Causes and consequences of emotions on consumer behaviour: A review and integrative cognitive appraisal theory. European Journal of Marketing. 41(56), 487–511 (2007).
24. Gaur, S. S., Herjanto, H., Makkar.: Review of emotions research in marketing, 2002–2013. Journal of Retailing and Consumer Services 21(6), 917-923 (2014).
25. Izard, C.E.: Human Emotions. New York: Plenum Press (1991).
26. Garg, N., Inman, J. J., Mittal, V.: Incidental and task-related affect: A re-inquiry and extension of the influence of affect on choice. Journal of Consumer Research 32(1), 154–159 (2005).
27. Koshkaki, E. R., Solhi, S.: The facilitating role of negative emotion in decision making process: A hierarchy of effects model approach. The Journal of High Technology Management Research. 27(2), 119–128 (2016).
28. Harth, N.S., Leach, C.W., Kessler, T.: Guilt, anger, and pride about in-group environmental behaviour: different emotions predict distinct intentions. Journal of Environmental Psychology. 34, 18–26 (2013).
29. Grappi, S., Romani, S., Bagozzi, R. P.: Consumer response to corporate irresponsible behavior: Moral emotions and virtues. Journal of Business Research 66(10), 1814–1821 (2013).
30. Singh, J. J., Garg, N., Govind, R., Vitell, S. J.: Anger strays, fear refrains: The differential effect of negative emotions on consumers' ethical judgments. Journal of Business Ethics. 1–14 (2016).
31. Oliver, R. L., Balakrishnan, P. S., Barry, B.: Outcome satisfaction in negotiation: A test of expectancy disconfirmation. Organizational Behavior and Human Decision Processes. 60(2), 252–275 (1994).
32. Bauer, R.: Consumer behavior as risk taking. In: Hancock, R. (ed.). Dynamic marketing for a hanging world. Chicago: American Marketing Association, 389–398 (1960).
33. Yates, J.: Risk-taking behavior. Manchester: John Wiley & Sons (1992).
34. Zikmund, W., Scott, J.: Variety analysis of perceived risk self-confidence and information sources. Advances in Consumer Research. 1, 406–416 (1974).
35. Bauman, Z.: Liquid modernity. John Wiley & Sons (2013).
36. Schiffman, L.G., Kanuk, L.L.: Consumer Behavioral. New Jersey: Prentice Hall (2014).
37. Brennan, L., Binney, W.: Fear, guilt, and shame appeals in social marketing.Journal of business Research 63(2), 140–146 (2010).
38. Vallerand, R., Blanchard, C., Mageau, G., Koestner, R., Ratelle, C., Léonard, M., Gagné, M.: Les Passions de l'Âme: On Obsessive and Harmonious Passion. Journal of Personality and Social Psychology. 85(4), 756–767 (2013).
39. Vallerand, R.: On the psychology of passion: In search of what makes people's lives most Worth living. Canadian Psychology. 49(1), 13 (2008).
40. Kotler et al. Marketing Management. Pearson. (2016).
41. Schultz, S.E., Kleine, R.E., Kernan, J.B.: These are a few of my favorite thinks: toward an explication of attachment as a consumer behavior. Advances in Consumer Research. 16 (1), 359–366 (1989).
42. Ahuvia, A. C.: Beyond the extended self: Loved objects and consumers' identity narratives. Journal of Consumer Research 32(1), 171–184 (2005).
43. Blackwell, R.D., Miniard, P.W., Engel, J.F.: Consumer Behavior. Cincinnati: tenth ed. South-Western College Pub (2011).
44. Scheier, M. F., Carver, C. S.: Optimism, coping, and health: assessment and implications of generalized outcome expectancies. Health psychology. 4(3), 219 (1985).

45. Bryant, F. B., Cvengros, J. A. Distinguishing hope and optimism: Two sides of a coin, or two separate coins? Journal of Social and Clinical Psychology 23(2), 273–302 (2004).
46. MacInnis, D. J., De Mello, G. E.: The concept of hope and its relevance to product evaluation and choice. Journal of Marketing. 69(1), 1–14 (2005).
47. Mano, H., Oliver, R. L.: Assessing the dimensionality and structure of the consumption experience: evaluation, feeling, and satisfaction. Journal of Consumer research. 20(3), 451–466 (1993).
48. Vigneron, F., Johnson, L. W. A review and a conceptual framework of prestige-seeking consumer behavior. Academy of Marketing Science Review. 1999(1), 1–15 (1999).
49. Vanhamme, J.: La surprise et son influence sur la satisfaction des consommateurs: le cas de l'expérience de consommation/achat. Louvain-la-Neuve, Bélgica: Université Catholique de Louvain. Thèse Doctorale (Doctorat en Sciences de Gestion), Institut d'Administration et de Gestion – Unité de Marketing, Université Catholique de Louvain (2002a.).
50. Kumar, A.: Customer delight: creating and maintaining competitive advantage. Bloomington: Indiana University. Phd Diss, School of Business, Indiana University (1996).
51. Vanhamme, J.: L'influence de la surprise sur la satisfaction des consommateurs: une expérimentation pilote. In: Conférence de l'Association Française du Marketing, 2002-b, Lille. Actes. Association Française du Marketing. 14, 17–43 (2002b).
52. Ghorbani, M., Liao, Y., Çayköylü, S., Chand, M.: Guilt, shame, and reparative behavior: The effect of psychological proximity. Journal of Business Ethics 114(2), 311–323 (2013).
53. Peloza, J., White, k., Shang, J.: Good and Guilt-Free: The Role of Self-Accountability in Influencing Preferences for Products with Ethical Attributes. Journal of Marketing. 77 (1), 104–119 (2013).
54. Lazarus, R. S.: Progress on a cognitive-motivational-relational theory of emotion. American psychologist 46(8), 819–835 (1991).
55. Lazarus, R. S., Averill, J. R.: Emotion and cognition: With special reference to anxiety. In Anxiety: Current Trends in Theory and Research. 2, 241–290 (1972).
56. Malhotra, N. K.: Marketing Research: An Applied Orientation. New Jersey: Prentice Hall, 6th Edition, p. 936 (2009).
57. Frijda, N. H., Kuipers, P., Ter Schure, E.: Relations among emotion, appraisal, and emotional action readiness. Journal of personality and social psychology 57(2), 212 (1989).
58. Bagozzi, R. P., Gopinath, M., Nyer, P. U.: The role of emotions in marketing. Journal of the academy of marketing science 27(2), 184 (1999).
59. Theotokis, A., Manganari, E.: The impact of choice architecture on sustainable consumer behavior: The role of guilt. Journal of Business Ethics. 131(2), 423–437 (2015).
60. MacDonald, W. L., Hara, N.: Gender differences in environmental concern among college students. Sex Roles. 31(5), 369–374 (1994).
61. Straughan, R. D., Roberts, J. A.: Environmental segmentation alternatives: a look at green consumer behavior in the new millennium. Journal of Consumer Marketing. 16(6), 558–575 (1999).
62. Boztepe, A.: Green marketing and its impact on consumer buying behavior. European Journal of Economic & Political Studies 5(1), 1–15 (2012).
63. Mostafa, M.: Gender differences in Egyptian consumers' green purchase behaviour: the effects of environmental knowledge, concern and attitude. International Journal of Consumer Studies. 31, 220–229 (2007).
64. Chekima, B., Wafa, S. A. W. S. K., Igau, O. A., Chekima, S., Sondoh, S. L.: Examining green consumerism motivational drivers: does premium price and demographics matter to green purchasing?. Journal of Cleaner Production 112, 3436–3450 (2016).
65. Kinnear, T. C., Taylor, J. R., Ahmed, S. A.: Ecologically concerned consumers: who are they?. The Journal of Marketing. 38 (2), 20–24 (1974).
66. de Medeiros, J. F., Ribeiro, J. L. D., Cortimiglia, M. N.: Influence of perceived value on purchasing decisions of green products in Brazil. Journal of Cleaner Production 110, 158–169 (2016).

67. Gan, C., Wee, H. Y., Ozanne, L., Kao, T. H.: Consumers' purchasing behavior towards green products in New Zealand. Innovative Marketing 4(1), 93–102 (2008).
68. Mahesh, N., Ganapathi, R.: Influence of consumer's socio-economic characteristics and attitude on purchase intention of green products. Int. J. Bus. Manag. 4, 33–37 (2012).

Prioritization of Critical Factors for the Improvement in the Visual Daily Shop Floor Management in Manufacturing Using AHP—A Case Study

J. C. Pereira and M. Bittencourt

Abstract This paper discusses the framework for identifying the critical factors in the visual daily production management system of an aircraft engine overhaul company aiming at reaching Operational Excellence with higher effectivity. This topic is very important because considering the continuous advances in information and communication technologies, organizations are generating and dealing with increasingly amount of data. Managers are often overwhelmed with data reports collected from multiple systems such as ERP, performance scorecards, and intelligence software. Team involvement around production targets in a volatile global environment is critical for companies that want to high-perform on managing their operations. An excellent tool for coordinating the production flow while spreading the teamwork spirit is the daily visual management. With the support of the ERP system, and several data collection, it is possible to visually show the dynamics of the production, processes that are working well, and processes that are bottlenecks, which need more attention. As a methodological approach, a case study was conducted, by conducting a survey, based on information obtained from previous literature and in interviews with employees from the field. As a result, the method revealed that the most significant factors for the Improvement in the Visual Daily Shop Floor Management in Manufacturing are: Communication (Meetings with leadership and dialogue with collaborators); Standardization (a single channel of metrics); Scanning (ADD technology to sup-port other factors); Participation (Give resources to employees to participate and give feedback) and Speed (Implement Kanban for identification and immediate response to problems.

J. C. Pereira (✉)
National Laboratory for Scientific Computation (LNCC) and Petropolis Catholic University, Petropolis, RJ, Brazil
e-mail: jpereira@lncc.br

M. Bittencourt
Department of Master in Engineering, Petropolis School of Engineering, Petropolis Catholic University, Petropolis, RJ, Brazil
e-mail: marcos_lisboa@hotmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_47

Keywords Daily shop management · Analytic hierarchy process · Critical factors · Engine overhaul companies

1 Introduction

Companies are experiencing an aggressive competition, rapid changing scenarios, implementation of technologies for competitive productivity, macro-market crises, etc. This challenging scenario needs to be faced with managerial adaptability, commitment to the results in all hierarchical levels, strategic, tactical and operational. Operational excellence is a not a new concept.

Previous work dealing with visual Daily Shop Floor Management in Manufacturing are, are for instance, the study of Ferro and Gouveia [1], which explained that visual management importance has been increasing in companies nowadays, mainly with the goal of staying competitive in the current world of so many uncertainties In Addition to a good business strategy implemented, companies need to use tools to reduce risks in the production line.

It is widely known that operational accidents affect the productivity of manufacturing industry [2] and evidences show that the adoption of a safety operation can influence economic performance. Several authors, such as [3–8] focused on showing that efficient communication and easy-to-read visualization are essential points for good management of a production line. These authors explained that visual management has an important role in the education of the production teams and their managers in order to achieve operational excellence.

Daily Visual Management system connects the objectives and strategies of the company at all levels, in a simple and intuitive way, seeking the standardization of products and services, traceability of information, prioritization of non-conformities, facilitating fast and effective actions to be taken [9, 10]. Considering the continuous advancements in information and communication technologies, and the fast flow of information in the business environment today, organizations are challenged to generate and deal with increasingly amount data. The managers are often overwhelmed with data reports collected from multiple systems such as ERP, performance scorecards, and intelligence software. Team involvement around production targets in a volatile global environment is critical for companies that want to attain high performance and excellence on managing their operations.

Another important contribution was given by Rusev [11], which made it clear that the culture of operational excellence aims to seek employee engagement, the pursuit of continuous improvement, the alignment of strategies to systematically deliver within the deadline a product or service with the quality that your customer expects, for operational excellence to work, must be aligned with the whole company making everyone know why they are doing that task and what is behind it, for this, the principles of operational excellence must be deeply embedded in the culture of the organization, when achieved employee engagement, they will be systemically

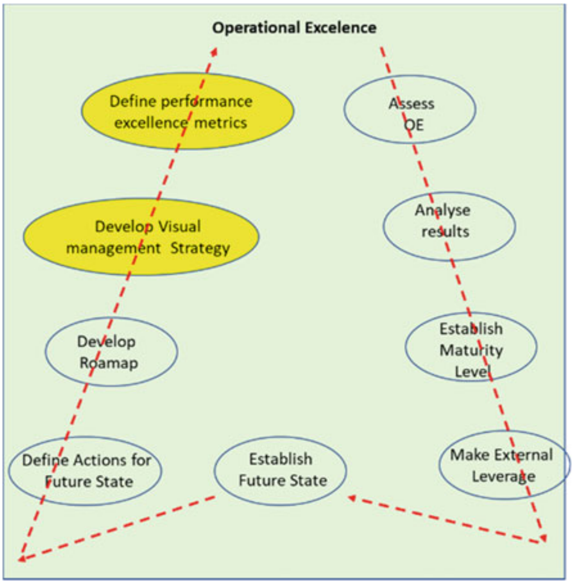


Fig. 1 OE Adaptation from the original of Rusev [11]

stimulated a process of continuous improvement of all processes, aligned with the strategic thinking of the company aiming at its client.

Daily Visual Management, Communication and Tracking of performance metrics digitally is a key factor in attaining of operational excellence. Figure 1, which is an adaptation from the original of Rusev [11] shows the interaction among the different factors in the development of the process of operational excellence.

Operational Excellence was defined as a consequence of the correct practices of a company that can be classified under four dimensions [11; Culture, continuous process improvement, business alignment and results, these are fundamental to achieve operational excellence. Figure 2 shows the dimensions of operational excellence and its principles, which is an adaptation from the original of Rusev [11].

Daily management was clarified is the ongoing process to ensure that work is being done in the right way and at the right time so that business success can be achieved as defined by the company's strategy [1]. The author elucidated that the biggest fear of companies is not being able to achieve the established goals, which was very normal in companies that do not have an effective management of strategies. The Daily Management System came precisely to follow up the strategy put in place much faster and more efficiently, so that actions can occur according to strategic planning in the shortest possible time, and if there is any non-compliance in the process the corrective and corrective actions are taken immediately.

Visual Management is the methodology that seeks transparency in the production system [10] and is considered a very important element of the Lean methodology that should always be present when implementing the Lean methodology. Visual

Fig. 2 Dimensions and principles—Adaptation from the original of Rusev [11]

management is interpreted as a vehicle to interpret current performance and provide an opportunity to stop some task or operation that went wrong, so that actions can be taken [12].

The impact of visual communication on area management can be defined by 5 min on the shop floor instead of 50 min of presentation [13]. Visual Management means the ability to understand the status of the production area in 5 min or less, through a simple observation. This author explained that in the shop floor and in the production lines in general, there are three main types of communication: visual communication, verbal communication and written communication (e.g. e-mail), considering that writing is the least intuitive of them, the same should be as visual as possible. To facilitate understanding by the receiver, language should be as visual and appropriate as possible, this maximizes the time of perception and understanding of information making any communication with any level be it managerial or operational much more effective.

People are more committed when they see themselves in the process, and can visually assimilate that they are contributing to something important, with this the employee is motivated to contribute ideas to improve the process, ideas that come from people with a great technical knowledge and who have a differentiated view of people who are in leadership positions or in the strategic core of the company, can bring fantastic innovations and contributions to the area and even to the company as a whole [12].

Saaty [14] made his contribution to decision making science by proposing AHP as a measurement tool that is used to rank on comparison scales that aid decision making.

These comparisons should be made through current measurements or reasoned scales that reflect preferences between comparisons.

Vargas [15] highlighted that there is a desire in organizations to build clear, objective and mathematical criteria in order to be able to measure them. Saaty [14] emphasized that decision-making is, in its entirety, a cognitive mental process resulting from the selection of the most appropriate course of action, based on tangible and intangible criteria) arbitrarily chosen by those who make the decision. The author pointed out that the AHP tool is used in complex decisions, where there are many variables and criteria to be considered for the prioritization of alternatives.

In order to verify and evaluate the factors that will be analyzed, the numbers are based on perceptions and judgments of the evaluators who have extensive knowledge about the subject to be evaluated. The great differential of AHP compared to other comparison techniques is the fact that AHP can transform the often-empirical comparisons into numerical values that are processed and compared, and these numerical values allow the evaluation of each of the elements within the defined hierarchy. This author proposed steps to use AHP, stating that initially, the problem to be analyzed should be defined and thus set the target to be achieved, after setting the goal, the goal must be decomposed into hierarchical criteria so that they can be analyzed and compared independently, with the well-defined criteria. The criteria should be decomposed into alternatives, from the alternatives, employees with experience in the subject should systematically evaluate all alternatives through their own judgment for each criterion. Figure 3 shows and example of AHP, which is an adaptation from the original of Vargas [15].

None of the previous studies dealt with the critical factors in the use of visual management in the shop floor of an aeronautical maintenance company. In this paper a comprehensive study is presented focused on an in-depth analysis of the critical factors that could impact the success of the operations. It may help manufacturing engineers and decision makers to deal with these factors and allocate resources

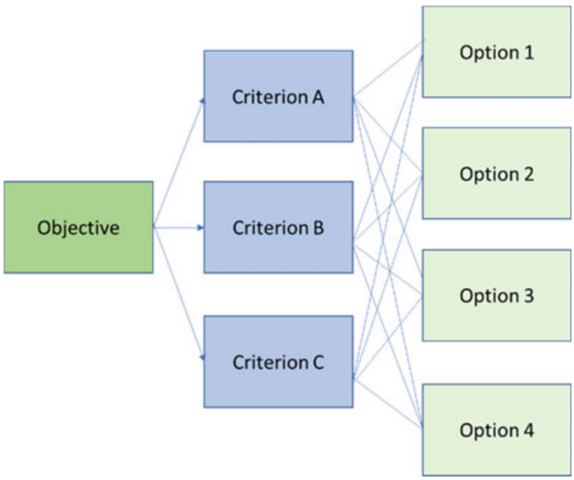


Fig. 3 Example AHP—Adaptation from the original of Vargas [15]

to improve operational excellence. The paper proposes responses to two research questions:

Research Question 1—What are the most critical factors to be considered in the Visual Daily Management System of Production that ensure operational excellence in an aeronautical maintenance company?

Research Question 2—In response to the second question: What actions should be taken to implement a Daily Visual Management System that guarantees operational excellence in an aeronautical maintenance company?

The paper is organized in five Sections. Section 2 presents the objective, Sect. 3 describes the method, Sect. 4 addresses the results and Sect. 5 the conclusion.

2 Objective

This paper proposes a framework for defining and prioritizing the critical factors for improving the current Daily Management Production System on the shop floor by using AHP, aiming at reaching Operational Excellence effectively. On the shop floor, the critical processes require tools that promote rapid and effective actions. This case study evaluates lack of speed and efficiency in the daily visual management system of production on the shop floor. This problem can lead to delayed decision making and even wrong decision making. A system that does not depict the processes with accuracy and does not work properly when transmitting the message to users, can also cause disturbances in production, and become a tool without utility.

3 Method

The case study was conducted by analyzing and reviewing previous work on Daily Production Visual Management applicable to shop floor; by conducting a survey, based on information obtained from previous literature and in interviews with employees from the field. Figure 4 shows the flowchart with the steps of the method.

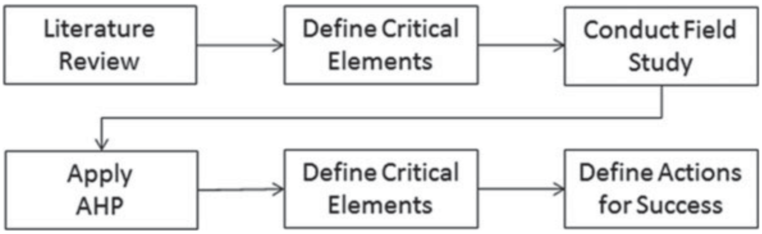


Fig. 4 Steps of methodology

Table 1 Relative importance scale

Importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute extreme importance
2, 4, 6, 8	Intermediate values

After performing interviews and brainstorming sessions with the expert team of three production leaders, all with more than 10 years of shop experience, it was decided that the 5 main elements that may impact on effectiveness of the system are the following: 1—Dashboard Size—Overall size of the visual board inside the shop; 2—Letters Size—Letters size compared to the visual board size; 3—Dashboard Layout—The shape/design of the fields which the information is displayed; 4—Dashboard Location—The location/place that the visual board is placed in the shop; 5—Digital Technology used—Use of LCD, leds, instant online information.

Once these 5 elements were defined, a questionnaire was created for field study by using the software "Google Forms". The most significant factors for the improvement of the Visual Daily Production Management System on the shop floor were identified from the previous work on the subject and these were analyzed and validated by experienced individuals in the field. The collected data was analyzed and prioritized by using AHP. It is an excellent tool to provide weight for the different risk levels, the first phase is to create a pairwise evaluation matrix (A), as introduced by Saaty [14] by utilizing the relative importance scale shown in Table 1.

The matrix A represents a pairwise evaluation matrix where each element a_{ij} (i, $j = 1, 2, \ldots, n$) represents the proportional importance of two compared elements (i and j). The higher its value, the stronger the preference of first element (i) over the second (j). The matrix is shown in Eq. (1).

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}, \quad a_{ii} = 1, \quad a_{ji} = \frac{1}{a_{ij}}, \quad a_{ij} \neq 0 \tag{1}$$

Subsequently, the priority weights of each criterion are established with the next equation:

$$w_i = \frac{1}{n} \left(\sum_{j=1}^{n} a_{ij} \right) \Big/ \left(\sum_{k=1}^{n} a_{kj} \right) \tag{2}$$

Table 2 Random consistency index

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The succeeding step in the AHP method is to demonstrate reliability of data [14]. suggested a basic equation to check if the evaluation pairwise matrix is reliable. The consistency index (CI) is calculated as follows:

$$CI = (\lambda_{\max} - n) \big/ (n - 1) \tag{3}$$

where n is the order of the matrix A and $\lambda_{\max}$ is its dominant Eigenvector, which satisfies the following equation:

$$\sum_{j=1}^{n} a_{ji} w_j = \lambda_{\max} w_i \tag{4}$$

A consistency ratio (CR) estimation is then needed to verify the sensible consistency. The CR value can be estimated by Eq. (4). The CR value needs to be equal or smaller than 0.10 if not the expert elicitation needs be revised to get a reliable result. In the equation, CRI represents the random consistency index (RCI), presented by [14].

$$CR = CI \big/ RCI$$

The RCI assessment table is obtained from Table 2, propose by [14].

4 Results

The survey revealed the factors considered most important by the research participants to improve the visual production management system, the AHP tool was used to prioritize critical elements. First, the comparative matrix was constructed, which each pair of established elements is compared, as to its importance, on a scale from 1 to 9, called Fundamental Scale, proposed by Saaty [14]. Table 3 shows the comparative matrix with the 6 factors considered the most important, and comparisons were made based on Table 1. Experts recorded all the relative importance between the elements on a matrix.

Based on the Table 3, the normalized matrix was obtained as shown in Table 4.

With the normalized matrix the next step was to obtain the Eigen Vector, which was obtained by the sum of values of the lines found in the normalization matrix and divided by the number of elements. With this, the numbers that provide the weights

Table 3 Comparative matrix

Critical Elements	Daily meeting with leaders	Visual Signs (Kanban) by Cell	Large table/screen of metrics for meetings	Feedback from employees on tablets/screens	Scan frames/screens with touch/voice interaction	Use "App" technology for use on
Daily meeting with leaders	1	5	1	3	7	9
Visual Signs (Kanban) by Cell	1/5	1	1/3	1	1/3	1
Large table/screen of metrics for meetings	1	3	1	3	5	5
Feedback from employees on tablets/screens	1/3	1	1/3	1	1	3
Scan frames/screens with touch/voice interaction	1/7	3	1/5	1	1	5
Use "App" technology for use on mobile phones and tablets	1/9	1	1/5	1/3	1/5	1

Table 4 Normalized matrix

Critical Elements	Daily meeting with leaders	Visual Signs (Kanban) by Cell	Large table/screen of metrics for meetings	Feedback from employees on tablets/screens	Scan frames/screens with touch/voice interaction	Use " App" technology for use on mobile phones and
Daily meeting with leaders	0,358	0,358	0,325	0,321	0,481	0,375
Visual Signs (Kanban) by Cell	0,072	0,072	0,108	0,108	0,023	0,042
Large table/screen of metrics for meetings	0,358	0,214	0,325	0,321	0,344	0,208
Feedback from employees on tablets/screens	0,119	0,072	0,108	0,108	0,069	0,125
Scan frames/screens with touch/voice interaction	0,051	0,214	0,065	0,108	0,069	0,208
Use "App" technology for use on mobile phones and tablets	0,040	0,072	0,065	0,035	0,013	0,042
Sum	1	1	1	1	1	1

were obtained to identify the importance of each of the 6 factors identified. Table 5 presents the normalized matrix with the calculated Eigen Vector.

Once the matrix was completed, the consistency index was calculated and found to be less than 0.1. This allows the calculations to continue once the data is proved to be consistent. The AHP showed that the Daily meeting with leaders would be the element that would highly impact on the effectiveness of the system. The use of Large table/screen of metrics for meetings would also allow the achievement of Operational excellence.

Table 5 Eigen vector matrix

Critical Elements	Daily meeting with leaders	Visual Signs (Kanban) by Cell	Large table/screen of metrics for meetings	Feedback from employees on tablets/screens	Scan frames/screens with touch/voice interaction	Use "App" technology for use on mobile phones and tablets	EIGEN VECTOR
Daily meeting with leaders	0,358	0,358	0,325	0,321	0,481	0,375	0,37
Visual Signs (Kanban) by Cell	0,072	0,072	0,108	0,108	0,023	0,042	0,07
Large table/screen of metrics for meetings	0,358	0,214	0,325	0,321	0,344	0,208	0,30
Feedback from employees on tablets/screens	0,119	0,072	0,108	0,108	0,069	0,125	0,10
Scan frames/screens with touch/voice interaction	0,051	0,214	0,065	0,108	0,069	0,208	0,12
Use "App" technology for use on mobile phones and tablets	0,040	0,072	0,065	0,035	0,013	0,042	0,04
Sum	1	1	1	1	1	1	1

5 Conclusion

The objective of the research is to define and prioritize critical factors for the improvement in the daily visual management process of production in a maintenance workshop of aeronautical engines using the AHP tool. Considering methodological guidelines of publications in the area in question, two research questions were defined.

In response to the first question related to the most critical factors to consider in the Daily Visual Production Management System that ensure operational excellence in an aeronautical maintenance company, it can be considered that the analysis of recent publications, field research, and prioritization of the most critical elements through the AHP tool provided substance for the response. The most critical factors to consider are: Communication (Meetings with leadership and dialogue with employees); use of large table/screen of metrics for meetings; and Scan frames/screens with touch/voice interaction.

In response to the second question regarding the actions that should be taken to implement a Daily Visual Production Management System that guarantees operational excellence in an aeronautical maintenance company, the following actions should be taken for implementation: 1—Improve communication through daily performance monitoring meetings with leadership, interacting with visual channels, including LCD screens and tablets with touch and voice technology, through which employees can respond to performance problems immediately, passing feedback to the system, to the team and leadership; 2—Have a visual channel of significant layout and size (large LCD screen) in central area of production, promoting clearer and unique communication of daily performance for access and visualization of all in real time—daily meetings should take place around this screen, which shows metrics and performance graphs of the company and each cell in 24 h a day, 7 days a week, and can be operated by any of the employees; 3—Implement "App" for performance monitoring by employees in their respective cells, through tablets or mobile phones connected to the same central system that accompanies the performance of the entire production area—employees must have empowerment to be able to address performance problems in these channels, passing feedback to the system, to be discussed in daily meetings and viewed by all on LCD screen in the production area; 4—Implement visual means such as Kanbans (lights or colour plates) in each work cell in order to inform remotely and instinctively any potential performance problems, and thereby give the team immediate response conditions.

The actions highlighted in this study, as response to the second question of the research, when implemented, will be of important value in the production process. The company will have direct benefit in its communication, standardization, digitization, and weighting of its employees, encouraging them to contribute directly to continuous improvement.

Both the critical factors and the actions for implementation are aligned with previous studies on the theme of visual management of production, this case study was developed in a company of maintenance of aeronautical engines, benefiting from field research with professionals in the area to obtain more data directed to the improvement of visual production systems in this branch of production. However, it can also be applied in other fields.

As proposed in the introduction, the study provided responses to the two research questions. AHP proved to be an effective method to assess and prioritize the critical factors. The in-depth analysis of current literature about the subject and the opinion of experienced individuals allowed the identification of critical factors in this process. This study is very important, because understanding the critical factors can influence the decision of operational managers, maintenance professionals, safety engineers and decision makers in companies.

References

1. Ferro J. Gouveia R., Strategy-driven daily management. Planet Lean, disponível em http://planet-lean.com/how-to-create-an-effective-daily-management-system (2015).
2. Pereira, J.C., Bordeaux, R., Zotes, L.P., Lima, G.B.A., Quelhas, O.L.G. Probabilistic risk analysis of safety management system failure and impact on economic performance: The case of jet engine manufacturing., International Journal of Management and Decision Making, 14(4), pp. 345-372 (2015).
3. Steenkamp L., Hagedorn-Hansen D., Oosthuizen G., Visual management system to manage manufacturing resources, ScienceDirect (2016).
4. Tezel, A., The functions of visual management. Proceedings of the International Research Symposium, Salford, UK (2009).
5. Rasmussen N., Chen C.Y., Bansal M., Business dashboards, a visual catalogue for design and deployment. Hoboke, New Jersey: John Wiley & Sons Inc. (2009).
6. Kawamoto T., Mathers B., Key success factors for a performance dashboard. DM Rev 20–1 (2007).
7. Chen W., Li J., Safety performance monitoring and measurement of civil aviation unit, Journal of Air Transport Management (2016).

8. Bhasin S., Burcher P., Lean viewed as a philosophy, Journal of Manufacturing Technology Management, 17(1), 56–72 (2006).
9. Eaidgah Y., Arab Maki A., Kurczewski K., Abdekhodaee A., Visual management, performance management and continuous improvement, International Journal of Lean Six Sigma (2015).
10. Bateman N., Visual management and shop floor teams – development, implementation and use, International Journal of Production Research (2017).
11. Rusev, S. J. Konstatinus, Operational Excellence Assessment Framework for Manufacturing Companies. Procedia CIRP, 55, 272–277 (2016).
12. Liker, J., The Toyota way. New York: McGraw-Hill, p. 37.Iuga (2005).
13. Iuga, M.V. Visual communication in lean organizations. 8th International Conference on Manufacturing Science and Education – MSE 2017 "Trends in New Industrial Revolution". MATEC Web Conf., 121, (2017).
14. Saaty T.L., The analytic hierarchy process: Planning, setting priorities, resource allocation. New York: McGraw-Hill International Book Co. (1980).
15. Vargas R., Utilizando a programação multicritério (Analytic Hierarchy Process - AHP) para selecionar e priorizar projetos na gestão de portfólio. PMI Global Congress (2010).

Economic Production Quantity for Products with Deterioration and Shortage Under Advanced-Cash-Credit Payment Scheme

Mariana Alves Londe, Gabriel Calvo Martinez, and Adriana Leiras

Abstract To increase the suitability of the existing models to real-life situations, this paper proposes a new Economic Production Quantity (EPQ) model for products with constant deterioration, the possibility of shortages, and Advanced-Cash-Credit (ACC) payment policy. This policy has three phases: (1) the buyer pays a part before the items are delivered, (2) payment on the act of delivery, and (3) postponed payment. This study contributes to the literature with the addition of shortages and its effects on the profit of the seller to an EPQ with ACC, deterioration, and discounted cash flow analysis. For this, we calculate both the optimum cycle time and price and the maximum permissible time for shortages. A sensibility analysis illustrates the applicability of the proposed approach. We conclude that the demand is the parameter with the most significant influence in the profit of the model, instead of the many costs and taxes associated with shortage, deterioration, or backlog.

Keywords EPQ · Shortage · Advanced-cash-credit

1 Introduction

The Economic Production Quantity (EPQ), introduced by Taft [1] and Harris [2], calculates the optimum value of the production batch of a single product, with constant demand and costs. Since its introduction, the model has been expanded in several ways. These addictions intend to augment its realism, thus improving the

M. A. Londe (✉) · G. C. Martinez · A. Leiras
Department of Industrial Engineering, PUC-Rio, Rio de Janeiro, RJ, Brazil
e-mail: mlonde@aluno.puc-rio.br

G. C. Martinez
e-mail: gabrielmartinez2812@gmail.com

A. Leiras
e-mail: adrianaleiras@puc-rio.br

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_48

comprehension of the studied phenomenon. The possibilities of deterioration and postponement of payment are some of the most studied changes [3].

Product deterioration happens to items that lost their quality throughout time and are, therefore, instable [4]. This deterioration may be due to end of shelf life, drying, vaporization, and other physicochemical processes [5]. This process occurs, for example, to food products, medicines, chemical and/ or radioactive products, and fuels. Deteriorating products are frequently combined with the possibility of shortage [5]. If a product deteriorates in an unforeseen manner and the decision-maker has not enough time for stock replenishment, a shortage may occur.

For the case of postponed payment, there are several possible policies for study and implementation. The advanced-cash-credit (ACC) policy considers an advanced payment of a part of the cost, the immediate payment once the product is received, and a subsequent delay of the remaining cost [6]. Those characteristics make this payment policy frequently used on situations in which product deterioration is possible [7], usually with a discounted cash flow analysis [8].

Tsao et al. [9] introduces the EPQ model with deterioration and ACC payment policy to maximize the profit by defining the selling price of the product and the optimum cycle time. This study aims to extend the model proposed by Tsao et al. [9], with the inclusion of the possibility of shortages and backlog. Therefore, we increase the realism of the EPQ model and analyze the effect on the profit. In addition to identifying the optimal selling price and cycle time, this paper determines the maximum time allowed for product shortages. The contribution of this study is, then, the introduction of shortages to an EPQ with ACC policy and deterioration, with discounted cash flow analysis, which, up to our knowledge, has not been studied before.

After this introductory section, Sect. 2 presents a review of EPQ literature, with a focus on deterioration, shortage, and trade credits. Section 3 introduces the mathematical model alongside the calculations to maximize profit, with the used algorithm shown in Sect. 4. In Sect. 5, there is a sensibility analysis of the parameters. Finally, Sect. 6 presents the concluding remarks.

2 Literature Review

As show in Andriolo et al. [3], the original EPQ model has gone through several additions and hypotheses relaxations on the hundred years since its introduction. Of the four most studied areas (imperfect products, trade credits, deterioration, and variable demand), the deterioration and trade credits are of interest for this work.

The model with product deterioration was first introduced by Ghare and Schrader [10], with a constant rate of deterioration through time. The model has been extensively studied and gradually developed by researchers such as Dave and Patel [11], Hariga [12], Chakrabarti and Chaudhuri [13], Chang and Dye [14], and Ouyang et al. [15].

Meanwhile, trade credits first appeared on the work of Goyal [16] and have become one of the most studied topics in EPQ models [17–19]. As detailed by Goyal and Giri [4], one of the tendencies in literature is the combination of trade credits and deterioration, such as in Chang [20], Chung and Huang [21] and Liao [22].

Furthermore, models that combine deterioration and shortages are also common. Chang and Dye [14], Abad [23], Wu et al. [24], Wu [25] and Begun [26] are examples of this trend. Taleizadeh and Nematollahi [27] studied an EPQ that combines deterioration with trade credits and backlog, thus combining the three different possibilities on a single model.

The addition of shortages and backlog is a factor that can increase the truthiness of the model. Grubbstrom and Erdem [28] implement this approach to the Economic Order Quantity (EOQ) model. For the EPQ, the model was developed by Cárdenas-Barrón [29].

Chen and Teng [8] analyze a model with deterioration and trade credits with a discounted cash flow analysis. The authors defend that this analysis should be used both in the calculation of costs and revenues and demonstrate that the problem has a single optimum solution.

The study of Li et al. [6] introduces the optimum solution for the ACC policy with deteriorating products. Using a discounted cash flow analysis, they obtain the optimum selling price and cycle time, which is part of a single solution. Moreover, they reach several conclusions after a sensibility analysis.

The article of Wu et al. [7] incorporates shortages and deterioration to a model based on ACC to study the optimum cycle time and the fraction of non-faults. They prove that, again, the model has a single optimal solution.

Li et al. [30] introduce a model in which shortages are possible in a specific time period, with the ACC payment scheme. Therefore, the model determines the optimum selling price, cycle time, and time allowed for product shortages to maximize the total profit.

At last, the study of Tsao et al. [9] develops the first EPQ with deterioration and ACC payment scheme. Using discounted cash flow analysis, the authors develop an algorithm to get an optimal cycle time and selling price, besides a sensibility analysis of the several parameters.

Thus, it is noticeable that the contribution of this study is an EPQ model with ACC, deterioration, and shortages, analyzed with discounted cash flow, that has not been before discussed in the literature. In particular, the introduction of the possibility of shortages and backlog has not been done yet to such a model.

3 Mathematical Model

This section presents the calculations of the mathematical model. It starts with the definition of the parameters, functions, and variables of interest, alongside the premises so that, then, the model can be fully explained. On Table 1, the parameters and variables of interest are presented, alongside their representations.

Table 1 Definition of parameters and variables of interest

Parameter	Definition	Parameter	Definition
α	Part of payment advanced	O	Ordering cost
β	Part of payment in cash	S	Lost sales cost
τ	Part of payment postponed	B	Backorder cost
μ	Time for postponement of payment	P	Production rate
l	Time for advance of payment	Q	Production Quantity in units
r	Interest rate per year	E	Number of backordered items
θ	Deterioration rate	A	Acquisition cost in $-l$
λ	Fraction of backlogged products	HC	Present value of holding cost per cycle
SR	Present value of sales revenue per cycle	CC	Present value of capital cost per cycle
PC	Present value of acquisition cost per cycle	BC	Present value of backorder cost per cycle
OC	Present value of ordering cost per cycle	SC	Present value of lost sales cost per cycle
c	Acquisition cost per unit	IC	Interest paid per year
h	Holding cost per unit without interest	IE	Interest earned per year
b	Backorder cost per unit	$\Pi(p, T, K)$	Present value of annual total profit
s	Lost sales cost per unit	p^*	Selling price per unit
$D(p)$	Annual demand	T^*	Cycle time in years
$I(t)$	Inventory level on time t	K^*	Fraction of time in which shortages are not allowed
t_p	Production time per cycle		

This article considers the follow premises, inspired by the ones adopted by Wu et al. [7] and Tsao et al. [9]:

1. Demand is dependent on the selling price p, so that $D(p) = ae^{\gamma p}$, and the demand falls when the price increases.
2. Demand is always smaller than the production rate.
3. Shortages are only allowed after production stops; in other words, $KT \geq t_p$.
4. The deterioration rate θ is constant.
5. The time horizon is infinite.

Figure 1 illustrates how the payments occur and the relationship between shortage and production.

The mathematical model is so that a α fraction of A is paid l years before the delivery of the product. On time 0 the Q items are delivered, and a fraction β of A is paid. This quantity Q is used to compensate the accumulated backlog E, and becomes

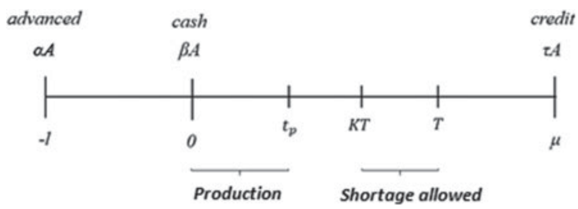


Fig. 1 Summary of the relationship between payments, production time, and cycle time. In the shown case, μ is higher than T—one of the possibilities

zero until KT. Then shortages are partially backlogged with rate λ, until the end of time T. The contribution of this study is the addition of moment KT, which modifies the calculations of several costs and parameters.

Therefore, there are three intervals in which the inventory level I(t) must be analyzed: during production, without production, and with shortages. For the first and second intervals, the equations were adapted from Tsao et al. [9]. In the first interval, [0, t_p], the variation of the inventory follows the differential equation:

$$\frac{\partial I_1(t)}{\partial t} = (P - D(p)) - \theta I_1(t) \tag{1}$$

$$I_1(t) = e^{\theta t} \int_o^{t_p} (P - D(p)) e^u du \tag{2}$$

$$I_1(t) = \frac{P - D(p)}{\theta} \left(1 - e^{-\theta t}\right) \tag{3}$$

Similarly, it is possible to obtain the inventory level between [t_p, KT]. In this interval, there is no production, but shortages are also not allowed.

$$\frac{\partial I_2(t)}{\partial t} = -D(p) - \theta I_2(t) \tag{4}$$

$$I_2(t) = \frac{D(p)}{\theta} \left(e^{-\theta(T-t)} - 1\right) \tag{5}$$

As the values of $I_1(t)$ and $I_2(t)$ must be the same on time t_p, it is possible to define the production time t_p as:

$$\frac{P - D(p)}{\theta} \left(1 - e^{-\theta t_p}\right) = \frac{D(p)}{\theta} \left(e^{-\theta(T-t_p)} - 1\right) \tag{6}$$

$$t_p = \frac{1}{\theta} \ln\left\{1 + \frac{D(p)}{P} \left(e^{\theta T} - 1\right)\right\} \tag{7}$$

Going back to the inventory level, on the interval [KT, T] there is the introduction of the quantity of products on backlog, defined as E.

$$E = \lambda D(p)(1 - K)T \tag{8}$$

$$\frac{\partial I_3(t)}{\partial t} = -D(p) - \theta I_3(t) - E \tag{9}$$

$$I_3(t) = \frac{D(p) + E}{\theta}\left(e^{-\theta(T-t)} - 1\right) \tag{10}$$

With the values of I(t), it is possible to define the many production costs. Starting with the ordering cost, and bringing its value to the present as do Tsao et al. [9], we have:

$$OC = Oe^{rl} \tag{11}$$

The present value of the acquisition cost uses the three different moments of payment with the value of A, which depends on the inventory level. Therefore, it is another offshoot of the introduction of shortages. Thus:

$$A = c\left(\int_0^{t_p} I_1(t)e^{-rt}dt + \int_{t_p}^{KT} I_2(t)e^{-rt}dt + \int_{KT}^{T} I_3(t)e^{-rt}dt\right) \tag{12}$$

$$PC = \alpha Ae^{rl} + \beta A + \tau Ae^{-r\mu} \tag{13}$$

The next cost to be analyzed is the holding cost. It is similar to the acquisition cost and being as such adapted from Tsao et al. [9] with the new member related to the third inventory period:

$$HC = h\left(\int_0^{t_p} I_1(t)e^{-rt}dt + \int_{t_p}^{KT} I_2(t)e^{-rt}dt + \int_{KT}^{T} I_3(t)e^{-rt}dt\right) \tag{14}$$

Following this, the values related to the possibility of shortages are defined, considering the ones of Wu et al. [7]. The present value of the backlog cost is dependent on the time in which shortages are allowed and the rate of the partial backlog:

$$B = \frac{1}{2}b\lambda D(p)(1 - K)^2T^2 \tag{15}$$

$$BC = \int_0^T Be^{-rt}dt \tag{16}$$

The cost of lost sales is similar to the previous one, calculated as:

$$S = s(1 - \lambda)D(p)(1 - K)T \tag{17}$$

$$SC = \int_0^T Se^{-rt}dt \tag{18}$$

The amount of interest paid is related to advanced and immediate payments. Thus, its present value can be defined as:

$$IC_0 = cD(p)TI_c\left[\int_{-l}^{t_p} Te^{-rt}dt + \int_0^{t_p} \beta e^{-rt}dt\right] + (\alpha + \beta)cD(p)I_c \int_{t_p}^{T} (T - t)e^{-rt}dt \tag{19}$$

The capital cost is related to the earned and paid interest. These values are modified by the size of time μ, which can be inserted on four distinct intervals. Therefore, the capital cost has four possible values:

Case 1: $0 \leq \mu \leq t_p$

In this case, μ is smaller than the production time which means that the capital cost is obtained with the sum between the interest derived from the advanced and cash payments, and the interest from the credit payment, as shown below:

$$\begin{aligned} CC = IC_0 + IC_1 = cD(p)TI_c&\left[\int_{-l}^{t_p} Te^{-rt}dt + \int_0^{t_p} \beta e^{-rt}dt\right] \\ &+(\alpha + \beta)cD(p)I_c \int_{t_p}^{T} (T - t)e^{-rt}dt \\ &+\tau cD(p)I_c\left[\int_{t_p}^{T} (T - t)e^{-rt}dt\right] \\ &+(\alpha + \beta)cD(p)I_c \int_{t_p}^{T} (T - t)e^{-rt}dt \\ &+\tau cD(p)I_c\left[\int_{t_p}^{T} (T - t)e^{-rt}dt\right] \end{aligned} \tag{20}$$

Case 2: $t_p \leq \mu \leq KT$

In this case, the capital cost is obtained with the value of the paid interest for the advanced and cash payments added to the interest earned with the postponed payment. This cost can be defined as:

$$\begin{aligned} CC = IC_0 + IC_2 - IE_1 = cD(p)TI_c&\left[\int_{-l}^{t_p} \alpha e^{-rt}dt + \int_0^{t_p} \beta e^{-rt}dt\right] \\ &+(\alpha + \beta)cD(p)I_c \int_{t_p}^{T} (T - t)e^{-rt}dt \\ &+\tau cD(p)I_c\left[\int_{\mu}^{KT} (T - t)e^{-rt}dt\right] \\ &-\tau pD(p)I_e\left[\int_{t_p}^{\mu} (\mu - t)e^{-rt}dt\right] \end{aligned} \tag{21}$$

Case 3: $KT \leq \mu \leq T$

This case is a sub-product of the contribution of this study, in which the capital cost is associated with the credit payment and the interest earned on the period in which shortages are allowed.

$$
\begin{aligned}
CC = IC_0 + IC_3 - IE_2 = cD(p)TI_c\left[\int_{-l}^{t_p} \alpha e^{-rt}dt + \int_0^{t_p} \beta e^{-rt}dt\right] \\
+(\alpha+\beta)cD(p)I_c\int_{KT}^{T}(T-t)e^{-rt}dt \\
+\tau cD(p)I_c\left[\int_{\mu}^{T}(T-t)e^{-rt}dt\right] \\
-\tau pD(p)I_e\left[\int_{t_p}^{\mu}(\mu-t)e^{-rt}dt\right]
\end{aligned}
\tag{22}
$$

Case 4: $\mu \geq T$

Finally, this case does not have the interest paid for the postponed payment, but only the interest earned for it. Thus, the capital cost is:

$$
\begin{aligned}
CC = IC_0 - IE_3 = cD(p)TI_c\left[\int_{-l}^{t_p} \alpha e^{-rt}dt + \int_0^{t_p} \beta e^{-rt}dt\right] \\
+(\alpha+\beta)cD(p)I_c\int_{t_p}^{T}(T-t)e^{-rt}dt \\
-\tau pD(p)I_e\left[\int_{t_p}^{T}(T-t)e^{-rt}dt + \int_T^{\mu} Te^{-rt}dt\right]
\end{aligned}
\tag{23}
$$

At last, the sales revenue is inspired on the definition of Wu et al. [7], being obtained by the equation:

$$
SR = p\int_0^T D(p)T[K + \lambda(1-K)]e^{-rt}dt \tag{24}
$$

Therefore, the total profit can have one of four values, that depend of the value of its capital cost. On Eq. 25 the simple form can be observed.

$$
\prod(p,T,K) = \frac{1}{T}(SR - OC - PC - HC - CC - BC - SC) \tag{25}
$$

4 Algorithm

The following algorithm allows solving the equations for the maximum profit. It sweeps the K**x* p* solution space, searching for the point in which the profit is maximum and obtaining the T* value afterward.

For each of the before defined cases, the algorithm seeks at first the value of K in which there is the highest profit, what happens between lines 3 and 12. This process considers small increases in the value of the variable, with ϵ being small and positive.

Then, as shown between lines 13 and 21, the procedure maximizes the profit with the selling price value, which is increased by ε increments that are small and positive. This procedure happens until a higher profit than the previous is found. The algorithm sweeps the quadrant p* by K* until the highest profit is found for each case *i*.

Algorithm 1: FindOptimumProfit

1 cases = 1…4
2 **for** i **in** cases
3 $p_{i,x}$ = c
4 $K_{i,x} = 0.01$
5 $T_{i,x} = argmax\,(\Pi_{i,x}(p_{i,x}, K_{i,x}, T_{i,x}))$
6 **repeat**
7 $K_{i,x+1} = K_{i,x} + \epsilon$
8 $T_{i,y} = argmax(\Pi_{i,y}(p_{i,x}, K_{i,x+1}, T_{i,y}))$
9 **if** $\Pi_{i,y} > \Pi_{i,x}$ **then**
10 $K_{i,x} = K_{i,x+1}$
11 **until** $\Pi_{i,y} \leq \Pi_{i,x}$
12 $\Pi_{i,z} = \Pi_{i,x}, T_{i,z} = T_{i,x}\ and\ K_{i,z} = K_{i,x}$
13 $p_{i,x+1} = p_{i,x} + \varepsilon$
14 $K_{i,x} = 0.01$
15 $T_{i,x} = argmax\,(\Pi_{i,x}(p_{i,x}, K_{i,x}, T_{i,x}))$
16 **repeat**
17 $K_{i,x+1} = K_{i,x} + \epsilon$
18 $T_{i,y} = argmax(\Pi_{i,y}(p_{i,x}, K_{i,x+1}, T_{i,y}))$
19 **if** $\Pi_{i,y} > \Pi_{i,x}$ **then**
20 $K_{i,x} = K_{i,x+1}$
21 **until** $\Pi_{i,y} \leq \Pi_{i,x}$
22 **if** $\Pi_{i,w} > \Pi_{i,z}$ **then** $T_{i,z} = T_{i,w}, K_{i,z} = K_{i,w}, p_{i,x} = p_{i,x+1}$ **and return to line 13**
23 **else** $\Pi_i^* = \Pi_{i,z}, T_i^* = T_{i,z}, p_i^* = p_{i,z}\ and\ K_i^* = K_{i,z}$
24 **end**
25 **end**
26 **return** $\Pi^* = max\{\Pi_i^* | i = 1 \ldots 4\}$ **and respective T*, p* and K***

A way to validate the algorithm is to consider K as 1, and the other parameters related to shortage and backlog as zero. This way, the problem returns to the case presented by [9]. As a result, the algorithm returned the same profit value in [9], U$14,256.89, with T* being 0.08631 years and p*, U$19.495.

5 Sensibility Analysis

The sensibility analysis is based on the variation of the parameters to identify the behavior of the variables of interest. The objective of this analysis is to obtain insights for industries that have the same characteristics as this problem. Table 2 shows the results. The initial values were obtained from Wu et al. [7] and Tsao et al. [9].

As a first observation, that is present on all parameters‘ changes, is that K* followed the same increases and decreases as T*. This finding means that when the cycle time increases, higher is the period in which shortages are not allowed. This behavior respects the limitations of production, as it becomes more tolerant to shortages.

The profit increases when p* and T* decrease, indicating that the higher the number of potential clients, the higher the profit. The number of possible clients grows with higher demand, which is inversely proportional to the selling price, and shorter cycle times, as there would be more cycles per year.

Following the parameters of the table, while the efficiency price γ augments, the profit and selling price lower, and the cycle time grows. This result shows that, if the price is subjected to the demand growth, then the cycle time also rises. Also,

Table 2 Sensibility Analysis

Parameter	Change (%)	Values	p^* (\$)	T^*(Years)	K^* (%)	Π^* (\$)	
a	−50	1,000	22.650	0.10900	0.52	7,525.80	– *
	0	2,000	19.244	0.08530	0.46	12,115.72	
	+100	4,000	19.339	0.08210	0.42	25,072.50	+*
γ	−50	0.025	25.650	0.07794	0.38	27,226.71	+*
	0	0.05	19.244	0.08530	0.46	12,115.72	
	+100	0.1	12.010	0.09207	0.52	6,745.56	– *
c	−33	10	19.244	0.08530	0.46	12,115.72	+
	0	15	21.220	0.07560	0.41	11,956.42	
	+33	20	33.720	0.07121	0.38	9,542.34	– *
h	−80	1	19.244	0.08530	0.46	12,115.72	–
	0	5	23.510	0.07523	0.42	11,974.81	
	+100	10	26.890	0.06782	0.34	11,902.11	+
μ	−50	0.1	19.244	0.08530	0.46	12,115.72	–
	0	0.2	19.656	0.08577	0.47	12,189.22	
	+100	0.3	19.889	0.08587	0.51	12,252.37	+
θ	−80	0.01	15.562	0.08542	0.46	12,043.25	–
	0	0.05	19.244	0.08530	0.46	12,115.72	
	+80	0.09	21.522	0.08512	0.45	12,145.72	+
l	−50	0.05	18.211	0.08517	0.45	12,102.36	–
	0	0.1	19.244	0.08530	0.46	12,115.72	
	+50	0.15	19.725	0.08538	0.46	12,140.78	+
r	−50	0.02	17.892	0.08758	0.47	12,132.84	+
	0	0.04	19.244	0.08530	0.46	12,115.72	
	+100	0.08	21.032	0.08115	0.42	12,107.56	–
P	−13	1,300	20.551	0.09010	0.55	12,205.54	+
	0	1,500	19.244	0.08530	0.46	12,115.72	
	+13	1,700	18.795	0.08120	0.40	12,092.72	–
b	−62,5	3	22.105	0.09153	0.52	12,892.56	+
	0	8	19.244	0.08530	0.46	12,115.72	
	+50	12	17.884	0.07254	0.37	11,450.35	–
s	−50	0.025	20.332	0.08892	0.47	13,002.50	+*
	0	0.05	19.244	0.08530	0.46	12,115.72	
	+100	0.10	18.465	0.07250	0.44	11,560.45	–
λ	−60	0.20	25.451	0.08952	0.47	12,803.42	+
	0	0.50	19.244	0.08530	0.46	12,115.72	
	+40	0.70	17.893	0.08221	0.45	11,320.51	–

comparing with the parameter a, the price efficiency has a higher effect on the total profit.

If the acquisition cost per unit c increases, then the selling price grows, and, inversely, the profit and cycle times shrink. This pattern is reasonable, as when the acquisition cost raises, the selling price must also rise to maintain a profit level.

For a higher holding cost h there are lower values for both total profit and cycle time. In practice, the holding cost for deteriorating items is considered high, as it translates the efforts to maintain the item in optimal quality. Therefore, managers must apply new technologies to reduce energy waste and economize holding costs.

Another aspect can be seen when the supplier concedes a longer credit period μ. In this case, the producer will increase the cycle time and selling price to benefit more from this increased period.

Between the specific parameters of this case, a higher rate of deterioration θ means that the profit and cycle time reduce, but the selling price increases. Accordingly, when items can suffer more from deterioration, a higher selling price is needed.

Confronted with a longer advanced payment period l, both the selling price and the cycle time increase, while the profit also grows. Also, for a higher interest rate, the selling price will be higher. However, cycle time and profit decreases. For parameter P, it is not advised to increase production without information about the demand, as it affects the selling price, profit, and cycle time inversely.

Finally, for the parameters that are related to shortages, b, s, and λ, their growth can be interpreted as a rise in the loss of profits. Thus, it is translated in a higher selling price and lower cycle period to compensate for the profit value.

A notable relation is that the 10% highest values for the profit, indicated on the table with +*, happen when there is a higher demand—related to the parameters a and γ—or, for a lesser effect, a lower lost sales cost. Similarly, the 10% worst values for the profit, signed with an -* on the table, occur when demand lowers or, to a lesser degree, when the acquisition cost increases.

These facts, when combined with the direct and indirect relations detailed beforehand, show that high demand is an essential factor for a high profit, having the most dramatic effects on the optimal profits. This way, strategies that can increase this potential demand are indicated for managers, instead of focusing on technological improvements or investments that could lower the production costs.

6 Conclusion

This paper presented an Economic Production Quantity model for products with deterioration, shortages, and advanced-cash-credit payment scheme. As a contribution, this model introduced the possibility of shortages to the EPQ with the indicated characteristics, which had not previously appeared in the literature.

The model considers a discounted cash flow analysis to bring different cost variables to the present time. With this, the four possibilities for the total profit were analyzed, each one having a different capital cost, as these depend on the proportion of the credit period μ in relationship with the other temporal variables. Because of the many possibilities, we proposed an algorithm to find the optimum value of the total profit Π*, the selling price p*, the cycle time T*, and the allowed shortage time K*.

The sensibility analysis not only demonstrated that the algorithm works but also showed the link between the several parameters and variables. It is of note that the most radical modifications to the profit are related to the potential product demand. This finding indicates that managers should focus on ways to raise product search, instead of investing in lowering the diverse costs or losses with deterioration and shortages.

For future works, it is suggested that the model be extended for cases in which deterioration is variable in time, to increase the realism of the model. Another possibility is the application for multiple items, a reality in production systems. At last, it would be interesting to observe how the model behaves in a total backlog setting.

References

1. Taft, E.W.: The most economical production lot. Iron Age 101(18), 1410–1412 (1918).
2. Harris, F. W.: How many parts to make at once. Factory: The magazine of Management 10, 135–136 (1913).
3. Andriolo, A., Battini, D., Grubbström, R. W., Persona, A., & Sgarbossa, F.: A century of evolution from Harris' s basic lot size model: Survey and research agenda. International Journal of Production Economics 155, 16–38 (2014).
4. Goyal, S. K., & Giri, B. C.: Recent trends in modeling of deteriorating inventory. European Journal of Operational Research 134(1), 1–16 (2001).
5. Bakker, M., Riezebos, J., & Teunter, R. H.: Review of inventory systems with deterioration since 2001. European Journal of Operational Research 221(2), 275–284 (2012).
6. Li, R., Chan, Y. L., Chang, C. T., & Cárdenas-Barrón, L. E.: Pricing and lot-sizing policies for perishable products with advance-cash-credit payments by a discounted cash-flow analysis. International Journal of Production Economics 193, 578–589 (2017).
7. Wu, J., Teng, J. T., & Chan, Y. L.: Inventory policies for perishable products with expiration dates and advance-cash-credit payment schemes. International Journal of Systems Science: Operations & Logistics 5 (4), 310–326 (2018).
8. Chen, S. C., & Teng, J. T.: Inventory and credit decisions for time-varying deteriorating items with up-stream and down-stream trade credit financing by discounted cash flow analysis. European Journal of Operational Research 243(2), 566–575 (2015).
9. Tsao, Y.C., Putri, R. P. F. R., Zhang, C., & Linh, V. T.: Optimal pricing and ordering policies for perishable products under advance-cash-credit payment scheme. Journal of Industrial Engineering International 15(1) 131–146 (2019).
10. Ghare, P. M., & Schrader, G. F.: An inventory model for exponentially deteriorating items. Journal of Industrial Engineering 14(2), 238–243 (1963).
11. Dave, U., Patel, L.K.: (T, S1) policy inventory model for deteriorating items with time proportional demand. Journal of the Operational Research Society 32 (2), 137–142 (1981).
12. Hariga, M.: Optimal EOQ models for deteriorating items with time-varying demand. Journal of the Operational Research Society 47 (10), 1228–1246 (1996).
13. Chakrabarti, T., Chaudhuri, K.S.: An EOQ model for deteriorating items with a linear trend in demand and shortages in all cycles. International Journal of Production Economics 49 (3), 205–213 (1997).

14. Chang, H., Dye, C.: An EOQ model for deteriorating items with time varying demand and partial backlogging. Journal of the Operational Research Society 50 (11), 1176–1182 (1999).
15. Ouyang, L., Chang, C., Teng, J.: Deterministic economic production quantity models with time-varying demand and cost. Applied Mathematical Modelling 29 (10), 987–1003 (2005).
16. Goyal, S. K.: Economic order quantity under conditions of permissible delay in payments. Journal of the Operational Research Society 36(4), 335–338 (1985).
17. Aggarwal, S. P., & Jaggi, C. K.: Ordering policies of deteriorating items under permissible delay in payments. Journal of the operational Research Society 46(5), 658–662 (1995).
18. Teng, J. T.: On the economic order quantity under conditions of permissible delay in payments. Journal of the Operational Research Society 53(8), 915–918 (2002).
19. Huang, Y. F.: Optimal retailer's ordering policies in the EOQ model under trade credit financing. Journal of the Operational Research Society 54(9), 1011–1015 (2003).
20. Chang, C.: An EOQ model with deteriorating items under inflation when supplier credits linked to order quantity. International Journal of Production Economics 88, 307–316 (2004).
21. Chung, K., & Huang, T.: The optimal retailer's ordering policies for deteriorating items with limited storage capacity under trade credit financing. International Journal of Production Economics 106 (1), 127–145 (2007).
22. Liao, J.: An EOQ model with non-instantaneous receipt and exponentially deteriorating items under two-level trade credit. International Journal of Production Economics 113, 852–861 (2008).
23. Abad, P. L.: Optimal lot size for a perishable good under conditions of finite production and partial backordering and lost sale. Computers & Industrial Engineering 38(4), 457–465 (2000).
24. Wu, J., Lin, C., Tan, B., Lee, W.: An EOQ inventory model with time-varying demand and Weibull deterioration with shortages. International Journal of Systems Science 31 (6), 677–683 (2000).
25. Wu, K.: An EOQ inventory model for items with weibull distribution deterioration, ramp type demand rate and partial backlogging. Production Planning and Control 12 (8), 787–793 (2001).
26. Begun, R., Sahu, S. K., & Sahoo, R. R.: An EOQ model for deteriorating items with Weibull distribution deterioration, unit production cost with quadratic demand and shortages. Applied Mathematical Sciences 4(6), 271–288 (2010).
27. Taleizadeh, A. A., & Nematollahi, M.: An inventory control problem for deteriorating items with back-ordering and financial considerations. Applied Mathematical Modelling 38(1), 93–109 (2014).
28. Grubbström, R.W., Erdem, A.: EOQ with backlogging derived without derivatives. International Journal of Production Economics 59 (1), 529–530 (1999).
29. Cárdenas-Barrón, L.E.: The economic production quantity (EPQ) with shortage derived algebraically. International Journal of Production Economics 70 (3), 289–292 (2001).
30. Li, R., Liu, Y., Teng, J. T., & Tsao, Y. C.: Optimal pricing, lot-sizing and backordering decisions when a seller demands an advance-cash-credit payment scheme. European Journal of Operational Research 278 (1), 283–295 (2019).

Sustainable by Accident: An Analysis of the Development of the Brazilian Electricity Sector

Juliana Botelho da Silva and Raoni Rajão

Abstract The Brazil's leaders present the national electricity sector as one of the most sustainable in the world. However, in the 21st century, a period in which the issue of sustainability prevailed, the electricity sector's policy influenced by this trend. In this context, we aim to analyze the forces that transformed the Brazilian electricity sector over time (from 1880 to 2018) and fed institutional inertia in terms of sustainability. Therefore, the research developed has an explanatory character as to its objectives, qualitative as to the approach, and documentary as to the technical procedure used. The New Institutional Theory theoretically bases this research, and Fligstein's (1990) approach to the conceptions of control. The result of this study shows that between 1880 and 1930 an oligopolistic logic prevailed in the country's electricity sector, but that between 1930 and 1960 a concept of statist control was established. This nationalizing worldview also acted synergistically during the military regime with a conception of geopolitical control. In the 1990s, however, the financial management paradigm was in place, but between 2003 and 2018 a timidly climatic and strongly neodevelopmentist concept prevented it. Thus, although the demands for sustainability were part of the electricity sector narrative, we conclude that there was no strengthening of it as an institutional pillar in the development of planning for the Brazilian electricity sector because there was a perpetuation of an inefficient nationalist model dominated short-term strategies.

Keywords Conception of control · New institutional theory · Energy planning · Electricity sector · Sustainability

J. B. da Silva (✉) · R. Rajão
Federal University of Minas Gerais, Belo Horizonte, Brazil
e-mail: botelhojulyana@gmail.com

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_49

1 Introduction

The decarbonization of the energy sector has been increasingly critical for development that will respond to the mitigation of climate change, given the fact that about two thirds of the world's greenhouse gas (GHG) emissions come from its production and use. In this context, the global energy system should undergo a profound transformation, moving from a model based mainly on fossil fuels to another based on renewable sources [1, 2].

In this scenario, Europe has become known for its efforts to promote the FR, among which we can mention the strategy of Energiewende in Germany which proposed a transition to a sustainable energy supply based on clean, excluding nuclear. In emerging countries, however, China has led the assertions of the transition, aiming for a radical decrease in the consumption of high-carbon fossil energy [3, 4].

In Brazil, however, there are different views regarding the status of the electricity sector with regard to the growing demands for sustainability and the national contribution to the mitigation of climate change. The official narrative of the federal government, from the end of the 1990s, sought to emphasize the predominance of hydroelectric sources in the national matrix as an important mitigation mechanism. In addition, in the 2000s, the implementation of the Incentive Program for Alternative Sources of Electric Energy enabled the diversification of the national matrix and had the merit of contributing to the birth and advancement of the wind industry in the country [5, 6].

At the same time, however, different studies note that the relatively comfortable position that Brazil has in its energy matrix is at risk, since there are different positions on the directions that the government should follow in this area. Broadly speaking, what is observed is that the electricity sector is undergoing a major transformation, given that an increasing share of electricity has been generated from carbon-intensive thermal processes, which demonstrates that the current policy has chosen for investing heavily in fossil fuels [7–9].

Thus, different studies point to the contradictory stance of policy makers in presenting Brazil as a green power worldwide and in providing a discourse that suggests that the structure of its matrix was built in line with the dynamics of sustainability [10, 11]. However, this imminent paradox has already been extensively analyzed by the literature, which pointed out that even in periods of deep activism, energy policy was not decisively influenced by sustainability issues [12–17]. In view of this, it is up to this article, then, to fill two still pressing gaps on this topic. The first refers to the temporality of the facts (1880 to 2018) and the second relates to understanding what would explain this institutional inertia in terms of sustainability specifically in the Brazilian electricity sector.

A research carried out is explanatory as to its objectives, qualitative as to the approach and uses a documentary research as a technical procedure. The New Institutional Theory and Fligstein's [20] approach to conceptions of control complete the theoretical foundation of this article.

The following chapters explain the theoretical foundation (Sect. 2); the methodology is explained (Sect. 3); the trajectory of the Brazilian electricity sector is detailed (Sect. 4); the discussion on the collected data is evidenced (Sect. 5) and then a brief conclusion (Sect. 6).

2 Neoinstitutional Theory

The study of institutions experienced a revival particularly in late 1970. The new institutional theory emerged in a context dominated by theories of economic origin, which presupposes nail m the existence of a rational actor seeking maximize their utility, usually expressed in financial terms [18].

In reaction to this predominant conception, different researchers in the field of organizational studies sought to emphasize the values, norms and perceptions of the actors. They focused on institutions, that is, on a shared system of rules that favored some groups with interests guaranteed by the prevailing sanctions and rewards [18].

In one of the pioneering studies in this area, Dimaggio and Powel [19] identified that, due to uncertainty, organizations in the field would tend to become isomorphic (i.e. Replicate organizational practices and structures). So far, the research on the diffusion of organizational practices, such as assembly line, were based son purely rational explanations (i.e. productivity gains). However, Dimaggio and Powel [19] noted that many of the changes adopted by companies, occurred outside of economic reason, in a context of coercion and changes in values.

One of the important contributions of institutional theory is to understand the evolution of sectors of the economy in a context of change. In this sense, the work of Fligstein [20] on the evolution of corporate management practices in large industrial conglomerates in the USA is particularly relevant. Within this, the author innovates by bringing the concept of control design. This approach will be presented in more detail below.

2.1 Conceptions of Control

In the book "The Transformation of Corporate Control", Fligstein [20] provided an institutional account of the changes in the largest US corporations from the late 19th to the 20th century. His analysis challenged the dominant evolutionary economic theory that believed that the United States naturally created efficient companies and managed them according to a timeless and universal rationality. In contrast, the author presented that such organizations have taken their current form due to a succession of dominant conceptions of control.

Subsequent paragraphs, however, are indented. Thus, according Fligstein [20, 21] over time, five conceptions of control were established in American industry: direct control of competition (1880–1900); production control (1900–1925); sales and marketing control (1925–1955); financial control (1955–1980), and, more recently, the control of shareholder value.

It is noteworthy that the conceptions of control did not follow serial steps, that is, the emergence of one conception of control did not immediately exclude the other, but gradually became legitimized. This means, for example, that the concept of production control did not succumb with the advent of the concept of sales and marketing, but that gradually the strategies that aimed at diversification and increased consumption were gaining strength at the expense of those that sought to control all productive chain. Likewise, when managers decided to financially design company balance sheets to please analysts and institutional investors, they reorganized their corporations using tactics to sell unrelated product lines, participating in mergers with similar sector firms [20, 22].

In this way, the managerial paradigms of how best to solve the competitive problem faced by large industries would reflect the change in conceptions of control, that is, of the worldviews that would allow actors to interpret the actions of others. They would also portray the principles of internal organization, competition and/or cooperation tactics, and the hierarchy or order of status of companies in a given market, based on a state ratification that would help to create or not oppose its operation [20].

Consequently, while in a new field there would be the growth of beginning players and the entry of others that would generate a fluid situation characterized by the existence of multiple conceptions of control, when stabilized it would reflect a worldview shared between them and accepted by the state. This demonstrates that the management paradigms were culturally constructed would create local social worlds and depend on the government for their legitimation, given that such rules would compose the result of a collective cognitive construct and that they would be used to control the interactions between the actors in a field [20, 21].

So informed s by the writings of the New Institutional Theory and Fligstein [20] on the concepts of control, this research will investigate the s forces that transformed the power sector since its origin to the present day and fed institutional inertia in terms of sustainability. To this end, we argue that the process of change in conceptions of control was conflicting and involved crises resulting from actions taken by the state, by organizations present in the field and by emerging macroeconomic conditions.

3 Research Methodology

The research problem treated through a qualitative research, which sought to interpret the analyzed phenomena and assign meanings to them. Regarding its objectives, this research is explanatory, because its central concern is to identify the factors that determined or contributed to the occurrence of the phenomena. For Gil [23] this is the type of research that further deepens the knowledge of reality, because it explains the reason, the why of things.

Regarding the technical procedures used for data collection, documentary research used on materials that have not received analytical treatment so far. The units of analysis chosen were the presidential speeches, as they are able to reveal the management strategies, the actors supported by the government, the interests involved in the actions and the worldviews of the actors. Through the website of the Library of the Presidency of the Republic, 274 documents selected between the years 1911 to 2017. The criterion for choosing was that the document contained any of these words: electricity; electric; light.

Then a critical reading carried out in the documents in order to identify the elements that dealt exclusively with the electricity sector. The reading results were tabulated in a spreadsheet that contained three categories of analysis: speech identification (speech title, president's name, speech date); overview of the discourse (social, political and/or economic context); and specific view of the Brazilian electricity sector. The next section details the results obtained.

4 The Brazilian Electricity Sector

A The use of electricity in Brazil began in the last decade of the imperial period and its first cycle extended from 1880 to 1929, at which time the country's economic base was agro-export and coffee producers were the main financiers in the sector. At that time, the basic function of the electricity sector was to supply squares, public buildings and avenues [24].

However, the growing urban population and the crisis of rural producers paved the way for foreign companies to enter and dominate the electricity sector. Although they were governed by legislation that regulated the use of hydraulic power in states and municipalities, concession services and tariff reviews; these organizations, particularly Light and Amforp, managed to establish bilateral contracts with the local government and built a regulatory framework that protected them from economic oscillations [25, 26].

In addition, the knowledge of international companies in the construction of hydroelectric dams and the geological conditions of the country allowed the execution of the projects close to the consumption centers, favoring the expansion of this source in the electrical matrix. Although, the beginning of the government of Getúlio Vargas, in 1930, fostered the structuring of a new legal-regulatory arrangement that aimed to grant public control and encourage the use of water for energy purposes. These measures were supported both by the national developmentalist group and by the military, who considered the electricity sector to be a strategic area for the country [24, 27, 28].

Still, if during the Estado Novo government control was intensified, the same did not occur between 1946 and 1963 and, in order to guarantee the necessary electricity for industrial expansion, there was a new movement favorable to the acquisition of private resources. Thus, foreign loans and direct investments made by foreign companies multiplied by 6 between 1950 and the beginning of 1960, of which 22% went to the electricity sector [29, 30].

Nevertheless, the years that followed marked by serious political and economic instability, collapsing in the rise of the military under the guarantee of security and development. Thus, in the early 1960s, a policy of tariff realism was instituted that increased the concessionaires' remuneration rate, and measures to stimulate the acquisition of foreign loans, which resulted in an increase from 13% to 32%, between 1967 and 1973, foreign resources in the electricity sector [31, 32].

Thus, through an administration oriented towards urban and industrial supply and based on the creation of large state-owned companies, a revolution promoted in the Brazilian electricity sector, through the construction of colossal hydroelectric plants, the interconnection of the national system and the increase in the number of carbon intensive thermoelectric plants. However, the consequences of the international oil crisis, during the 1970s, coupled with the continuity of a state policy centered on large investments and misalignment with the new global order in terms of sustainability, led the electricity sector to bankruptcy, particularly due to the interruption external credits [33, 34].

In this way, the calamitous political and socioeconomic situation, in which the country was inserted in the early 1980s, unbalanced the military government, enabling the reestablishment of the democratic regime. Thus, the subsequent governments aimed to open up the market so that the private sector could bear the costs that the government could no longer afford to pay. Thus, aiming to raise funds and attract investors, the government guaranteed the economic and financial balance of the contracts through readjustments and tariff reviews, and the freedom was given to consumers with a load equal to or greater than 3,000 kW to choose their energy suppliers [35, 36].

However, what was witnessed throughout the 1990s was a climate of insecurity among investors, given the evident institutional inability of the government to operationalize the new model established in the electricity sector. To this was added both the slowness of public agencies to enable planning that would guarantee the expansion of the sector, and a long period of water crisis, resulting in an insufficiency of the system to supply its consumers. To reverse this situation, the government developed a rationing policy and several programs that encouraged the expansion of thermoelectric plants powered by fossil fuels, especially natural gas; the resumption of works for the construction of hydroelectric plants; and the flexibility of environmental licensing [37, 38].

Consequently, the instability present in the electricity sector served as a political argument during the presidential campaign that followed and, in 2004, during the term of ex-president Luiz Inácio Lula da Silva, a new model for the electricity sector was instituted, whose guidelines were low tariffs, security of supply and universal service. To achieve these objectives, the government used its power of intervention and articulation to carry out institutional centralization, promoting the elevation of the internal energy market and the business of private companies [39, 40].

Nevertheless, although there was an increase in unconventional sources in the electric matrix and the signing of international agreements to reduce emissions from the electricity sector (such as the Paris Agreement), the reduced expectation for the use of carbon-intensive thermoelectric plants has not been realized throughout of the years, particularly during the government of Dilma Rousseff. In addition, there was an increase in charges and taxes to subsidize energy inclusion programs and fossil fuels, further to an artificial reduction in electricity tariffs that caused a compromise in the concessionaires' budget and the National Treasury [41].

Ultimately, during Michel Temer's short term as president there were innocuous attempts to reestablish the electricity sector's pedictability, including starting a consortium to redo the mathematical models of water reserves; to enable a reform that would provide transparency to the abstruse regime of subsidies, tax exemptions, and incentives paid by consumers; and to review the contracts related to Itaipu royalties [42]. However, the government's lack of legitimacy in this area, the conflicting political interests and the intense lobbying of powerful pressure groups have hindered any negotiating agenda.

5 The Trajectory of Control Conceptions in the Brazilian Electricity Sector

The decision to introduce electricity in Brazil had as its starting point a deliberation by the state itself, which initially sought to provide public places with such innovation. This fact demonstrates that the government used its unique power, which is the competence to build an organizational field, to found this sector in the country. From this first movement, the initial rules for its operation were also elaborated [18, 24].

However, the potential of the market attracted the interest of foreign companies. Among them, Light and Amforp managed to exercise an oligopoly in the electricity sector that caused a change in the relationship between them and the state, particularly with regard to the development of rules for the operation of the sector [34]. Thus, it observed that the structuring of the organizational field has been composed of companies with a power that made them capable of influencing the rules of interaction and dependence, according to their interests. As established by Fligstein [21], circumstances such as this reflect the position of companies in the social structure of the field and the advantages they obtained for the construction of stable rules that determined the actions considered legitimate.

But, the concept of oligopolistic control became devitalized throughout the second half of the 1920s, a period in which Light and Amforp began to carry out divestments in the country, tariff prices grew by leaps and bounds, and energy rationing occurred in several regions. At the international level, the crash of the New York Stock Exchange in 1929 devastated the Brazilian economy, mostly dependent on coffee exports [24].

In view of this context, Fligstein [20] approach is used, which demonstrates that the interdependence between the actors, the internal agreements signed and the facts outside their domain in the structuring of the organizational field are based on a political commitment capable of favoring the interaction and stability between its members and the state. However, these institutional projects can end in disaster as often as in success, depending on the way in which the state intervenes and on which side in the configuration of political forces. In the case of the electricity sector, socioeconomic tensions resulted in a crisis that made it possible for Getúlio Vargas to become the president of the republic and changed the direction of the Brazilian electricity sector.

Thus, with a nationalist government project, Getúlio Vargas removed the granting power from the municipalities and drafted the Water Code, making the state the controller of water sources. However, these measures generated regulatory instability and alienated foreign investment, compromising the development of the electricity sector throughout the 1930s [28]. It is noteworthy that, although this statist conception pleased the national developmentalist group and the military, the dominant actors intensified articulation with politicians to delay the implementation of new regulations.

This frame demonstrates that the state has the power to elaborate the rules of interaction and it is the final arbiter of the organizational fields. However, the powerful actors who initially fail to impose a social order will form political coalitions and attract the main actors (such as members of the legislative branch) to maintain their privileges and consolidate the devices necessary to preserve the stability of the countryside through their worldview [21].

Nevertheless, the statist policies for the control of the electricity sector remained, but the initiatives taken to strengthen it were not able to prevent its deterioration, in view of the industrial and urban advance of the time, which required a significant increase in its installed capacity [30]. This context fostered a movement towards tariff and institutional restructuring of the electricity sector, demonstrating the difficulty encountered by the government in reaching a stable set of rules that could determine its operation.

Thereby, during the 1950s, the government proposed policies to encourage the construction of hydroelectric, thermoelectric and the first links for the construction of nuclear plants. In addition, the government inaugurated the National Bank for Economic and Social Development, with the objective of ordering investments in the electricity sector; and the Ministry of Mines and Energy, which centralized the main institutions in the energy area. In addition, the government contracted large loans with the World Bank for the construction of the Furnas hydroelectric plant and for expansion to state-owned energy companies [30, 43].

Therefore, the loans contracted by the state made it possible to maintain a state logic in the electricity sector, enabling the takeover of private companies and expanding the role of the government throughout its production chain, including in the basic industry. That said it is identified that the transforming forces of the field influenced the development of a stable set of understandings that were used to reinforce the existing order and promote political coalitions [21, 24].

Thus, the institutional arrangement established by the military, during the 21 years in which they ruled the country, appeared in the vicinity of the old field and models of action were captured, among them the state logic that coexisted with a geopolitical worldview, which guided the guarantee national sovereignty through the available political, economic and material resources. In this case, an antagonism was identified with the approach presented by Fligstein [20] regarding the permanence of different conceptions of control in the same organizational field, because during this period there was no conflict between them, but a balance.

Thereby, the measures adopted by the government fostered the expansion of the electricity sector and the reforms carried out leveraged investments in the entire production chain [34]. In addition, major infrastructure works had the symbolic power of supremacy, which came from producing rules that defined the positions of actors in the field and demonstrated government authority. In this way, the concepts of geopolitical and state control consolidated the structuring norms and used to interpret and reinforce the existing logic.

However, the economic context of the 1970s coupled with a strengthening of international socio-environmental movements promoted the interruption of external resources, which were essential for maintaining high public investments. In order to reverse this situation, the government sought to align with the new guidelines of developed countries and modified the regulatory aspects that governed the issue of the environment; it also listed as a priority the generation of energy via hydropower and national fossil fuels, such as coal, demonstrating it central power as a defining agent of the rules in its organizational field [44].

Although, economic bankruptcy was inevitable and was reflected in the decapitalization of concessionaires, in the precariousness of energy supplies and in tariff deterioration. This generated a process of conflict in the institutional field, because on the one hand there were actors who sought to maintain the status quo and on the other there were those who aimed to reform the existing system. In this context there was a gradual reorientation of the role of the state and the construction of new political coalitions, which left the state and geopolitical logic aside and led to the institutionalization of a financial worldview, in which the sanitation of public accounts and privatizations became priority [36, 45].

In a complementary way, in the first half of the 1990s, international negotiations in the energy area stopped being carried out in terms of national security risk and started to be considered as an economic asset. In addition, a movement began in which thermal power plants started to form a specific expansion program, despite the government having invested heavily in external advertising to reverse the image of Brazil as an environmental villain [30].

This context demonstrates that institutionalization was a process dependent on the government, which had the power to limit the actions of the actors through the construction of rules. Thus, what can be verified throughout the 1990s was the search for an alignment with the new globalizing order of economic liberalization, starting from the creation of a minimally interventionist and competitive environment, in which the state started to exercise a regulatory function. To this end, legal norms and specific institutions were built to guarantee the autonomy and independence of the electricity sector [18, 34].

However, the controversies about the rules of planning, investment, pricing, quality control and meeting demand have revealed weaknesses and inconsistencies in the fundamentals of the model proposed by the government. Such elements caused the generation industry to remain in the hands of the state and the reliability of the services provided to fall [38, 45].

If, on the one hand, the performance of the state unintentionally generated a crisis in the electricity sector, on the other, this scenario of instability strengthened the adversary group that emerged victorious in the presidential elections. Thus, in the 2000s, the new management proposal for the sector reformulated the rules of the field and established as guidelines the institution of a hybrid logic composed of a climate and neodevelopmental worldview that reconfigured political forces.

Thus, there was a state-sponsored intervention in the electricity sector, which benefited segments of the population and used as a social policy tool and as a driver of economic growth. Furthermore, there was a reconstitution of power relations, given that in order to maintain governance, it was necessary to articulate segments with initially divergent interests, among them unions, governing coalitions, opposition politicians, businessmen, and representatives of traditional oligarchies [24].

On the other hand, with regard to socio-environmental issues, the governments of Lula and Dilma Rousseff went through periods of profound optimism and others guided by conservative policies. If, during the period when Marina Silva was Minister of the Environment, progressive public policies were strengthened, taking Brazil to a new level in international negotiations and the prohibitions in the North region for the construction of large hydroelectric plants were intensified; after its shutdown, there was a reinforcement of the expansionist policy, through carbon-intensive sources and hydroelectric plants in the Amazon [11, 17].

Therefore, the strategies adopted by the state reflected its power of intervention and articulation, made possible by public economic capital, to implement the institutional centralization necessary to foster the internal energy market and private business. To this end, the neodevelopmental model initiated in 2003 was opposed to traditional rhetoric and inaugurated a hybrid, complex and aggressive logic that co-opted fields once seen as competitors.

6 Conclusion

The overall aim of this paper has been to analyze the forces that shaped the Brazilian electricity sector over time (from 1880 to 2018) and favored its institutional inertia in terms of sustainability. Therefore, through an in-depth investigation, from 1880 to 2018, this paper demonstrated how, since its inception, government regulation and pressure from outside agents legitimized its institutional structure leading to the accidental construction of a hydroelectric matrix complemented by a thermoelectric infrastructure, which is carbon intensive.

Thus, a paradigm that focuses on sustainability has not managed the Brazilian electricity sector over the years. Instead, it was initially managed by an oligopolistic worldview that aimed to promote the implantation and consolidation of the sector in the country through small hydroelectric plants close to the cargo centers, which was the technology available at the time. Subsequently, in response to government policies, which aimed at institutionalizing the electricity sector through a stifling private initiative, a state logic began and ran in parallel, starting in the 1960s, with a conception of geopolitical control, which aimed the expansion of the electricity sector through the execution of large hydroelectric and thermoelectric projects that came with a nationalist stance that did not consider socio-environmental constraints. Then, the country's economic crisis underpinned the establishment of a financial worldview, which aimed to increase competition in the sector, based on the improvement of public accounts, the expansion of privatizations and their verticalization. This trajectory, indeed, was interrupted throughout the 2000s and replaced by a timid climate initiative, which brought external visibility through the presentation of projects that encouraged non-conventional sources of energy and the international commitment to reduce GHG emissions in the country. However, this institutional logic failed to break with the political agreements defended by the powerful pressure groups that, on the other hand, benefited and supported the institutionalization of a neo-developmental worldview that expanded subsidies to the electricity sector, generating an increase in participation of fossil fuels in the electric matrix through tax exemptions, and encouraged the construction of new and inefficient hydroelectric plants in the Amazon from the point of view of sustainability.

References

1. Irena, Renewable Energy: A Key Climate Solution, https://www.irena.org/climatechange/Renewable-Energy-Key-climate-solution, last accessed 2019/04/04.
2. Irena, Global Energy Transformation: A Roadmap to 2050, https://www.irena.org/publications/2018/Apr/Global-Energy-Transition-A-Roadmap-to-2050, last accessed 2019/04/04.
3. Dowling, R., McGuirk, P., Maalsen, S.: Multiscalar governance of urban energy transitions in Australia: The cases of Sydney and Melbourne. Energy Research & Social Science 44, 260–267 (2018).
4. Gao, C., Fan, F., Liao, C.: Application of german energy transition in Taiwan: A critical review of unique electricity liberalisation as a core strategy to achieve renewable energy growth. Energy Policy 120, 644–654 (2018).
5. Dutra, R.M., Szklo, A.: Incentive policies for promoting Wind Power production in Brazil: Scenarios for the Alternative Energy Sources Incentive Program (PROINFA) under the new Brazilian electric power sector regulation. Renewable Energy 33(1), 65–76 (2008).
6. Vieira, L., Cader, R.: A política ambiental na década 2002–2012, em 10 anos de governos pós-neoliberais no Brasil: Lula e Dilma. FLACSO, Rio de Janeiro (2013).
7. GOLDEMBERG, J., LUCON, O.: Energia e meio ambiente no Brasil. Estudos Avançados 21(59), 7–20 (2007).
8. Lucon, O., Romeiro, V., Fransen, T.: Bridging the Gap Between Energy and Climate Policies in Brazil: Policy Options to Reduce Energy-Related GHG Emissions. WASHINGTON, DC (2015).
9. Vahl, F.P., Filho, N.C.: Energy transition and path creation for natural gas in the Brazilian electricity mix. Journal of Cleaner Production 86, 221–229 (2015).
10. Brasil, Discurso da presidenta da República, Dilma Rousseff, durante cerimônia de anúncio do Programa de Investimento em Energia Elétrica, http://www.biblioteca.presidencia.gov.br/presidencia/ex-presidentes/dilma-rousseff/discursos/discursos-da-presidenta/discurso-da-presidenta-da-republica-dilma-rousseff-durante-cerimonia-de-anuncio-do-programa-de-investimento-em-energia-eletrica-brasilia-d, last accessed 2019/04/04.
11. Viola, E., Franchini, M.A.: Brazil and climate change: beyond the Amazon. Routledge, New York (2018).

12. Aamodt, S.: From green to black emissions in Brazil?: The energy policy transition of an emerging oil exporter. FLACSO-ISA, Buenos Aires (2014).
13. Hochstetler, K., Viola, E.: Brazil and the politics of climate change: beyond the global commons. Environmental Politics 21(5), 753–771 (2012).
14. La Rovere, E.L., Pereira, A., Wills, W.: Brazil beyond 2020: From deforestation to the energy challenge. Climate Policy 13(1), 70–86 (2013).
15. Sperling, E.V.: Hydropower in Brazil: Overview of Positive and Negative Environmental Aspects. Energy Procedia 18, 110–118 (2012).
16. Vieira, M.V., Dalgaard, K.G.: The Energy Security Climate Change nexus in Brazil. Environmental Politics 22(4), 610–626 (2013).
17. Viola, E.: Transformations in Brazilian Deforestation and Climate Policy. Theoretical Inquiries in Law 14(109), 109–124 (2013).
18. Powell, W.W., DiMaggio, P.J.: The New Institutionalism in Organizational Analysis. 1st edn. The University of Chicago Press, Illinois (1991).
19. DiMaggio, P.J., Powel, W.W.: The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields. American Sociological Review 48(2), 147–160 (1983).
20. Fligstein, N.: The Transformation of Corporate Control. Harvard University Press Cambridge, Massachusetts, London, England (1990).
21. Fligstein, N.: Social Skill and the Theory of Fields. Sociological Theory 19(2), 125–205 (2001).
22. Fligstein, N., Shin, T.: Shareholder Value and the Transformation of the U.S. Economy, 1984–2000. Sociological Forum 22(4), 399–424 (2007).
23. Gil, A.C.: Métodos e técnicas de pesquisa social. 6th edn. Atlas, São Paulo (2008).
24. Dias, R.F.: Panorama do setor de energia elétrica no Brasil, 1st edn. Centro da Memória da Eletricidade, Rio de Janeiro (1988).
25. Brasil, Lei nº 1.145, de 31 de Dezembro de 1903. Fixa a despeza geral da Republica dos Estados Unidos do Brazil para o exercicio de 1904, e dá outras providencias, https://www2.camara.leg.br/legin/fed/lei/1900–1909/lei-1145-31-dezembro-1903-775726-publicacaooriginal-139481-pl.html., last accessed 2018/04/03.
26. Brasil, Decreto nº 5.407, de 27 de Dezembro de 1904. Regula o aproveitamento da força hydraulica para transformação em energia electrica applicada a serviços federaes, https://www2.camara.leg.br/legin/fed/decret/1900-1909/decreto-5407-27-dezembro-1904-527509-publicacaooriginal-1-pe.html, last accessed 2018/04/03.
27. Brasil, Decreto nº 24.643, de 10 de Julho de 1934. Decreta o Código de Águas, http://www.planalto.gov.br/ccivil_03/decreto/D24643.htm, last accessed 2018/04/03.
28. Neto, T.: Uma análise histórico-jurídica do Código de Águas (1934) e o início da presença do Estado no setor elétrico brasileiro no primeiro Governo Vargas. Revista Eletrônica História em Reflexão 9(17), 1–16 (2015).
29. Bndes: Exposição sobre o Programa de Reaparelhamento Econômico. Rio de Janeiro, 1963.
30. Cachapuz, P.B.: Panorama do setor de energia elétrica no Brasil - panorama of electric power sector in Brazil. 2nd edn. Centro da Memória da Eletricidade, Rio de Janeiro (2006).
31. Borges, O.F.: Formação e controle de preços de energia elétrica no contexto da economia brasileira. Rio de Janeiro (1987).
32. Brasil, Ex-presidentes - Discurso - Castelo Branco, Biblioteca da Presidência da República, 1964, http://www.biblioteca.presidencia.gov.br/presidencia/ex-presidentes/castello-branco/discursos/1964-1, last accessed 2019/04/04.
33. Brasil, Decreto-Lei nº 1.383, de 26 de Dezembro de 1974. Altera a redação do artigo 4º da Lei nº 5.655, de 20 de maio de 1971 e dá outras providências, Casa Civil, 1974, http://www.planalto.gov.br/ccivil_03/Decreto-Lei/1965-1988/Del1383.htm, last accessed 2019/04/04.
34. Lorenzo, H.C.: O setor elétrico brasileiro: passado e futuro. Perspectivas 1(24), 147–170 (2002).
35. Brasil, Lei nº 8.987, de 13 de Fevereiro de 1995. Dispõe sobre o regime de concessão e permissão da prestação de serviços públicos previsto no art. 175 da Constituição Federal, e dá outras providências, http://www.planalto.gov.br/ccivil_03/leis/l8987compilada.htm., last accessed 2019/04/04.

36. Gomes, A.C., Abarca, C.D., Faria, E.A.S., Fernandes, H.H.: O Setor Elétrico, Banco Nacional de Desenvolvimento Econômico e Social 50 anos: Histórias Setoriais. 1st edn. DBA, Rio de Janeiro (2002).
37. Gce: Relatório da Comissão de Análise do Sistema Hidrotérmico de Energia Elétrica. Brasília (2001).
38. Sauer, I.L.: Um Novo Modelo para o Setor Elétrico Brasileiro. 1st edn. USP/IEE, São Paulo (2002).
39. Brasil: Discurso do Presidente da República, Luiz Inácio Lula da Silva, na cerimônia de entrega oficial das obras de construção e instalação das turbinas nºs 14, 15, 16 e 17 da Usina Hidrelétrica de Tucuruí, http://www.biblioteca.presidencia.gov.br/presidencia/ex-presidentes/luiz-inacio-lula-da-silva/discursos/1o-mandato/2004/25-11-2004-discurso-do-presidente-da-republica-luiz-inacio-lula-da-silva-na-cerimonia-de-entrega-oficial-das-obras-de-construcao-e-inst, last accessed 2019/04/04.
40. Jardim, M.C., Silva, M.R.: Programa de aceleração do crescimento (PAC): neodesenvolvimentismo?. 1st edn. UNESP, São Paulo (2015).
41. Walvis, A., Gonçalves, E.D.L.: Avaliação das reformas recentes no setor elétrico brasileiro e sua relação com o desenvolvimento do mercado livre de energia. Rio de Janeiro (2014).
42. Gouvêa, A., Gonçalves, F., Fernandes, G.: Desafios e oportunidades no Setor Elétrico em 2020. Rio de Janeiro (2019).
43. Kuramoto, R., Appoloni, C.: Uma Breve História da Política Nuclear. Caderno Brasileiro de Ensino de Física 19(3), 379–392 (2002).
44. Brasil: Discurso da solenidade de assinatura de atos criando Reservas Biológicas, http://www.biblioteca.presidencia.gov.br/presidencia/ex-presidentes/jb-figueiredo/discursos/1982/102.pdf/view, last acessed 2019/04/04.
45. Giambiagi, F., Moreira, M.M.: A economia brasileira nos anos 90. Rio de Janeiro, Rio de Janeiro (1999).

Success Critical Factors on the Civil Construction Projects Management, Utilizing Artificial Neural Networks

Mauro Luiz Erpen, André Luiz Aquere, Clóvis Neumann, Maria Cristina Bueno Coelho, and Diego Patrick Nusrala Dias

Abstract This study aims to create a model, which determines the most influencers SCFs (Success Critical Factors) on the civil construction project management, utilizing artificial neural networks (ANNs). The usage of ANNs to originate a SCFs determining model in the Civil Construction Industry appears as the differential of this study, since it was observed, in the literature, the absence of studies which investigate extremely dynamic phenomenons similar as SCFs. The PRISMA Method was utilized for the questionnaire elaboration and the answers analysis was performed, initially, by the Relative Importance Index and, posteriorly, by the ANN usage with the *Resilient Propagation* algorithm. The most critical factor was "Unrealistic Inspection and Test Methods Proposed in Contract", on the project management area. ANNs provide insights, which allows to know the adopted input variables relevance, and are efficient on the knowledge transferring, being characterized as a fast and accurate method of SCF identification. In theory and considering their interdependence, by proposing the most impactful SCF determination in projects management, the research provides important information, focused on processes improvement actions, in the project area. In a practical sight, the analysis contributes, in an applied way, with the project managers, since any civil construction company can use the resulting management information system.

Keywords Garson algorithm · Resilient propagation · PMBOK guide · Success

M. L. Erpen (✉) · D. P. N. Dias
Federal Institute of Tocantins, Gurupi, TO 77410-470, Brazil
e-mail: mauroluiz@ifto.edu.br

A. L. Aquere
University of Brasília, Brasilia, DF 70910-900, Brazil

C. Neumann
University of Brasília, Brasilia, DF 70904-970, Brazil

M. C. B. Coelho
Federal University of Tocantins, Gurupi, TO 77402-970, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_50

1 Introduction

Performance measurement systems should be a support tool for the company's management, assisting decisions and helping on the improvement actions identification. To this extend, the organization is able to measure its performance, not only in the productive area, but also in the social, economic and environmental perpectives, having the same importance, as well, as analyze the acquired data and adopt the necessary measures, based on the results [1]. In this context, there are Success Critical Factors (SCF), which identify the essential set of key areas for the company to achieve its mission [2]. The SCF determination allows managers to identify which processes are essential for the business proper functioning. Blanning [3] affirms the SCF identification provides strategic information and can assist in managers' decision.

Valença and Ludemir [4] affirm that efficient communication, the "empowerment", changes management, requirements management, preparation to face risks and support from senior management increase the tendency of projects achieving success. Kog and Loh [5], at the same time as determining critical factors in project management, observed a case study in a large world-class Latin American company, which identified the relevance of business processes constant monitoring, aiming to better understand the realized activities and to identify potential problems, making corrections on the processes dynamics, by proposing changes in the methods and tools applied in project management.

The need for civil construction to remain competitive generated research to increase efficiency and, therefore, was reflected in the Project Management area as an interesting motivator: the incorporation of new capacities that allow greater assertiveness for the project management. In this perspective, the existence of tools such as the PMBoK guide and the softwares International Competence Baseline (ICB) Scrum, Projects in Controlled Environments (PRINCE2); Project Planning and Project Management (P2M); Association for Project Management (APM) (Ghosh et al. 2012), when associated with the project management, become into an efficient method for the SCF detecting, as is the case of Artificial Neural Networks (ANNs), this study's focus. Artificial neural networks (ANNs) are computational techniques with a non-linear approach, based on artificial intelligence mathematical models, which aim to represent or approximate systems [6]. In most cases, the models are based on real observations and experiments; however, they can also be used as metamodels, based on other models, as well as computer simulation [7]. Authors such as [8–11] presented the ANNs' advantages and applicabilities, however, did not demonstrate the modeling appliance on the Civil Construction Industry project management.

Therefore, this research aimed to analyze, based on artificial neural networks modeling, the main influencers Success Critical Factors on the civil construction industry projects sucess, according to the perception of professionals in a specific expert range, in this case, the academic area.

2 Methodology

A systematic literature review was carried out on the identification of Success Critical Factors (SCF), with an emphasis on project management in the Civil Construction Industry, according to the methodology presented by [12, 13]. This review begins with the search for qualitative data on the scientific bases Scopus and SciELO. Both scientific bases act in a complementary way, adjacent to being public and having their calculation methodologies published. All papers associated to the terms “project management in the civil construction industry”, “success critical factors” (SCF) and “artificial neural networks (ANNs) applied in the civil construction industry” were selected. The scientific bases were accessed through the CAPES/MEC journals portal, via Federal Institute of Tocantins (IFTO) and University of Brasília (UnB). The research has counted registers until December 2018 (since the year 2000), limited to articles and reviews.

In the qualitative phase, the documents analysis was made through PRISMA method (main items, aiming to report systematic literature review and Meta-analyze), composed with four distinct parts: Identification, Selection, Eligibility and Inclusion.

Posteriorly, in the quantitative phase, a pilot questionnaire was sent with a set of 120 SCFs, selected from the most relevant, determined by [14–16], for professionals and researchers in the graduate and postgraduate courses of Civil Engineering, registered in the Ministry of Education (MEC), totalizing 90 e-mails (about 10% of the total population), where the 20 most important factors in project management were determined. In this aspect, a semi-structured questionnaire was created, composed of open questions (dissertations) and closed questions (multiple choice, predefined answers), to assess the effect of each factor [13], consisting on two parts, where the first procedure refers to the experience time and researches in the civil construction area related to project management. In the second phase, a set of factors related to practices were evaluated, in terms of the extent to which the circumstances affect the companies’ productivity. For the second process, the 5-point Likert scale was utilized [17] since it is a perception where the experience-based opinion is required, being the possible answers: very low impact; low impact; medium impact; high impact; very high impact.

The number of items on the scale is validated by [18], who affirms the five-point scale had, on average, good precision and proved to be easier and faster than the seven-point scale. Therefore, for this study, the scale that proved to be the most adequate was the five points one. The search for respondents was shaped by their characteristics. Researches were made in all Civil Engineering graduate and postgraduate courses in higher education institutions (HEIs) registered in the Ministry of Education (MEC). The sample characterization was based on the questionnaires’ random and heterogeneous feedback, since the sending was intended to reach the entire described population, and the data collection was performed, exclusively, by electronic means (google forms), with the sending of a link by e-mail and/or cell phone (WhatsApp), for virtual filling, between the months of May and June 2018.

The index is formulated for each specific factor and for each participants' experience year, according to [17, 19]. The interview responses from the Relative Importance Index (RII) (Eq. 1) was calculated:

$$(RII\%)_k = \frac{5(n5) + 4(n4) + 3(n3) + 2(n2) + n1}{5(n1 + n2 + n3 + n4 + n5)} \times 100 \tag{1}$$

where: (RII%)k = annual percentage of relative importance index of each factor (calculated separately for the categorized respondents' corresponding experience year (k)); k = categorized respondents experience years (for first experience year: k = 1; for the last experience year: k = K); n1, n2, n3, n4 e n5 = are the numbers of interviewed who chose: "1" for very low impact, "2" for low impact, "3" for medium impact;"4" for high impact, and "5" for very high impact.

Equation 2 was utilized to calculate the Global Relative Importance Index (RII) for all respondents' each factor, considering all the combined respondents' experience years, which is calculated as a weighted average of RII_k.

$$GlobalRII(\%) = \frac{\sum_{k=1}^{k=K} (k \times RII_k)}{\sum_{k=1}^{k=K} k} \tag{2}$$

where: Global RII (%) = percentage of each factor's total relative importance index weighted average (calculated, having as basis all combined interviewee's experience years); k = categorized respondents' experience years (k = 1 for first experience year; k = K to last experience year:); RII_k = annual percentage experience of each factor's Relative Importance Index (calculated separately for the categorized respondents' corresponding experience year (k)).

ANN was used to evaluate the most significant SCFs, utilizing the Neuro4 software (receives the information of each factor's contributing weight and, with that information, performs the training process). For the Neuro4 software insertion, an output value is required for these variables, so the weighted average (Eq. 3) was chosen.

$$V_s = \frac{\sum_{i=1}^{n} \left(x_{ij} \times GII_j\right)}{\sum_{j=1}^{n} GII_j} \tag{3}$$

where: V_s = output value; xij = each factor's value per respondent; GIIj = importance index of each factor. The ANN training consists of the parameters adjusting iterative process, weights and excitation threshold (plotted with a weight), originated from examples sets successive presentations to a training algorithm, until a stopping criterion is achivied, finalizing the process. The propagative training algorithms were utilized for the supervised learning paradigm-fit ANN training, in other words, the training algorithm receives a pair of inputs and their respective desired outputs. The propagation algorithm passes through interactions series, aiming to minimize the estimation error.

The utilized algorithm was Resilient Propagation® [20] which, in its conception, was designed to optimize BackPropagation processes, aiming the satisfactory ANN obtaining. The data space was separated into two data sets: training and validation. The used data set, during the training phase, presents calculated error in relation to training cycles, where data is utilized to test the network during development/training, by continually making corrections and adjusting network connection weights, having as purpose to reduce the error. The validation set is the data part used to validate the model (s). A network training is finished when a certain stopping criterion is achivied. In this study, three criteria are used: medium error, cycles number and convergence. Considering the kth training sample, the quadratic error function measures the output neuron values (j) performance (Eq. 4):

$$e(k) = \frac{1}{2}\sum_{j=1}^{n}\left(y_d^j(k) - y_j(k)\right)^2 \tag{4}$$

where: y_d^j is the desired output value e y_j is the network obtained value.

Considering a training set, consisting of p samples, the training algorithm overall performance can be measured by the medium quadratic error (e_M), or, simply, medium error (Eq. 5):

$$e_M = \frac{1}{p}\sum_{k=1}^{p} e(k) \tag{5}$$

A cycle (or period) corresponds to all complete training set presentation elements, accompanied by adjustments of the net weights. Therefore, a stop criterion, based on the cycles number, finishes a network training after reaching a certain number of cycles. The criterion termed as convergence defines the number of cycles after which, assuming the medium error does not decrease, the training is complete. In the variables selection, a technique consisted in selecting a subset of the given data most relevant characteristics, the Garson algorithm, proposed by [21], involves the connection weights partitioning, between the hidden layer and the output of each intermediate neuron into associated components to each input neuron. To obtain each variable relative importance, the algorithm performs the following steps:

1. For each intermediate neuron i, the connection weight absolute value, between this neuron and an output one is multiplied by the connection weight absolute value, between the same hidden neuron and an input neuron. This calculus is done for all jth input layer neurons (Eq. 6).

$$P_{ij} = w_{ij} \times w_{i0} \tag{6}$$

2. For each hidden neuron, Pij is divided by the sum of all Pij, for each input neuron, obtaining Qij (Eq. 7):

$$Q_{ij} = \frac{P_{ij}}{\sum_{j=1}^{n} P_{ij}} \tag{7}$$

3. For each input neuron, Qij values are summed to obtain Sj (Eq. 8):

$$S_j = \sum_{i=1}^{n} Q_{ij} \tag{8}$$

4. Dividing each value of Sj by the sum of all values of Sj, the relative importance R for each variable j is found (Eq. 9):

$$R_j = \left(\frac{S_j}{\sum_{j=1}^{n} S_j} \right) \times 100 \tag{9}$$

The Garson algorithm utilizes connection weights absolute values to calculate the variable contribution, not allowing a change direction analysis of the output variable when input variables change [4].

3 Results

The following subsections present the results of the systematic literature review and the perception of Brazilian researchers about the selected SCF.

3.1 Systematic Literature Review

In the literature review phase, where Project Management, Success Critical Factors (SCF) and Artificial Neural Networks (ANNs) were researched, the results were: for "Project Management in the Civil Construction Industry (CCI)" a total of 37822 articles (2328 journals), for "Critical Factors and Project Management" were found 977 articles (68 journals), for "Critical Factors and ANNs", 94 articles (in 7 journals), for "Project Management and ANNs", 105 articles (in 2 journals) and for "Project Management, Critical Factors and ANNs", 4 articles. For the theme "Success in Civil Construction", 1903 articles were found and for "Success Critical Factors in construction", 157 articles. For "Artificial Neural Network in construction" were found 2628 documents.

After the selected and contributing archives analysis, the questionnaire elaboration was based on the factors related by [15, 16, 22, 23], also doing a correspondence with the PMBok Guide's Knowledge Areas, potentially impactful in project management in the civil construction industry. The study factors identification and

Table 1 Selected success critical factors relation

Cod	Impact factors
F1	Work scope increasing
F2	Ambiguity in specifications and/or conficting interpretation
F3	Rework due to project changing
F4	Unrealistic schedule imposed on contract
F5	Rework due to an execution error
F6	Inaccurate location condition specification
F7	Difficulty accessing information, materials and equipment in project office
F8	Poor coordination between the interested parts (Stakeholders)
F9	Lack of companies' registration for subcontracts
F10	Engineer's or architect's reluctance to change
F11	Conflict between owners and other parts
F12	Obtaining permission from local authorities
F13	Changes in government regulations and laws
F14	Simplicity and clarity in project specification
F15	Poor coordination between project parts
F16	Lack of project information feedback
F17	Lack of quality requirements knowledge
F18	Clear definition of project scope
F19	Lack of experienced project team
F20	Unrealistic inspection and test methods proposed in contract

the questionnaire preparation are an essential phase for the research success, being listed in Table 1 (selected and adapted from the cited authors' conclusions).

3.2 *Perception of SCF by Researchers at Brazilian HEIs*

To colect the perception of Brazilian researchers about the 20 selected SCF, 874 e-mails were sent to all coordination and secretariats of graduate and post-graduate courses in Civil Engineering at Higher Education Institutions (HEIs) registered on the e-MEC system to, posteriorly, be forwarded to the faculty, being obtained a total of 191 respondents, distributed in the 27 Brazilian states. Considering the 191 obtained questionnaires and the 20 SCFs contemplated on the field research, a questionnaire/variable ratio of 9.55 is obtained, which is higher than the superior limit suggested by [24] and conforms with [25]. The ratio is still reinforced by Guadagnoli and Velicer (1988) apud [26], who, in defying Gorsuch's criterion, argued that no theoretical or empirical basis exists for the number of participants and the number of variables relation recommendations.Posterior to the data collection, the states where

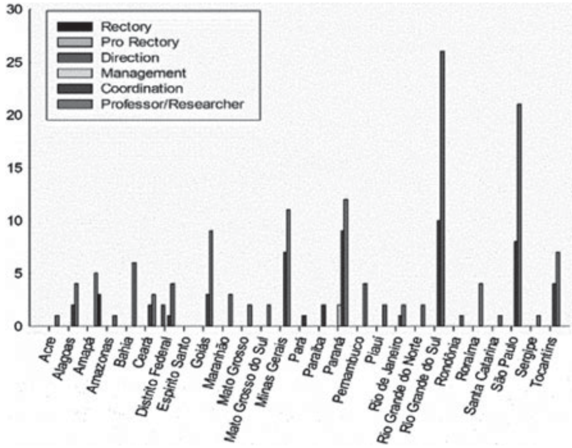


Fig. 1 Respondents by state and position held in institutions

the respondents reside can be characterized. The 191 respondents are placed in the 27 Brazilian states, where 70% held the professor/researcher position, 26% were coordinators, 2% held the Dean position and 1% from Direction and Management, presenting proportionality in relation to the institutions administrative organization (Fig. 1).

The factors, according to the responses percentage and considering each respondents' research times, were classified with weights (Table 2).

Factor 8 achieved a high rate: 88.7%, being the highest index, and was followed by factor 4: 87%. A similar result to this study was found by [1], who, with the application of a questionnaire to the professionals involved in civil construction, obtained, as a result, the efficiency in decision making, the planning effort and the project management previous experience with SCFs involved.

Similar answers were found by [20], when evaluating influencers SCFs on civil construction projects performance, who determined four success dimensions (efficiency, operational learning, customer satisfaction and future preparation) and their project management impactful SCFs. Also, the results obtained by [27], determined that, in general, the most critical items considered by the team were those related to planning and managerial support. Jordão et all [28], when evaluating Success Critical Factors in Civil Construction Projects, utilizing the systematic literature review and its subsequent validation, found, in respect to the project management

Table 2 Factors classification in the project management area

Factor	Ind. %	Factor	Ind. %
F8	88.67	F15	81.55
F4	87.10	F2	81.37
F19	87.07	F6	79.32
F3	86.72	F20	79.11
F5	86.09	F10	78.49

category, the three most relevant SCF: “project monitoring and feedback”, “project risk management” and “managing changes to the project”. The previous three cited factors corroborate this study. Posterior to the Factors classification, according to the Relative Importance Indexes and found according to Eqs. 2 and 3, the data matrix (Table 2), to be inserted in NEURO4, was obtained, associated with the output values (Vs) definition.

For data insertion, utilizing Neuro4, the variables “factors” were characterized as quantitative and the variable “Vs” as an output variable. In the processing, some software structure configuration tests were necessary, being configured for the training with the number of 100 networks for each configuration.

The stopping criteria setting was due to the average error of 0.0001, considered a sufficient value for the research objectives, according to [29], and the determined number of cycles was 3000, as it is a similar value to the obtained data from 4000 cycles. In the structure stopping parameters configuration, the average error variations were initially tested and, then, studying this configuration with the number of cycles variations, clearly was realized that after 3000 cycles, the error convergence does not present major changes in the average values, considering the processing-tested 100 networks (Fig. 2).

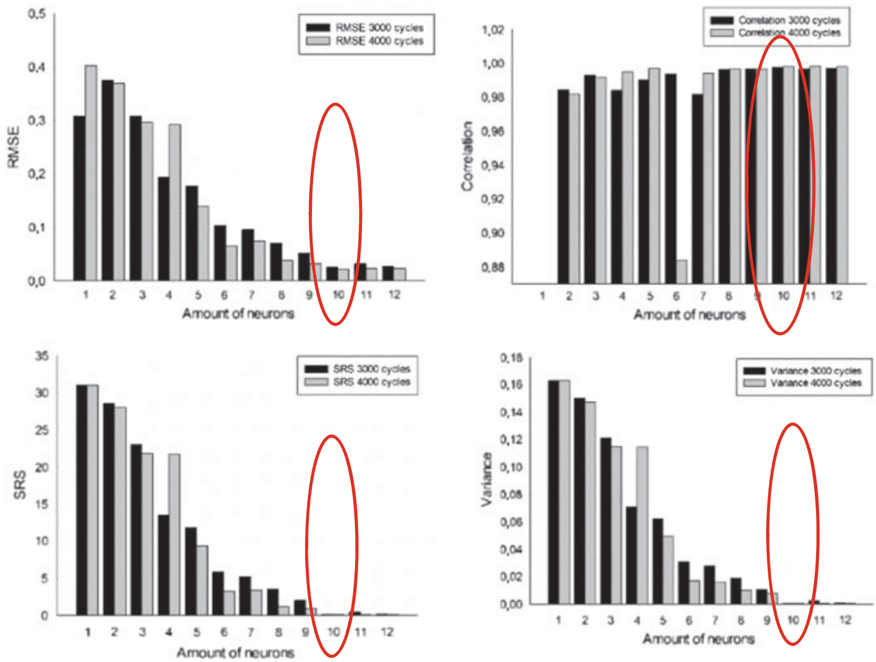


Fig. 2 Variables error average square sum, sum of the residual square, variance and correlation coefficient for 3000 and 4000 cycles

Statistical values were obtained for the Error Average Square Sum (EASS), Variance and SRS (Sum of the Residual Square), obtained with 10 neurons in its hidden layer (verified the values stabilization), considering the precession ideal configuration.

After obtaining the best configuration for the training, the data were, again, inserted on Neuro4, willing to obtain the variables characterization weights. In this phase Neuro4 was configured to separate 70% of the data (134 respondents), randomly for the training, and allocating 30% (57 respondents) for validation.

With the selected network weights values extracted from Neuro4, the Garson algorithm was applied. For this phase, it was necessary to extract each weight's values, assigned by the algorithm in the 10 hidden layers. The Garson algorithm, with the tested 100 networks results analysis and performing a data scanning, presented more significant statistical results, with the aid of the Excel Software.

After the factors classification, in descending order (Table 3), in each processing, it was ascertained that factor No. 20 "Unrealistic inspection and test methods proposed in contract" was the result that most appeared in the first 4 positions (50 appearances in 100 networks as the most impactul factor on), 19 times in 2nd place, 8 appearances in third place and 3 times in fourth place.

Posteriorly, factors 17 and 5, respectively, "Lack of quality requirements knowledge" and "Rework due to an execution error" with 28 and 23 appearances, in the first 4 positions. Factor 17 appears 6 times in the first position, 9 times in the second position, 4 times in the third and 9 in the fourth. Factor 5 had 3 appearances in the first position, 9 times in the second, 4 times in the third and 9 times in the fourth. Factor 9 "Lack of business registration for subcontracts" also appears: 9 times in the

Table 3 Response matrix for the artificial neural network using

Resp	F1	F2	F3	F4	F5	F6	..	F12	F13	F14	F15	F16	F17	F18	F19	F20	Vs
1	4	4	5	4	5	5	..	5	3	5	4	4	5	4	4	5	4.09
2	5	3	4	4	5	4	..	3	3	4	4	5	4	5	5	4	4.30
3	5	3	5	4	3	4	..	4	2	4	4	4	4	5	4	5	3.84
.							..										
.							..										
189	3	5	5	4	5	4	..	3	2	2	4	4	3	4	2	1	4.07
190	4	5	3	4	5	4	..	3	4	5	5	4	5	3	5	3	4.35
191	5	5	5	5	5	2	..	5	1	3	4	4	3	3	4	3	4.14

Table 4 Factors classification by number of appearances as the most impactful

Factors	Number of appearances on the 4 first positions	Number of appearances on each position			
		1°	2°	3°	4°
20	80	50	19	8	3
17	28	6	9	4	9
5	23	3	3	6	11
9	22	9	5	3	5
12	22	1	6	11	4

first position, 5 times in the second, 3 times in the third and 5 times in the fourth. If only the factors that appear as the most impacting in the 100 selected networks were considered, factor 20, followed by factor 17, factor 5 and factor 9, respectively, are the most impactul SCFs on the Civil Construction Industry (CCI) project management (Table 4).

The obtained results confirm those found by [9], who, with the use of ANNs and the Resilient Propagation algorithm, identified twelve success key factors in construction management. The results concluded the model allows construction project managers to focus on success critical factors, reducing construction risk.

Al-zwainy [10] applied modeling, utilizing artificial neural networks and with the usage of the back-propagation algorithm, to determine the productivity in civil construction for the marble industry and paving finishing. The autors identified nine critical factors. The data found by [29], when studying the most impactful SCF on project management (also with the ANN utilization and the Gauss activation function for intermediate layers), determined ten project success indicators, divided into five categories (financial, interaction processes, labor, configurations counterpart and project characteristic). Kog and Loh [5] determined that the suppliers contract incentive mechanisms, realistic obligations, motivations and contractual incentives are among the ten most important critical success factors in civil construction projects. Fortune and White [11] applied ANN, through the neuro-fuzzy adptative methodology Inference system (ANFIS), to analyze project risks in the civil construction industry and concluded that risk management can be studied by modeling the human experience on judgments and without the specialists presence, having structured and mathematic methodologies.

It was observed that the ANNs were applied on difficult solution problems, with the traditional mathematical resources and statistical methods. The study provides comprehensive ANN reputation in construction engineering and management, for application in different areas, willing better accuracy and reliable predictions.

4 Conclusions

The selection of the already consolidated critical factors, in the bibliography, led to the construction, formulation and application of the questionnaire, which achieved its objective: providing subsidies for the work analysis.

The ANNs utilization, considering that the entire process was based on the professionals' perceptions, related to a formal model, should be recognized with a multidimensional approach (according to the associations that constitute the socio-technical network, in which the model participates and, constitutively, entangles human and social elements with formal and technical artifacts). They should not be considered as a human interpretation attribute or action, nor as an inherent characteristic of design models.

The classification method by the Relative Importance Index (RII), provided by [8, 23, 27, 30], contributes as a valid and consistent usage matrix, in the ANNs processing. The Resilient Propagation algorithm also proved to be effective in the ANNs training, as it provided a consistent weights matrix, for the Garson Algorithm application.

The model described by 3000 cycles, 100 networks and 10 hidden layers described the SCFs "unrealistic inspection and test methods proposed in the contract" (20), "lack of quality requirements knowledge" (17), "rework due to execution error" (5) and "lack of companies registration for subcontracts" (9), respectively, as the most impactul on the Civil Construction Industry (CCI) project management.

The ANNs utilization produced subsidies to know the adopted input variables relevance, through later use of the Garson method. The variables' importance, associated to the used SCFs, was confirmed.

References

1. Riedmiller M.; Braun, H.: A direct adaptive method for faster backpropagation learning: The rprop algorithm. proceeding of the IEEE International Conference on Neural Networks, pp 586–591. São Francisco (1993).
2. Santos, P. R.: Santos, M. R.; Shibao, F. Y.: Comparação entre os padrões de gerenciamento de projetos PMBOK, ICB E PRINCE2. Caderno de Administração, 25 (2), UEM (2017).
3. Blanning, R. W.: Response to Michel, Kleijnen and Permut. Interfaces, 5(3), 24–25 (1975).
4. Valença, M.J.S.: Ludemir, T. B.: Explicando a relação entre as variáveis de uma rede neural: Iluminando a "Caixa Preta". In: XVII Simpósio Brasileiro de Recursos Hídricos, ABRH, São Paulo (2007).
5. Kog, Y. C., Loh, P. K.: Critical Success Factors for Different Components of Construction Projects. Journal of Construction Engineering and Management, 138(4), 520–528 (2012).
6. HAIR, J. F. Jr. *et al.:* Multivariate data analysis. New Jersey, Prentice Hall (1998).
7. Barros, V. P.: A Avaliação do Desempenho de Algoritmos de retropropagasção com redes neurais artificiais para a resolução de problemas não lineares. Master's Thesis - Universidade Tecnológica Federal do Paraná e Diretoria de pesquisa e pós graduação em ciência da computação. Ponta Grossa, Paraná (2018).
8. El-Gohary K. and Aziz R.: Factors Influencing Construction Labor Productivity in Egypt. In: Journal of Management in Engineering, 30 (1), 1–9 (2014).

9. Apanaviciene, R.; Daugeliene, A.: New Classification of Construction Companies: Overhead Costs Aspect. Journal of Civil Engineering and Management, 17(4), 457–466 (2011).
10. Al-zwainy F. M. S.: The Use of Artificial Neural Networks for Productivity Estimation of finishing Stone works for Building Projects. Journal of Engineering and Development. 16(2), 42–60 (2012).
11. Fortune, J., White, D.: Framing of project critical success factors by a systems model. In: International Journal of Project Management,24(1), 53–65 (2006).
12. Vezzoni, G; Pacagnella, A.C.J. Banzi, A.L.J.; Silva, S.L.: Identificação e análise dos fatores críticos de sucesso em projetos. Revista Gestão e Projetos, 4(1), 116–137 (2013).
13. FRANÇA, D. C.: Modelagem de um Adaptative Neuro Fuzzy Inference Sistem para análise de risco em projetos. Master's Thesis - Universidade Fedral da Paraíba e Centro de Tecnologia. Programa de pós graduação em Engenharia de produção (2016).
14. Enshassi A., Mohamed, S. Abu Mustafa Z. and Mayer E.: Factors Affecting Labor Productivity in Building Projects in the Gaza Strip. Journal of Civil Engineering and Management, 13 (4), 245–254 (2007).
15. Dalmoro, M., & Vieira, K. M.: Dilemas na construção de escalas Tipo Likert: o número de itens e a disposição influenciam nos resultados?. Revista Gestão Organizacional, 6(3), 161–174 (2013).
16. Meisel, W. S.; Collins, D. C.: Repro-Modeling: An Approach to Efficient Model Utilization and Interpretation. IEEE Systems, Man and Cybernetics Society, 3(4), 349–358 (1973).
17. Leite, A. C. P.: Fatores Críticos de Sucesso em Projetos de Construção. Dissertation for Escola Superior de Tecnologia e Gestão Politécnico do Porto. Felgueiras, pp 55 (2018).
18. Cooke-Davies, T. The "real" success factors on projects. International Journal of Project Management, 20(3), 185–190 (2002).
19. Doloi, H.: Cost overruns and failure in project management - understanding the roles of key stakeholders in construction projects, Journal of Construction Engineering and Management, 139(3), 267–279 (2013).
20. Morioka, S., & Carvalho, M. M.: Análise de fatores críticos de sucesso de projetos: um estudo de caso no setor varejista. Produção, 24(1), 132–143 (2014).
21. Freitag, A. E. B.: Fatores críticos de sucesso para adoção da gestão enxuta pela indústria da construção civil do Estado do Rio de Janeiro. Doctoral Dissertation - Universidade Federal Fluminense. Niterói, RJ (2015).
22. Colauto, D. R.; Gonçanves, M. C.; Beuren, M. I.; Santos, N. Os Fatores Críticos de Sucesso como Suporte ao Sistema de Inteligência Competitiva: O Caso de uma Empresa Brasileira, Revista de Administração Mackenzie, 5(2), 119–146 (2004).
23. Saqib, M., Farooqui, R. U., & Lodi, S. H.: Assessment of Critical Success Factors for Construction Projects in Pakistan. In: First International Conference on Construction in Developing Countries, Karachi, pp 392–404 (2008).
24. Lopes, D.: Critérios de avaliação do desempenho de gerenciamento de projetos: uma abordagem de estudo de casos. Master's Thesis - Escola Politécnica da Universidade de São Paulo, São Paulo (2009).
25. Garson, G.D.: Interpreting neural network connection weights. Artificial Intelligence Expert, 6(4), 47–51 (1991).
26. Laros, J. A.: O Uso da Análise Fatorial: Algumas Diretrizes para Pesquisadores. In: Análise fatorial para pesquisadores, LabPAM Saber e Tecnologia, Brasília (2012).
27. Jarkas A. and Bitar G.: Factors Affecting Construction Labor Productivity in Kuwait.: Journal of Construction Engineering and Management, 138(7), 811–820 (2012).
28. Jordão, R.V. D., Pelegrini, F. G., Jordão, A. C.T. and Jeunon, E.: Fatores críticos na gestão de projetos: um estudo de caso numa grande empresa latino-americana de classe mundial. Gestão e Produção, 22(2), 280–294 (2015).
29. Asgari, M; Kheyroddin A.; Naderpour, H.: A Proposal Model for Estimation of Project Success in Terms of Radial Based Neural Networks: A Case Study in Iran., Civil Engineering Journal, 3, (10), 904–919 (2017).
30. Likert R. A technique for the measurement of attitudes. In: Arch Psychol, pp. 1–55. (1932).

Production Planning and Control in Industry 4.0: Maintenance or Breakdown of the Principles and Fundamentals

Paulo Eduardo Pissardini and José Benedito Sacomano

Abstract The PPC presents numerous challenges in terms of command and coordination of the productive sector with company's sectors. With the emergence of new production paradigms, the complexity of planning and controlling production has increased a lot. In 2011 Industry 4.0 brought with it the need to verify whether there was a maintenance or rupture of the principles and fundamentals as well as of a whole theory developed over years of research. To verify the maintenance or rupture of the fundamentals, a bibliographic review was carried out, identifying the fundamentals of the PPC in the light of the main authors in the area, making a comparison of these fundamentals with the functional architecture of the PPC in Industry 4.0. The result points to the confirmation of the maintenance of a whole theory that underlies the PPC. Finally, the results of the comparison and the respective suggestions for future work was shown.

Keywords Production planning and control · Industry 4.0 · Operations management · Principles and fundamentals

1 Introduction

At the beginning of the 19th century, the emergence of the mass production paradigm brought with it the alignment with the market's needs at that time where demand consumed supply. This paradigm led to the emergence of other paradigms, arising with the gradual inversion in the demand X supply relationship and the consequent change in the consumer market's requirements. Subsequent to mass production, we went through lean production when the market started to demand quality and after responsive, agile production and mass customization. The evolution of Strategic

P. E. Pissardini (✉)
Federal University de São Carlos, São Carlos, SP 13565-905, Brazil
e-mail: paulo.pissardini@estudante.ufscar.com.br

J. B. Sacomano
Paulista University, São Paulo, SP 04026-002, Brazil

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_51

Paradigms of Manufacturing Management (SPMM) has brought with it an increase in the complexity of Production Planning and Control systems (PPC).

The transformation of Production Planning and Control systems was due to the increased need for integration between processes, as the new paradigms emerged.

Godinho Filho [1] presented the classification and structure of five production paradigms.

In 2011, the existing base of computerized automation and a business vision focused on digital transformation gave rise the Industry 4.0 concept, whose name came from a German industry project, called *Plattform Industrie 4.0* (Platform Industry 4.0), at the Hannover fair [2].

Pissardini [3] presented the functional architecture of the five paradigms previously classified by Godinho Filho [1] using the same methodology to propose a functional architecture for PPC in Industry 4.0, classifying it as a Strategic Paradigm of Manufacturing Management.

Based on the production paradigm´s configurations, this study will seek to analyze the evolution of PPC systems, from mass manufacturing to industry 4.0 in the light of the main authors of the area. This study is justified by the intention of assessing whether there was maintenance or rupture of the principles and foundations of PPC with the evolution of SPMM.

2 Objectives

This study addresses the principles and fundamentals of PPC. The objective of this work is to carry out a study of the PPC's formatting in industry 4.0, checking if there was a rupture or maintenance of the principles and fundamentals. The principles, foundations and formatting of industry 4.0 are shown in Sect. 3. The findings are discussed in Sect. 4 and the final considerations are presented in Sect. 5.

3 Methods

To carry out this work, a systematic bibliographic review was done. According to Gil [4], a bibliographic research has an exploratory character, as it allows greater familiarity with the problem, improvement of ideas or discovery of intuitions.

For Kitchenham [5] some of the reasons that contributed to a systematic literature review are:

- Evidences consolidation and results obtained in previous studies on the interest topic;
- Identify gaps in theory and recent research as a basis for improving research;

- Provide models and theoretical models to position new topics and research opportunities, until even, refute/validate hypotheses, or create hypotheses about a specific topic for research.

In this way, a wide bibliographic review was carried out in the light of the main authors in the PPC area between 1979 and 2007 period, seeking to identify the principles and fundamentals of the conventional PPC.

A proposal of a Functional Architecture for the PPC in the Industry 4.0 SPMM was presented by Pissardini [3].

It was verified if the principles and foundations of the conventional PPC are present or not in Industry 4.0, in order to understand whether there was maintenance or rupture, weaving the final considerations about the current state of the art and the current and future of the PPC in the 4.0 environment.

4 Results

4.1 *Principles and Fundamentals of PPC*

For Zaccarelli [6] PPC is configured as a set of interrelated functions that aim to command the production process and coordinate it with the other sectors of the company.

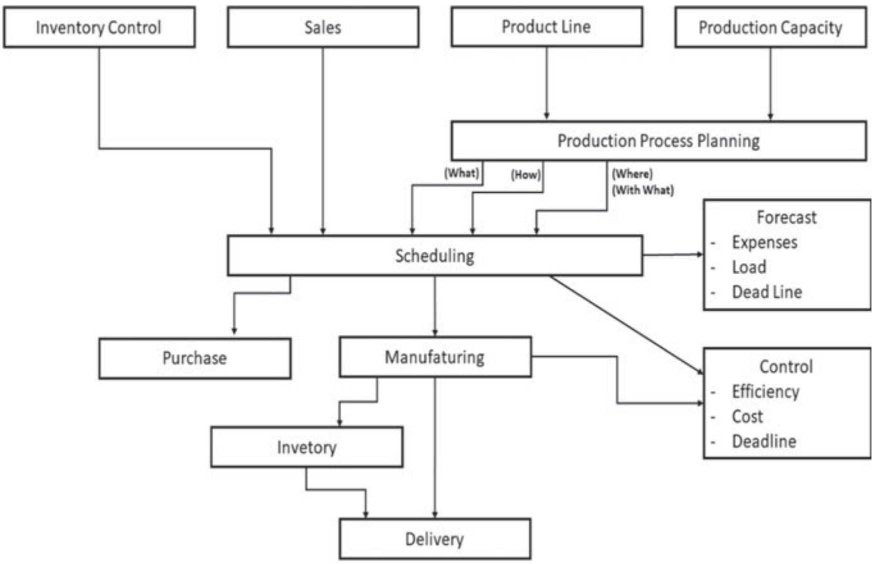


Fig. 1 Primary information flow. *Source* Adapted from Zaccarelli [7]

Zaccarelli [7] shows the Primary Information Flow (Fig. 1), where we can verify the guiding principles and foundations of a PPC system.

Burbidge [8] points out that the objective of the PPC is to allow an adequate resources use, in order that specific products are produced by specific methods, to meet an approved sales plan.

Contador [9] and Côrrea [10] points to the existence of hierarchical phases in the PPC's decision-making process.

Fernandes [11] presents three major functions of the PPC:

1. Master Production Scheduling (MPS);
2. Order Coordination System;
3. Operations Programming.

The PPC, according to Wiendahl et al. [12] is the central logistical control mechanism of a manufacturing system.

For Stevenson et al. [13] some of the fundamentals of the PPC are:

1. Material Requirements Planning (MRP);
2. Demand Management;
3. Capability Resource Planning (CRP);
4. Scheduling and
5. Sequencing of works.

Vollmann et al. [14] presents three areas that strongly influence the design of the PPC system:

1. Internationalization degree—the increase in exchanges between countries increasingly influences the design and execution of PPC systems, generating adaptation needs, making organizations more internationalized, transparent and with more effective logistics.
2. Importance of the customer in the system—the new customer's expectations generated by the competitiveness between organizations in order to always offer new products and services play a decisive role in the PPC, once these expectations demonstrate how the company must adapt to the market consumer, guaranteeing its presence in the market, creating the need to work on meeting requests.
3. Use of information technology—information technology is a response to the demand for communication and coordination.

For Fernandes and Godinho Filho [15] there is much controversy in the literature regarding the planning horizons of activities and the PPC scope.

4.2 Functional Architecture of Industry 4.0's PPC

Pissardini [3] proposed a framework to make the PPC in Industry 4.0 functional (Fig. 2). The model presents the Architecture containing vertical integration, horizontal integration, the Order Coordination System and the elements that constitute each of the four pillars of a SPMM.

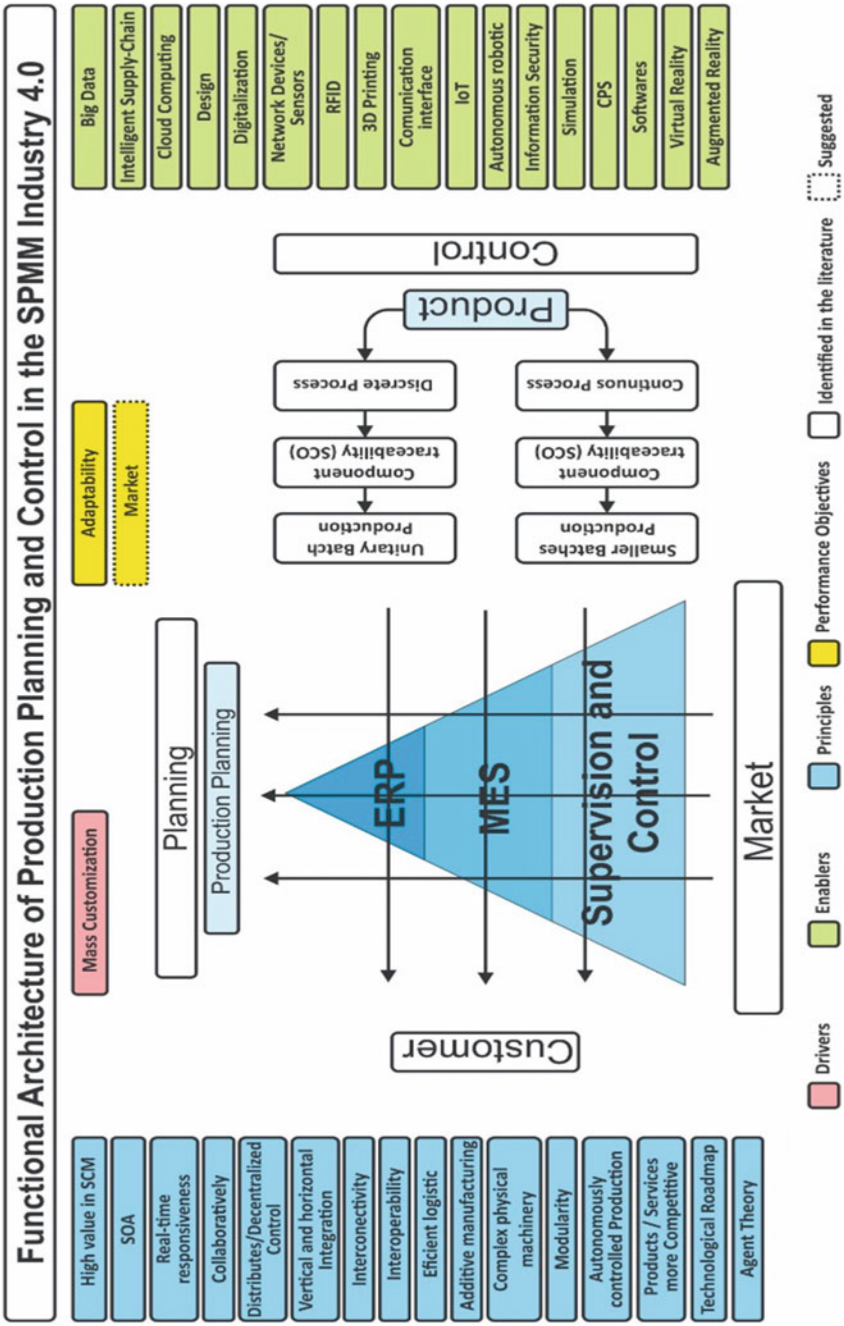


Fig. 2 Functional archtecture of production planning and control in SPMM Industry 4.0. *Source* The author

4.3 A Comparative Between the Presented Model and It's Theory Adherence

The Functional Architecture model for PPC in Industry 4.0 proposed by Pissardini [3] adheres to the first principle of Zaccarelli [6], presenting a set of interrelated functions that aim to command the production process and coordinate it with the other sectors of the company since the Manufacturing Execution Systems (MES), responsible for the two levels integration, collects information from the production line, stocks, quality levels, and information from several other sectors and feeds the Enterprise Resource Planning (ERP), responsible for planning the company's resources.

The model also adheres to the Primary Information Flow, proposed by Zaccarelli [7] from the moment that the MES, responsible for the integration of information receives data coming from inventory control, sales, and production planning, arising from the information about product lines and production capacity to generate forecasts of expenses, machine load and deadlines, contributing to an effective efficiency control, costs and deadlines, ensuring the manufacture of the product for delivery to the final consumer.

The fundamental presented by Wiendahl et al. [12], where affirms that the PPC is the central logistic control mechanism of a manufacturing system, is present in the PPC of Industry 4.0 from the moment that it uses MES as a central tool, integrating mechanism of the vertical and horizontal levels of information, making the PPC become the center of the manufacturing system, receiving information inputs and providing information outputs (for decision making) and operationalization of production plans in both levels of integration.

Among the fundamentals presented by Stevenson et al. [13], the MRP, in the Industry 4.0's PPC, converts the market's needs into a language that can be understood by production, generating, for example, production orders, bill of materials, etc. and MES is responsible for the connection between outputs (from production planning) and inputs (supplied to production control systems). Demand management, the second fundamentals of the PPC pointed out by Stevenson et al. [13], according to the APICS dictionary, is configured as a process linked to the recognition of all the demands for goods and services necessary to meet the market, imposing the need to establish an order's hierarchy to be fulfilled when supply is low, an essential condition for obtaining profitable business results, reducing costs and increasing productivity in all organization areas. In the 4.0 environment, demand management is aided by several elements present in the pillars of Industry 4.0 such as Big Data Analytics, Cloud Computing, Networked Devices/Sensors and Internet of Things. Moeuf et al. [16] agrees with the existence of this foundation in the Industry 4.0's PPC, stating that in all cases, the Industry 4.0 concept is based on the emergence of new technologies such as cloud computing, Internet of Things, Cyber-Physical Systems and Big Data. Such technologies should improve the transmission of information throughout the system, which allows better control and operations to be adapted in real time according to different demands. Capacity Planning, the third PPC's foundation, pointed out by Stevenson et al. [13] is present in an integrated way in the company's ERP system, a system that occupies the top of vertical integration, helping management decision making and providing information to the MES.

Also, due to the great capacity for data acquisition and treatment, the decision-making process in terms of production capacity investment is more efficient. Mussbach-Witer et al. [17] point out that based on this coordination between the various hierarchical levels through complementary IT solutions, efficiency is increased and production times reduced. The scheduling and sequencing of production, fourth and fifth fundamentals mentioned by Stevenson et al. [13] are also present in the PPC of the Industry 4.0. This sequencing is aided by networked devices/sensors, Internet of Things and autonomous robotics.

These elements, when working together, allow machine-to-machine (M2M) communication, making the production system respond the demand in real time, scheduling and sequencing new orders according to the current state of the production system, reducing the production pace of machines that have some defect, relocating products in other lines if necessary, rescheduling orders autonomously. The biggest difficulty of this system, according to Rossit et al. [18] is to incorporate the human decision-making process, which is configured as a black box.

In the PPC of other paradigms such as mass production, lean production and others, all tasks of scheduling and sequencing production as well as resequencing suffer from a natural inertia, due to the lack of system autonomy and the absence of machine to machine communication.

Thus, it is possible to verify the presence of scheduling and sequencing activities in the architecture of Industry 4.0 presented, with the fundamental difference remaining in terms of reduced inertia and greater efficiency and effectiveness in the PPC of Industry 4.0 due to the greater information's accuracy, collected and processed in real time.

Vollmann et al. [14] also present three fundamentals that strongly influence the PPC system's design, the internationalization's degree, the client importance in the system and the use of IT. Regarding the degree of internationalization, Vollmann et al. [14] points to the need for constant adaptations in the system, in line with the increase in the internationalization degree, transparency and efficient logistics. These needs pointed out by Vollmann et al. [14] meet the elements of high value in the supply chain and efficient logistics and intelligent supply chains, present in the "Principles" pillar of the Industry 4.0's PPC. The importance of the customer in the system is present in the elements of adaptability and market, which form the "Performance objectives" pillar and which directs the PPC system to meet the customer's needs. These elements support the second fundamental presented by Vollmann et al. [14], which states that customer expectations demonstrate how the company must adapt to the consumer market, offering new products and services constantly. The use of information technologies, the third foundation pointed out by Vollmann et al. [14] is essential for the perfect functioning of the PPC in industry 4.0, being numerous constituent elements of the PPC of this paradigm, such as Big Data, Cloud Computing, Digitalization, Networked Devices/Sensors, RFId, Communication Interface, IoT, Software and others. The difference between information technology in other production paradigms and industry 4.0 is the focus on the integration between systems achieved through communication interfaces and the Internet of Things.

The lack of a clear definition for issues involving the planning horizons and the PPC scope, pointed out by Fernandes and Godinho Filho [15], seems to be nonexistent in industry 4.0, since elements such as the communication interface allow greater synchronization between tools that address the short (Control), medium and long term (Planning) periods, and the 4.0 environments can extend to supply chains, bringing a precision level never before imagined.

5 Conclusion

In this work, a bibliographic review was made to identify the PPC's principles and foundations in the period before the emergence of the Industry 4.0 paradigm, verifying then, if these principles and foundations were maintained in Industry 4.0 paradigm. It was verified whether the principles and foundations were found in the model proposed by Pissardini [3]. The operation's principles of the fundamentals of the PPC, in the Industry 4.0 were demonstrated.

The results of this study point out to the maintenance of the fundamentals of the PPC in the paradigm of Industry 4.0.

The novelty of this work lies in the fact that, although the technology has caused a great digitalization, with an increase in the mass of data, operation's accuracy and decision making, the principles and foundations that guide the PPC in Industry 4.0 remain the same. Thus, the PPC in Industry 4.0 does not mean the discontinuity of principles and foundations that goes from Zaccarelli [6] to Volmann et al. [14]. This work could also contribute to fill an existing gap in the theory from the moment that it points to the elimination of the controversy existing in the literature that addresses the planning horizons of the PPC.

Furthermore, there are currently some restrictions on the model since it is generic and presents all elements identified in the literature as simultaneous influencers of the Industry 4.0's PPC.

In future research, the base model presented here could be used as a background for the specific model's development for the production of goods and services sector. The existence of a conditional hierarchy of the elements that make up the "Principles" and "Enablers" pillars show also an opportunity for future research once the model may undergo changes and adaptations to better represent specific sectors such as metallurgy, food, technology among others.

References

1. Godinho Filho, M., Paradigmas estratégicos de gestão da manufatura: configuração, relações com planejamento e controle da produção e estudo exploratório na indústria de calçados, Tese (Doutorado). São Paulo: Universidade Federal de São Carlos, 286p, (2004).
2. Sátyro, W.C., Sacomano, J.B., Gonçalves, R.F., Bonilla, S.H., Da Silva, M.T., Indústria 4.0: Conceitos e fundamentos. Editora Blucher, (2018).
3. Pissardini, P. E., Arquitetura Funcional do Planejamento e Controle da Produção na Indústria 4.0: Uma Proposta. Dissertação (Mestrado). São Paulo: Universidade Paulista, 119p, (2019).
4. Gil, A., Como elaborar projetos de pesquisa. Atlas: São Paulo, (2007).
5. Kitchenham, B., Procedures for performing systematic reviews, Joint Technical Report Software Engineering Group, Department of Computer Science, Keele University, United King and Empirical Software Engineering, National ICT Australia Ltd., Australia, (2004).
6. Zaccarelli, S.B., Programação e controle da produção. 5. ed. São Paulo: Pioneira, 292 p., (1979).
7. Zaccarelli, S.B., Programação e controle da produção. Livraria Pioneira Editora, (1987).
8. Burbidge, J.L., Planejamento e controle da produção. Atlas, (1988).
9. Contador, J. C.; Contador, J. L., Programação e Controle da Produção para Indústria Intermitente. In: Contador, J. C. Gestão de Operações. p. 235–256, Edgar Blücher Ltda: São Paulo, (1997).
10. Côrrea, H.; Gianesi, I., (1997), Sistemas de Planejamento e Controle da Produção. In: Contador, J. C. Gestão de Operações. p. 287–308, Edgar Blücher Ltda, São Paulo, (1997).
11. Fernandes, F.C.F., Coordenação de Ordens de Produção e Compra. Material de aula da disciplina de Planejamento e Controle da Produção 2. Universidade Federal de São Carlos, (2003b).
12. Wiendahl, H.-H., Von Cieminski, G., Wiendahl, H.-P., Stumbling blocks of PPC: Towards the holistic configuration of PPC systems. Production Planning & Control 16, 634–651. https://doi.org/10.1080/09537280500249280, (2005).
13. Stevenson, M., Hendry, L.C., Kingsman, B.G., A review of production planning and control: the applicability of key concepts to the make-to-order industry. International Journal of Production Research 43, 869–898. https://doi.org/10.1080/0020754042000298520, (2005).
14. Vollmann, T.E., Berry, W.L., Whybark, D.C., Jacobs, F.R., Sistemas de planejamento e controle da produção. Porto Alegre: Bookman, (2006).
15. Fernandes, F.C.F., Godinho Filho, M., Sistemas de coordenação de ordens: revisão, classificação, funcionamento e aplicabilidade. Gestão & Produção, v. 14, p. 337–352, (2007).
16. Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., Barbaray, R., (2017), The industrial management of SMEs in the era of Industry 4.0, International Journal of Production Research, https://doi.org/10.1080/00207543.2017.1372647.
17. Mussbach-Witer, U., Schatz, A., Vertikale IT-Integration im Auftragsmanagementprozess: Aspekte der Aufgabenverteilung und des Informationsaustauschs zwischen ERP - und MES - Software [Vertical IT integration in task management: Aspects of task allocation and exchange of information between ERP MES software], in: Software Markt, 1–6 (5), http://www.it-matchmaker.com/public/downloads/1062.pdf, last acessed (2020.01.25), (2015).
18. Rossit, D.A., Tohmé, F., Frutos M. Industry 4.0: Smart Scheduling, International Journal of Production Research, https://doi.org/10.1080/00207543.2018.1504248, (2018).

Lean Office in the Monitoring of Public Building Works

Talita Dal'Bosco Re, André Luiz Aquere, and Rui M. Lima

Abstract The article presents how the Lean Office approach can contribute to improving the process of monitoring public works. The monitoring process conducted by the National Education Development Fund—FNDE—for the works of the *Proinfância* program is adopted as a case study. Based on design science research as a methodology, the article presents a literature review, survey and analysis of the data on restrictions and nonconformities collected with the current monitoring process and, finally, the proposal for a new procedure for data collection. As a result of the work, a new system is obtained for the collection of data on restrictions and nonconformities during inspections conducted to monitor the works. The proposed procedure is applied to 15 works, and the results are analyzed. The results show a potential for reduction in the processing and overproduction of information by 36%, contributing to the effectiveness of the analyses by the technical team.

Keywords Lean office · Monitoring of public works · Quality assurance

1 Introduction

The increasing complexity of markets and the world in general, embodied by major technological advances and changes in markets and the economic environment, presents not only opportunities but also challenges [1]. In this environment of accelerated and continuous change, organizations need to make constant changes and allow new management philosophies to be implemented.

T. Dal'Bosco Re (✉) · A. L. Aquere
Department of Civil and Environmental Engineering, University of Brasília, Brasília, DF 70910-900, Brazil
e-mail: talitadalbosco@gmail.com

R. M. Lima
Algoritmi Center, Engineering School, University of Minho, Guimaraes, Braga 4800-058, Portugal

A. M. T. Thomé et al. (eds.), *Industrial Engineering and Operations Management*, Springer Proceedings in Mathematics & Statistics 337,
https://doi.org/10.1007/978-3-030-56920-4_52

In this context, some methods and techniques of industrial productive environments, such as Lean Production, are being applied in administrative environments. The application of Lean concepts in the administrative environment is called Lean Office, and its importance is linked to the objectives of becoming Lean: eliminating waste, producing products and providing services with the best possible quality at the lowest cost, always seeking the satisfaction of customer needs [2].

Public administration faces a similar situation. Given increasing pressure from citizens and control bodies to deliver better results, public administration needs to seek solutions for more effective and quality deliveries to the entire population.

According to Radnor and Osborne [3], the concept of lean public administration can be applied to maximize advantages, such as increasing the update rate, improving the use of resources and maintaining the quality of services.

Bruschi and Forcellini [4], in their literature review, observe that Lean philosophy has been successfully applied in several contexts; however, its application in the scope of public service is still incipient.

This point is reinforced by Rodgers and Antony [5], who, in addition to identifying the lack of studies of Lean philosophy in public administration, note that there is an excessive focus on tools and techniques and less importance placed on a more holistic approach to implementation through a business process improvement strategy integrated into work practices.

This research was motivated by the observation, in professional life, of activities developed in the work environment. During monitoring activities in the construction works agreed upon between the National Education Development Fund (FNDE) and the municipalities and the Federal District, it was noted that many works presented a considerable number of restrictions and executive nonconformities in relation to the standard project provided.

Over the months, the absence of a methodology for data collection was empirically identified, which undermined action to improve the process and, above all, a more careful analysis of the factors that cause these nonconformities and restrictions. In addition, there was a need to establish a standard procedure for the categorization of these nonconformities during site inspections.

Thus, the objective of this article is to propose improvements to the data collection system at construction sites to reduce overprocessing during the data analysis process in the office. To do so, this research considers as a case study the public construction of kindergartens in the National Program for Restructuring and Acquisition of Equipment for the Public School Network of Early Childhood Education (*Proinfância*) monitored by the National Education Development Fund (FNDE) in Brazil. This study aims to identify the wastes that occur throughout the process and propose ways to eliminate them. This research presents a relevant contribution to the establishment of a procedure for monitoring future works agreed upon by the FNDE.

2 Literature Review

2.1 Lean Office in the Public Sector

The concept of the Lean Office is based on the principles of Lean Manufacturing adapted for administrative activities. It means applying to office operations not the sequential logic of the assembly line but lean production practices [6]. According to Greef, Freitas and Romanel [7], "the objective of the Lean Office is to reduce or eliminate waste related to information flows".

However, in a factory environment, processes are more visible since waste and rework are more evident. In the administrative environment, most activities are related to the generation of information, which makes the identification of waste more complex. Campos et al. [2] mention that the Lean Office challenge lies precisely in the abstract nature of the processes. Therefore, removing these concepts from the industrial area and applying them in an administrative environment requires considerable caution and attention [8].

Nasato [9] highlights that one of the problems in making offices leaner is the need for participants to perceive and become more committed to the application of techniques or tools that differ from those used in the usual way and thus to be forced to leave their comfort zones. From a practical perspective, Jesus [10] concluded that the application of Lean Office concepts showed significant gains in the administrative processes of the researched institution since the flowchart and the mapping of the value flow showed efficient potential as elements for the identification and elimination of waste.

The Lean Office brings an adaptation of the seven wastes defined by Taiichi Ohno for the shop floor to the office space. However, Lareau [11], Oliveira [12] and Gentil and Terra [13] identified a vast amount of waste in the administrative environment. For the implementation of the Lean Office, Tapping and Shuker [14] present seven wastes in administrative environments that need to be identified and eliminated: overproduction, waiting, overprocessing, inventory, motion, defects, and transportation.

Bateman et al. [15], who presented the current panorama of Lean philosophy applied in public service, noted that although this philosophy is rarely used, it can contribute to the reform of public services provided. In addition, Antony et al. [16] showed that the application of Lean in public service, in addition to improving the service provided, provided more focus on the needs of customers.

Siqueira et al. [8], who researched the applicability of Lean Office concepts to the public sector, concluded that with the necessary adaptations, the methodology can be successfully applied to improve the service provided to the population. Furthermore, Bruschi and Forcellini [4] demonstrated that with the implementation of Lean in public service, it is possible to develop work in a more structured and standardized way, reduce waste and increase the quality of services. According to Greef et al. [7], waste is associated with processes, and one of the reasons for the existence of waste may be the way the process is designed.

3 Methodology

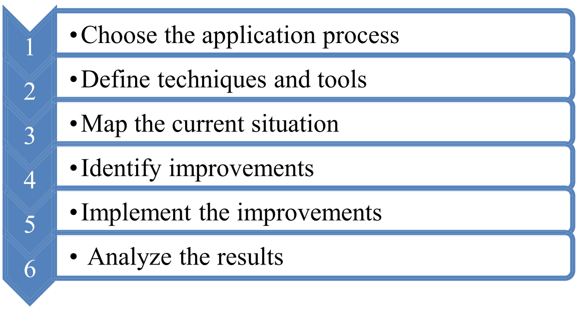
This article adopts design science as its scientific method and design science research as its research method. According to Vaishnavi et al. [17], this is interpreted as a set of techniques and methods for performing the mapping of needs for the creation of an artifact that satisfies a set of functional requirements. Therefore, the researcher is no longer an observer but an individual who acts in the researched context, seeking to understand a certain reality in which he uses his creative potential to generate solutions to real problems or needs [18].

The literature review is exploratory to provide greater familiarity with the problem raised and to analyze what has already been published on the subject in addition to tracing the conceptual structure to support the development of the research. Data collection was based on several sources of evidence: documentary, interviews and direct observation.

Proinfância program works with standardized projects called Type B and Type C [19] were adopted as a case study because of the large volume of completed projects. Additionally, the research was based on the years 2007 to 2014 since as of 2015, the Type B and Type C projects were discontinued.

Once the sample was delimited, steps were taken to develop this research, as shown in Fig. 1.

Fig. 1 The steps of research development



4 Case Study

4.1 Proinfância Program

The National Program for the Restructuring and Acquisition of Equipment for the Public-School Network for Early Childhood Education (*Proinfância*) aims to act directly to expand the attendance of early childhood education, mainly by financing the construction of early childhood education units [20].

According to the data available in the Integrated Monitoring, Execution and Control System of the Ministry of Education (SIMEC), between 2007 and 2014, 4,914 terms of commitment were signed across the country [21].

These construction works were carried out by the municipalities and the Federal District according to a standard project, with the FNDE only monitoring the application of public resources [22].

For the monitoring of these works, the FNDE established two parameters: executive nonconformities and executive restrictions. Executive nonconformity is any absence of conformity, divergence, or disagreement between the work carried out at the construction site and the standard project and does not lead to the interruption of the transfer of installments. Executive restriction is any noncompliance that represents a potential risk to the use of the building in terms of both performance and safety. These risks cause the transfer of installments to stop [22].

However, this method is not very effective during the monitoring of the work. Because there is no methodology to guide the classification of these parameters, this classification becomes a discretionary decision of the public technician who inspects the work.

4.2 Data Collection

The survey and analysis of data on restrictions and nonconformities, extracted from the SIMEC system, aimed to organize and identify the causes of the identified nonconformities.

In the initial analysis, stratification of the data in design disciplines was performed so that it was possible to observe which disciplines involve the largest number of occurrences. Then, the Ishikawa diagram was drawn up to represent the possible causes of these divergences.

To assist in the elaboration of the Ishikawa diagram, brainstorming was carried out with the FNDE technical team responsible for analyzing these data.

Of the 4,914 works agreed upon, as shown in Table 1, only 3,834 works referring to the sum of completed works (3,554) and works in progress (280) were considered because only works these could provide the necessary data for the research.

Table 1 Situation of the constructions agreed upon, 2007–2014

Situation	Year of agreement								
	2007	2008	2009	2010	2011	2012	2013	2014	Total
Completed	470	370	539	497	1.009	503	88	78	3.554
Contract	0	0	0	0	1	5	2	2	10
Execution	1	1	10	12	79	137	13	27	280
Unfinished	32	44	83	84	200	183	14	10	650
Bidding	0	0	1	0	17	12	2	2	34
Canceled	12	33	73	46	46	70	39	18	337
Interrupted	0	0	0	0	20	20	5	4	49
Total	515	448	706	639	1.374	930	162	140	4.914

For the 3,834 works, 83,226 parameters of noncompliance and executive restrictions were identified. Of this amount, 62,115 occurrences were considered to be generated in the construction phase. The others were excluded because they referred to nonconformities in the documentation, bidding and accountability phases.

The information included in the 62,115 occurrences by the companies supervising the works was analyzed with the aim of grouping the occurrences of noncompliance by design disciplines: architecture, structure, hydraulic installations (cold water, sanitary sewage, rainwater and prevention and combatting fire), electrical installations (electrical, structured cabling and SPDA) and mechanical installations (exhaust, air conditioning and combustible gas) and subsequently classifying them as not executed and executed in nonconformity, as shown in Table 2.

To identify the possible causes of the occurrences, a cause and effect diagram was developed for all project disciplines in brainstorming sessions with the FNDE technical team.

From the diagram, it was observed that the causes were similar in the different design disciplines. Therefore, it was decided that this research would incorporate only the cause and effect diagram of the architecture discipline, which corresponds to 60.68% of the registered occurrences. This diagram can be seen in Fig. 2.

In another analysis, it was observed that all the causes identified in the occurrences that were not executed were contained in the occurrences executed in noncompliance. Thus, to obtain the root causes, it was decided that this information would be combined.

4.3 *The Current Monitoring Process*

The monitoring of the work is performed through the module "Obras 2.0" of the Integrated Monitoring, Execution and Control System of the Ministry of Education

Table 2 Classification of occurrences by design disciplines

Item	Design disciplines	Not performed	Performed with noncompliance	Total	%
1.0	Architecture	12.409	25.284	37.693	60.68
2.0	Structure	2.038	5.285	7.323	11.79
3.0	Hydraulic systems				
3.1	Storm water	908	2.776	3.684	5.93
3.2	Sanitary sewer	342	739	1.081	1.74
3.3	Cold water	321	608	929	1.50
3.4	Fire protection	320	436	756	1.22
4.0	Electrical systems				
4.1	Lighting protection	953	1.298	2.251	3.62
4.2	Power system	485	1.597	2.082	3.35
4.3	Communication	979	983	1.962	3.15
5.0	Mechanics				
5.1	GLP	759	1.072	1.831	2.95
5.2	Ventilation	779	486	1.265	2.04
5.3	Air-conditioning	841	417	1.258	2.03
	Total	21.134	40.981	62.115	100.00

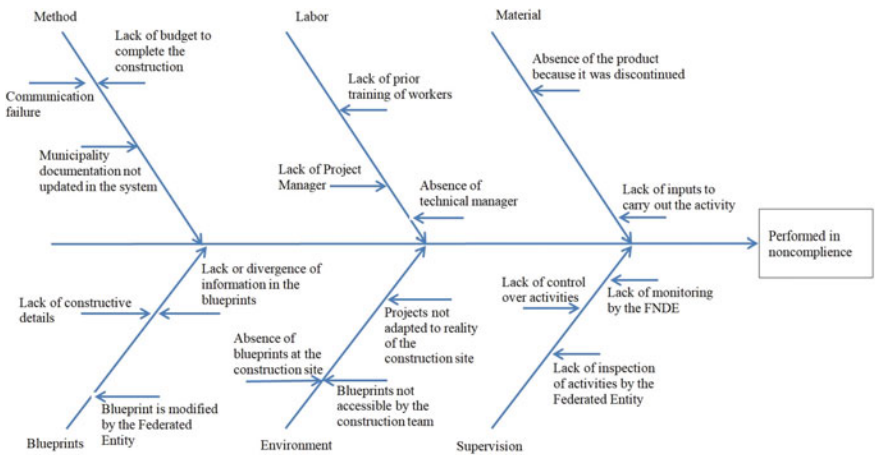
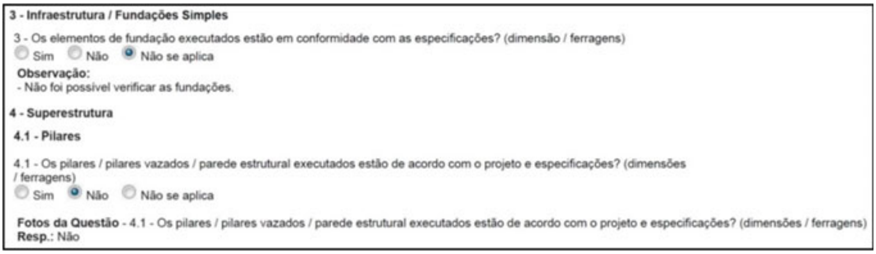


Fig. 2 Diagram of cause-effect for architecture—noncompliance

(SIMEC—Obras 2.0). It has several monitoring "tabs" that are released according to the evolution of the process.

The FNDE team of analysts monitors the evolution of the execution of the work as follows:


3 - Infraestrutura / Fundações Simples

3 - Os elementos de fundação executados estão em conformidade com as especificações? (dimensão / ferragens)
Sim Não Não se aplica
Observação:
- Não foi possível verificar as fundações.

4 - Superestrutura

4.1 - Pilares

4.1 - Os pilares / pilares vazados / parede estrutural executados estão de acordo com o projeto e especificações? (dimensões / ferragens)
Sim Não Não se aplica

Fotos da Questão - 4.1 - Os pilares / pilares vazados / parede estrutural executados estão de acordo com o projeto e especificações? (dimensões / ferragens)
Resp.: Não

Fig. 3 Sample of part of the current checklist (*in Portuguese)*

1. Through the information inserted by the inspection of the federal entities in the "Inspections" tab;
2. Through the information entered by three supervisory companies, hired by the FNDE, under the "Surveys" and "Restrictions and Nonconformities" Tabs.

Periodically, the FNDE team defines lots of inspections and sends the supervising company to verify the status of the work. These lots take into account the percentage of execution of the work, which are approximately 25, 50, 75 and 100%.

The supervisory companies perform on-site inspections and feed the SIMEC—Obras 2.0 system by completing a checklist, in the "Inspections" tab, consisting of 24 items. An excerpt from this checklist can be seen in Fig. 3.

Each item in the checklist corresponds to a stage of the work that is structured according to the agreed-upon budget spreadsheet. It is at this point that the supervisory company establishes restrictions and nonconformities in the "Restrictions and Non-Conformities" tab.

With the mapping of the current situation and the data on restrictions and conformities, it is possible to observe some critical factors in the process, which are summarized in Table 3.

From Table 3, it is clear that the root causes can be summarized in the lack of standardized procedures and the need for greater guidance and control by the FNDE.

Nevertheless, it is observed that the waste is mostly concentrated on overprocessing (over-revision due to lack of standardization) and overproduction (excessive production of information). Therefore, a new procedure is proposed for the collection of data on restrictions and nonconformities during the monitoring of the works.

The proposed procedure consists of a new quality monitoring process, a new tool (checklist) for data collection and an inspection guide. The inspection guide is currently under construction by the FNDE technical team.

This article focuses on the proposed tool to collect data on restrictions and noncompliances and nonconformities.

Table 3 Summary of the identified problems

Item	Problem	Causes	Waste type
1	Delayed monitoring	Lack of established routine for monitoring the work in the "bidding" phase	Defect
2	Poor quality in the fiscal information provided	Lack of a more detailed checklist containing qualitative and quantitative information	Defect
3	Supervisory company does not provide technical support	Lack of involvement of supervisory companies; Lack of established work routine; Lack of technical assistance leads to new nonconformities	Overprocessing
4	Lack of standardized procedure for the information provided by the supervisory company.	Lack of a more detailed checklist containing qualitative and quantitative information	Overprocessing; Overproduction
5	Checklist completed by the supervisory company presents descriptive information	Lack of a more detailed checklist containing qualitative and quantitative information	Overprocessing; Overproduction
6	Single document to overcome all types of noncompliances	Lack of standardization of solutions to overcome noncompliances; The information is generic or excessive	Overprocessing; Overproduction
7	Repeated pointing to outdated items	Lack of work procedures and routines; Lack of alert system	Overproduction
8	Noncompliances not treated by the federative entity	Lack of control to overcome noncompliances; Federated entities are not concerned with resolving the identified noncompliances	Inventory

5 Tool for Collecting Restrictions and Noncompliances

A new tool for collecting information is proposed to make it more quantitative and less descriptive, thus facilitating the technician's analysis at the FNDE. In addition, it is necessary to define which nonconformities are likely to be overcome without the need for technical analysis.

For this, the risk matrix from Eye [23] is used where for each stage of the work, nonconformities are classified according to their severity index. In his research, Eye identified the impact and probability of each occurrence, classifying them according to the criteria of functionality, quality, performance, and safety. The product between the impact of an occurrence and its probability generates a severity index and, finally, a priority classification.

CHECK-LIST ESPAÇOS EDUCATIVOS						
ITEM	**SERVIÇOS**	**IDENTIFICAÇÃO**	**PRIORIDADE**	**FOTOS**	**PROVIDÊNCIAS**	**SEVERIDADE**
7.2	**TELHA DA COBERTURA**					
	As telhas da cobertura estão executadas de acordo com o especificado em projeto?					
7.2.1	**SIM**, estão executados em conformidade			Foto legendada		
7.2.2	**NÃO**, não estão executados em conformidade					
7.2.2.1	**Alteração das dimensões** - Alteração no tamanho das peças, espessura das chapas, etc.)	Identificar	**I2**	Foto legendada	**J**	**10**
7.2.2.2	**Alteração da cor**					
7.2.2.2.1	Variação da tonalidade (mais escura ou mais clara) na parte inferior	Identificar	**I1**			**5**
7.2.2.2.2	Alteração na cor na parte superior (exposta ao tempo)	Identificar	**I2**		**J**	**10**
7.2.2.3	**Alteração do tipo do material especificado**	Descrever o material empregado	**R**		**L**	**25**
7.2.2.4	**Execução do Serviço**					
7.2.2.4.1	Falhas na execução dos transpasses das telhas	Identificar*	**I2**		**J**	**10**
7.2.2.4.2	Falhas na execução dos transpasses das cumeeiras	Identificar*	**I2**		**J**	**10**
7.2.3	**Não execução do serviço**	Identificar*	**I2**		**C**	
7.2.4	**No momento da supervisão não se encontram executados (Fase de Obra)**					
7.2.5	**Outros**: (relatar aqui alguma observação que não esteja acima referenciada):	Relatar	**I2**		**J**	

Fig. 4 Sample of part of the proposed checklist for roof tile quality control (*in Portuguese*)

Based on the FNDE Risk Matrix [24] and on the survey of the historical data on restrictions and nonconformities described in item 4.2, a new data collection tool was proposed in which nonconformities classified as low priority are automatically overcome by the system without the need for analysis by the FNDE technician. A sample of part of this data collection tool, related to roof tiles, can be seen in Fig. 4.

6 Discussion and Results

Based on the data collection described in item 4.2 and classified in Table 2, it is observed that the highest number of occurrences is in the disciplines of architecture and structure, corresponding to 72.47% of the total occurrences.

Using the 5 W technique, it was possible to identify two main causes of the occurrences, Fig. 2 shows the lack of standardized procedures and the need for greater guidance and control by the FNDE.

In addition, as shown in Table 3, the problems generated by these causes are related to their waste. It is possible to observe that the majority of the waste is concentrated in processing (excess review due to lack of standardization) and overproduction (excessive information production).

Given this information, a new procedure for the collection of data on restrictions and nonconformities during the monitoring of the works was presented in item 5.

With the new tool in their hands, FNDE technicians go into the field and perform inspections. The works that are inspected by supervisory companies in the last ten days using the current method are used to compare the results. For the survey, 15 works were inspected. The inspection included works that were close to the following execution percentages: 15, 30, 50, 75 and 95%.

Table 4 Classification of occurrences by project discipline, current collection system and new collection tool

It.	Design disciplines	Current collection system			New collection tool					%
		Not performed	Performed in noncompliance	Total	I1	I2	I3	R	Total	
1.0	Architecture	152	86	101	47	21	15	18	101	54,89
2.0	Structure	3	32	35	5	5	8	17	35	19,02
3.0	Hydraulic Systems									
3.1	Storm Water	2	8	10	2	3	2	3	10	5,43
3.2	Sanitary Sewer	1	2	3	2		1		3	1,63
3.3	Cold Water	1	5	6	2	1	2	1	6	3,26
3.4	Fire Protection		3	3	1		2		3	1,63
4.0	Electrical Systems									
4.1	Lighting Protection	2	5	7	1	3	2	1	7	3,80
4.2	Power System	1	3	4	1	2	1		4	2,17
4.3	Communication		2	2	2				2	1,09
5.0	Mechanics									
5.1	GLP	3	2	5		2	2	1	5	2,72
5.2	Ventilation	1	3	4	2	1	1		4	2,17
5.3	Air-Conditioning	2	2	4	2		2		4	2,17
	Total	31	153	184	67	38	38	41	184	100

Of the works inspected, 184 nonconformities were found. According to the current collection system and using the proposed checklist, the nonconformities are classified as shown in Table 4.

Based on the verified works, it was found that in the current report, the FNDE technicians should verify 184 notes made. In the proposed procedure, the same 184 notes were identified, but only 117 should be analyzed by the technicians since the 67 notes classified as I1—low priority—are automatically overcome by the system.

Additionally, the organization of the new checklist by the criteria of functionality, quality, performance and safety, as shown in Fig. 4, provides a better categorization of nonconformities. Through this classification, new improvements can be mapped and implemented.

It is observed that the highest number of occurrences remains concentrated in the disciplines of architecture and structure, corresponding to 73.91% of the total occurrences, which indicates that these should be mapped and improvements should be implemented.

To assess the effectiveness of the checklist application, an unstructured interview was conducted with the FNDE technicians who performed the survey. In this discussion environment, the technicians approved the implementation of the new checklist and asked for improvements in the inspection route to optimize the inspection time.

7 Conclusion

In this research, waste of overprocessing and overproduction was identified in the current procedure for monitoring works. With the new tool, it was possible to observe a 36% reduction in the volume of nonconformities to be analyzed by the FNDE technicians, which indicates the elimination of the identified waste.

Considering the 62,115 occurrences presented in Table 2, this represents 22,361 occurrences that do not need to be analyzed at the FNDE office.

Roughly estimating that a technician takes an average of 10 min to analyze each occurrence, this represents savings of 3,726.9 man-hours, or 426.9 work days at the office.

This tool is suggested for new works in addition to the analysis of results with the full implementation of the process redesign and the checklist proposed here. The same procedure can be used to improve other important processes, such as technical analysis and accountability processes.

Acknowledgments This work was partially supported by FCT—Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020.

References

1. Miguel, A.: Gestão moderna de projetos: melhores técnicas e práticas. 7nd edn. FCA, Lisboa (2013).
2. Campos, A.T.; Queiroz, J.A.; Montevechi, J.A.B.; Leal, F.; Pereira, A.P.: Integração entre Lean Office e simulação a eventos discretos: um estudo de caso no setor de autopeças. In: XLVIII SBPO, pp. 2971–2982. SBPO, Vitoria (2016).
3. Radnor, Z.; Osborne, S.P.: Lean: a failed theory for public services?. Public management review 15, 265–287 (2013).
4. Bruschi, M.; Forcellini, F.A.: Lean in the Public Service – an analysis of the literature. Journal of lean systems 4, 02–20 (2019).
5. Rodgers, B; Antony, J.: Lean and Six sigma practices in the public sector: a review. International journal of quality & reliability management 36, 437–455 (2019).
6. Lago, N.; Carvalho, D.; Ribeiro, L.M.: Lean office. Fundição 2, 248–249 (2008).
7. Greef, A. C.; Freitas, M. C. D.; Romanel, F. B.: Lean office: operação, gerenciamento e tecnologias. Atlas, São Paulo (2012).
8. Siqueira, R. M.; Paranhos, U.; Rodrigues, R. A.; Silva, E. C. C.: Lean Office: estudo de caso no setor público do Estado de São Paulo. Brazilian jornal of development 4, 2150–2162 (2018).
9. Nasato, C. M.: Lean Office aplicado no gerenciamento de informações no setor de pesquisa e desenvolvimento. Trabalho de Conclusão de Curso (Graduação em Gestão de Comércio Internacional) – Universidade Estadual de Campinas, Limeira (2016).
10. Jesus, T.C.: Aplicação dos conceitos do Lean Office no processo de planejamento, execução, monitoramento e avaliação orçamentária em uma instituição de ensino superior pública. Dissertação (Mestrado em Engenharia de Produção) – Faculdade de Engenharia, Universidade Estadual Paulista, São Paulo (2018).
11. Lareau, W.: Office Kaizen: transforming office operations into a strategic competitive advantage. ASQ Quality Press, USA (2002).
12. Oliveira, J. D.: Escritório Enxuto (Lean Office). Lean Institute Brasil,São Paulo (2003).

13. Gentil, J. V.; Terra, L. A. A.: As vantagens competitivas do lean office. Facef Pesquisa: desenvolvimento e gestão 18, 304–317 (2015).
14. Tapping, D.; Shuker, T.: Lean Office: gerenciamento do fluxo de valor para áreas administrativas: 8 passos para planejar, mapear e sustentar melhorias Lean nas áreas adminsitrativas. Leopardo, São Paulo (2010).
15. Bateman, N.; Radnor, Z.; Glennon, R.: Editorial: The landscape of Lean across public services. Public Money & management 38, 1–4 (2018).
16. Antony, J.; Rodgers, B.; Gijo, E.V.: Can Lean Six Sigma make UK public sector organnisations more efficient and effective?. International Journal of Productivity and Performance Management 65(7), 995–1002 (2016).
17. Vaishnavi, V.; Kuechler, W; Petter, S.: Design Science Research in Information Systems Homepage, http://www.desrist.org/design-research-in-information-systems/, last accessed 2019/06/30.
18. Lima, S. H. O.; Oliveira, F. D.; Fialho, K. E. R.; Deusdara, D. F. M.; Neto, J. P. B.: *Design Science*: Perspectivas paradigmáticas e comparações com estudo de caso e pesquisa-ação. In: VIII ANPAD, pp 1–16. ANPAD, Gramado (2014).
19. Aquere, A. L., Dinis-Carvalho, J., Lima, R. M.: Project Cell: Cellular Organization of the Building Design Process. Journal of Constructios Engineering and Management 139, 538–546 (2013).
20. Rezende, L. M.: Monitoramento e avaliação do programa nacional de reestruturação e aquisição de equipamentos para a rede escolar pública de educação infantil – Proinfância: uma proposta metodológica. Dissertação (Mestrado Profissional em Educação) – Faculdade de Educação, Universidade de Brasília, Brasília (2013).
21. SIMEC. Sistema Integrado de Monitoramento, Execução e Controle do Ministério da Educação Homepage, http://www.simec.gov.br, last accessed 2019/08/15.
22. Fundo Nacional de Desenvolvimento da Educação, FNDE: Obras Convencionais: Orientações ao Gestor Público na execução de obras de infraestrutura para educação básica Metodologia Construtiva Convencional. (2010).
23. Eye, R. B.: Proposta metodológica para o monitoramento do programa nacional de reestruturação e aparelhagem da rede escolar pública de educação infantil – Proinfância. Dissertação (Mestrado em Gestão Pública) – Faculdade de Planaltina, Universidade de Brasília, Brasília (2017).
24. Fundo Nacional de Desenvolvimento da Educação, FNDE: Manual de Análises Técnicas – Matriz de Risco: Restrições e Inconformidades. Volume 1 (2017).