Lecture Notes in Management and Industrial Engineering

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Organizational Engineering in Industry 4.0

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Preface

Organizational engineering may be defined as "the science that designs, improves, implements and operates an organization through the use of engineering and analysis methods" (Pascoa and Tribolet 2015). This discipline, which in many countries is referred to as *industrial engineering* (see Ortiz 2016), is therefore concerned with the optimization of complex processes and systems within organizations, often integrating different types of resources (human, financial, material, and information).

Its origins date back to the First Industrial Revolution in the second half of the eighteenth century, with Frederick Taylor often being considered as the father of this discipline. Since then, the field of organizational engineering has enormously evolved, thanks to distinguished contributors like Lillian Gilbreth, Henry Gantt, Henry Ford, Taiichi Ohno, among many others. The advancements gained track during the Second and Third Industrial Revolutions.

Nowadays, organizational engineering is undergoing a continuous evolution within the context of the so-called *Industry 4.0* (for example, see Rüßmann et al., 2015). This refers to the current Fourth Industrial Revolution, which has its roots in the emergence of digitalization and its huge industrial implications. Under these circumstances, organizational engineering needs to adapt its principles and methods to the new industrial context, taking advantage of the new technological opportunities and also considering increasingly important challenges, including environmental concerns.

From this perspective, *Organizational Engineering in Industry 4.0* was the motto of the "13th International Conference on Industrial Engineering and Industrial Management/XXIII Congreso en Ingeniería de Organización (CIO 2019)", which took place in Gijon (Asturias, Spain) on July 11 and 12, 2019. This conference gathered around 150 academics and practitioners from several countries, who discussed the opportunities and challenges for the discipline of organizational engineering in Industry 4.0.

This book compiles extended and improved versions of selected presentations at this conference, representing a good sample of the current state of the art in the discipline of organizational engineering. The contributions have been structured in five main blocks.

Block 1 (Chapters "Impact of European Union Projects on Airspace Operations Management" to "Additive Manufacturing Disruption on Manufacturing Sector. Spanish Evolution in last Triennium") discusses *strategic issues* within the practice of organizational engineering. The chapters cover different topics that are intimately related to Industry 4.0, such as open innovation, blockchains, and additive manufacturing.

Block 2 (Chapters "Optimisation of water supply network design based on a Tabu search algorithm" to "Identifying and Analyzing Operations Management Strategic Problems in Home Care") and Block 3 (Chapters "Additive Manufacturing in Aerospace Industry: Impact on Purchasing Process" to "The Behaviour of Lean and the Theory of Constraints in the Wider Supply Chain: A Simulation-Based Comparative Study Delving Deeper into the Impact of Noise") subsequently cover two important subfields within the organizational engineering discipline, operations research and supply chain management, respectively. These works use innovative computational methods like tabu and firefly algorithms and agent-based systems; revolve around important theories and methodologies, including Lean Management and the Theory of Constraints; and study organizations in different industries, such as the pharmaceutical and the aerospace industries.

Block 4 (Chapters "Influence of Gamification on Student Motivation in Business Organization Subjects" to "Design Thinking (DT) in Engineering Education (EE): A Systematic Literature Review (SLT)") considers education and training in the Industry 4.0 era, taking into account that it challenges not only the way companies are managed but also how organizational engineers need to be educated and trained. These chapters address promising concepts, like gamification, design thinking, and supercomputing.

Finally, Block 5 (Chapters "Ready for Industry 4.0—A study of SMEs in Spain" to "Industry 4.0 for the Development of More Efficient Decision-Support Tools for the Management of Environmental Sustainability in the Agri-food Supply Chain") reflects on the role of sustainability in current organizational engineering practices. These contributions discuss how circular economies may be facilitated by the technological opportunities derived from Industry 4.0.

The Editors of this book would like to express their sincerest gratitude to all the contributors of this book, including authors, reviewers, and Springer's production team. They have enormously aided the publication of this book. Moreover, the Editors of this book deeply appreciate the effort and interest of all the attendees, sponsors, and collaborators of CIO2019. They have generously dedicated their time and expertise to hold a high-quality conference that was built on the experience of previous CIO conferences.

Gijón, Spain

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Contents

Strategic Issues

Impact of European Union Projects on Airspace Operations Management

J. A. Calvo-Fresno, J. Morcillo-Bellido, and B. Rodrigo-Moya

Abstract The Single European Sky initiative was launched in 2000. Since then, the performance of the operations of the air navigation system in Europe has shown a clear tendency to improve. It is recognized that the use of EU funds in the related air navigation projects has a positive effect on this performance improvement. Nevertheless, the relation between the use of EU funds and the performance of the European air navigation system has not been clearly determined yet, despite the numerous studies done on this topic. This paper presents the result of applying a data envelopment analysis methodology (DEA) to assess the relative efficiency of the use of EU funds in research, development, innovation, and implementation projects aiming at improving safety, capacity, and the environmental impact of the European air navigation system. The results of this analysis confirm a positive evolution of the performance of the air navigation system in the last 15 years. Nevertheless, it is inferred that the efficiency of the use of EU funds in air navigation projects can be further improved.

Keywords Air traffic control · Single european sky · Airspace operations

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1 Introduction

The reform of the air navigation system in Europe began early in 2000 with the Single European Sky initiative, which aimed at providing solutions to the capacity crisis of the 80 and 90s [1]. But the involvement of the European Commission in this domain had started well in advance. The use of funds from the European Union (EU) in the execution of air navigation research projects began in 1995 under the 4th Framework Programme, and has been continuously increasing since then through the use of the 5, 6, and 7th Framework Programmes [2], and Horizon 2020 funds. The EU financial support to air navigation implementation projects has also been increasing since 2003 through the TEN-T and the Connecting Europe Facilities budget.

It is acknowledged that the operational performance of the air navigation system in Europe has improved since the start of the Single European Sky initiative [3], even recognizing that there is still room for improvement for this operational performance [4]. But although there is a general agreement on this point, to date it has not been possible to clearly determine the relations between the use of EU funds in research, development, innovation, and implementation projects, and the performance of the air navigation system. Several impact assessments [5, 6], done on research, development, and innovation projects in the aviation field under the 6 and 7th Framework Programmes, have underlined the difficulties in establishing such relations. The authors of this paper have considered a new approach, in order to simplify these relations as far as possible. To do so, the authors have made use of the available information on the performance of the air navigation system for the period 2000–2015.

2 Air Navigation System and EU Funds

Vice-President Barrot [7] defined in 1995 the four high-level performance objectives to be achieved by the Single European Sky on the operation of the air navigation system. These four objectives, also confirmed by the European Commission [8], correspond to the areas of safety, capacity, cost of the air navigation services, and environmental impact. These objectives can be quantified through a certain number of indicators obtained from official documents from EU institutions and bodies, such as the European Air Traffic Management Master Plan from the SESAR Joint Undertaking [9]; the “Vision 2020” document [10] and the Strategic Research and Innovation Agenda [11] from the Advisory Council for Aviation Research in Europe, or the Commission regulation on performance [12]. Table 1 shows the list of these indicators.

The effect on the operational performance of the use of EU funds in related projects is not immediate. For research and development projects, Ciocanel [13] estimates the delay in 2 years; nevertheless, the heterogeneity across sectors must be also considered [14]. For the air navigation domain, the authors found a typical delay

Table 1 Air navigation system indicators in Europe

Objective	Indicator
Safety	Accident rate[a]
	Accident rate for commercial aviation
	Fatal accident rate for commercial aviation
	Accidents during approach and landing for commercial aviation
	Accidents other than those of commercial aviation
	Accidents with ATM[b] as a causal factor
	CFIT[c] accidents
	CFIT accidents for commercial aviation
	CFIT accidents for commercial aviation with ATM as a causal factor
	Serious incidents with ATM as a causal factor
	ATM incidents caused by human error not avoided by technical systems
Capacity	Effective Capacity[d] Percentage of arrival flights delayed more than 15' Percentage of departure flights delayed more than 15'
	Average en-route ATM delay per delayed flight
Cost	ATM cost
	En-route unit cost
Environment	CO_2 emissions per flight
	NOx emissions during take-off and landing per flight

[a]Rates are defined as events per million flights
[b]Air Traffic Management
[c]Controlled Flight into Terrain
[d]Traffic handled with optimum delay expressed in millions of kilometres offered
Source authors

of approximately 5 years [15]. As indicated above, the period for which the relation between the use of EU funds and the performance of the air navigation system is sought corresponds to the 2000–2015 one. Consequently, the period of reference to quantify the corresponding use of EU funds is the one that extends from 1995 to 2010.

3 Methodology and Objective

The quantification of the air navigation system operational performance during 2000–2015 is done by the authors using reliable secondary databases. The databases have been selected following the recommendations of Ajayi [16]. These databases consist mainly of official documents and reports from several EU agencies, from international organizations and from intergovernmental organizations, as summarized in Table 2.

Table 2 Databases

Entity	Source of secondary data	Related objective
Eurocontrol	Performance Review Commission annual reports	Capacity
Eurocontrol	Safety Regulatory Commission annual reports	Safety
EASA[a]	Annual safety reviews	Safety
EASA	Aviation environmental report	Environment
EEA[b]	Environmental reports	Environment
ICAO[c]	Annual safety reviews	Safety

[a]European Aviation Safety Agency
[b]European Environmental Agency
[c]International Civil Aviation Organization
Source authors

Table 3 Use of EU funds in air navigation projects

MFF[a]	Research projects (EUR)	Implementation projects (EUR)
1995–1999	13.810.216	–
2000–2006	136.112.399	8.511.476
2007–2010	257.017.745	40.612.327

[a]Multiannual Financial Framework
Source authors

The information to estimate the use of EU funds for each objective is extracted from the EC webpages: Transport Research and Innovation Monitoring and Information System (TRIMIS) [17] and Community Research and Development Information Service (CORDIS) [18], as well as from the webpage of SESAR Joint Undertaking [19] and other related documents. Table 3 summarizes these values.

The consolidation of the performance information, as well as the attribution of the EU funds to each objective, is done through an action research approach that benefits from the professional experience of one of the authors in the field of air navigation research.

One of the main difficulties in establishing clear relations between the use of EU funds and the operational performance in air navigation is the effect of external factors [5], which can be significant but difficult to quantify. The objective of the paper is to study these relations by assessing the relative efficiency of the use of EU funds aimed at improving the operational performance of the air navigation system through research, development, innovation, and implementation projects. The methodology used is a standard data envelopment analysis (DEA) [20]. The analysis is performed independently for each of the following three performance objectives: safety, capacity, and environmental impact. Each of the decision-making units (DMUs) used in the analysis is defined as the air navigation system in one specific year during 2000–2015. There are several reasons to choose the DMUs in this particular way. On the one hand, the EU objectives for the European air navigation system are applicable to the whole system, and not separately to service units or business units. On the other hand, both the real values and the expected values of the indicators that quantify these EU objectives are expressed and recorded as annual values for the whole system. Therefore, the natural year is the most adequate unit to establish comparisons. The result of the DEA analysis is then expressed in terms of the relative efficiency of the use of EU funds in a given year compared with the efficiency obtained for the rest of the years. This provides a view of the evolution of efficiency in time.

For each of the objectives mentioned, the outputs are the values of the indicators listed in Table 1 in each year of the period. The input that corresponds to that given year is the amount of EU funds used 5 years ago. To ensure that the numerical data for the outputs are all positive [21], they are expressed as ratios. Each ratio uses the value of the indicator in a given year and its average value during 2000–2015, Similarly, the input in each year is calculated as the EU funds used during that given year and the total amount of EU funds used during 1995–2010. Finally, and disregarding the effect of external factors, it is assumed that an increase in the use of EU funds brings an improvement of performance, and therefore an output increase. As a consequence, the ratios used to define the outputs for safety and environmental impact will be calculated as the average value of the indicator for the 2000–2015 period divided by its annual value, whereas in the case of capacity, the ratio for the output in each year will be defined inversely as the value of the indicator in that year divided by the average value for all the periods.

Due to the already mentioned influence of external factors, it is not possible to ensure whether an input increase will always result in a proportional increase of outputs, or that it would result in a disproportionate output increase. Therefore, the use of a variable return to scale (VRS) approach cannot be justified [22]. Besides, the use of a constant return to variable (CRS) approach provides more conservative results than the use of VRS [23], for which a CRS approach is finally adopted.

The aim of using EU funds in air navigation projects is to increase the performance of the system; so, from the two existing options [24], the output-oriented one will be adopted. The application of the DEA methodology in this particular study will not lead to an optimization of DMUs, as these are defined as already finished years; but the application of the methodology requires the selection of a DMU within the 2000–2015 period as a reference for the output optimization. For this purpose, the years corresponding to the end of each EU Multiannual Financial Framework (namely 2004 or 2011) are considered. The authors have verified that there are no significant differences in the results obtained when using either of these 2 years. The year finally selected as a reference for output optimization is 2011, that is, 5 years after the closure of the Multiannual Financial Framework 2000–2006.

4 Results and Discussions

Figures 1, 2, and 3 depict in a graphic way the results of the data envelopment analysis for the three objectives considered. Each of these figures presents, for every year in the period of study, the relative positions of the performance of the air navigation system with respect to the related objective. For each objective, the performance is calculated as a weighted sum of the values of the indicators that allow the quantification of the objective. These indicators are listed in Table 1. The weighting factors are obtained using a linear programming mathematical model developed by J. E. Basley and available in his Notes on Operations Research (OR-Notes). The figures show also for each objective the ratio between the performance of the air navigation system and the EU funds used in air navigation projects aimed at achieving the objective. The initial year in each figure corresponds to the first year for which the available data is considered reliable enough. As already indicated, the results are limited to relative positions of the operational performance for each of the years in the study period, and to relative positions of the ratios of performances and use of EU funds for those same years.

Safety performance has a positive tendency, although it shows an irregular pattern due to the generally small number of safety occurrences. Its efficiency ratio also shows a high variability but does not show any clear tendency to increase or to decrease.

Capacity performance shows a stagnation, partly due to the 2008 crisis and the labor unrest in the air navigation sector, but tends to increase as of 2012. The relative efficiency of the use of EU funds in this objective dropped significantly in 2005 and it is rather stable since then.

This behavior could be due to the increase of EU funds used under the 5th Framework Programme and onwards.

Environmental performance does not show any significant change in the period, while the efficiency of the use of EU funds for this objective shows a remarkably decreasing tendency. The tendency to decrease the relative efficiency of the use of EU funds goes in parallel with the increase of the use of EU funds.

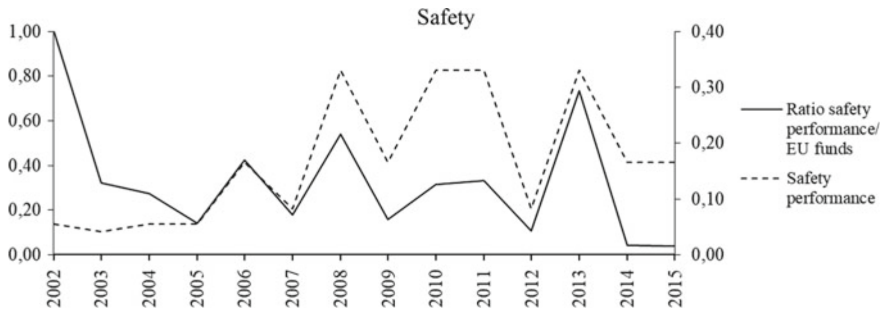

Fig. 1 Results for the safety objective. *Source* authors

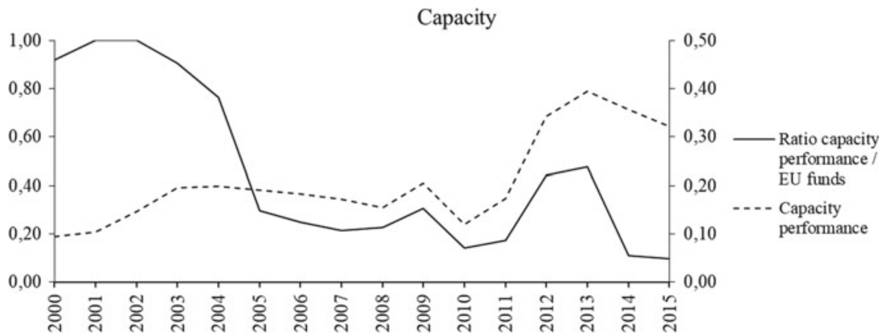

Fig. 2 Results for the capacity objective. *Source* authors

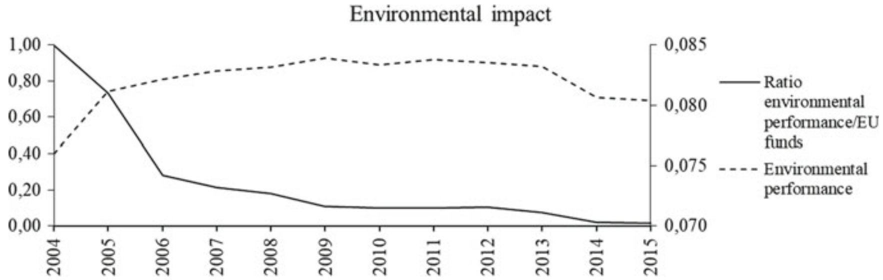

Fig. 3 Results for the objective of environmental impact. *Source* authors

This tendency should not be interpreted as the consequence of deficient management of EU funds for environmental projects, but rather as the consequence that environmental impact is more dependent on engine technology and traffic than on the air navigation system.

5 Conclusions

The results of the analysis confirm the tendency of the operational performance to be stable or to increase in time during 2000–2015. This tendency is not steady though and presents many variations that can have their roots in the origin partially on the effect of external effects.

On the other hand, the ratios between objectives and EU funds show that, in general, the efficiency in the use of EU funds tends to decrease after the end of the Multiannual Financial Framework 1993–1999, stabilizing later and even recovering in the cases of safety and capacity. This tendency could have its origin in the fact that some initiatives in the air navigation domain, mainly driven by the launching of the Single European Sky, exerted a positive influence on the performance of the system in the early 2000s while the related use of EU funds in the previous 5 years had been modest compared with the subsequent ones.

Nevertheless, it can be inferred that the efficiency in the use of the EU funds for air navigation research, development, innovation, and implementation projects can be further improved. Beyond the mere technical and operational aspects, planning the future in this field would be an opportunity to review the mechanisms by which EU financial support to these air navigation projects is provided.

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Exploring Objectives and Barriers of Open Innovation Implementation in Research and Technology Organisations

R. Uribe-Echeberria, J. I. Igartua, and R. Lizarralde

Abstract This paper presents an exploratory analysis of the objectives and barriers of open innovation implementation in Spanish research and technology organisations (RTOs). RTOs act as research entities; they provide research and technology services to industries and SMEs, and therefore are considered key agents in the innovation system. The study has an exploratory nature, using data gathered through a structured questionnaire fulfilled by managers of RTOs in Spain. The results presented in this exploratory research emphasizes the alignment of the objectives for open innovation in RTOs with the mission and associated challenges these organizations are confronting. Furthermore, this study shows that objectives and barriers toward open innovation are different compared to studies focused on big companies and SMEs, with special mention to the impact of intellectual property rights (IPR) management in open innovation. The value of this ongoing research lies in its contribution to the quantitative research of open innovation in service organizations involved in science, technology, and innovation, as well as in the study of this strategic phenomenon.

Keywords OI: Open innovation · RTO: Research and technology organisation · STI: Science, technology, and innovation

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1 Introduction

Research and Technology Organisations (RTOs) or Technology Centers are key to innovation systems and policies at the national or regional level [1], especially in contexts with a network of small and medium-sized companies [2].

RTOs are organizations whose total or partial mission is to "perform a creative work in a systematic way to increase the volume of knowledge, including the knowledge of humanity, culture and society, and the use of that knowledge to create new applications" [3]. RTOs have a "hybrid nature" [4] and play an intermediary role as creators and transferrants of knowledge, developing their own research and development activities [5]. Acting as a research entity, they provide research and technology services to industries, acting as a special type of KIBS—knowledge-intensive business service firms [6].

Due to their nature, RTOs play an active role in the deployment of public policies on science, technology, and innovation [7] with a special emphasis on their role as knowledge transfer agents for the industry [8]. Their activity helps companies to increase their innovation and technological capabilities [6] and thus to increase the innovation ratios and innovation capacities of the regional innovation system (RIS) in which they operate.

In this context is where an open innovation (OI) plays its role, due to its capability to influence several strategic objectives RTOs need to undertake [9].

2 Open Innovation in RTOs

Collaboration between firms is not a novel phenomenon [10]. Collaboration occurs between different types of agents: between companies, between companies and RTOs, in research and development, or the development of new products and production technologies [1]. Yet, in the literature there is a wide nomenclature when referring to this type of collaboration in R&D, such as "collaboration", "cooperation", "strategic alliances", "Joint Ventures", and "networking" [11].

Thus, the literature on strategic alliances has had a great development as can be seen in the recent study of literature on the subject [12]. However, in 2003, a new stream of research emerged when Chesbrough coined the term "open innovation" [13], to describe a trend in innovation theory, which evolved from a closed to an open approach. Open innovation was defined as "the use of external and foreign knowledge flows to accelerate the innovation process and to expand the market through the external use of innovation, respectively" and laid the foundations for a new research stream.

Although these two research streams have evolved separately based on different research questions, they share a natural affinity between them in terms of described phenomena, theoretical predictions, and implications for management [14]. Both research streams assume that innovation is collaborative and often complementary, and that such collaborations are crucial for companies when creating and capturing the value of their innovations [15]. Thus, some authors consider OI as a broader concept [14], which integrates the concepts, mechanisms, and models of the stream of strategic alliances. In addition, the fact that the innovation paradigm considers knowledge flows as an essential element makes it very suitable for application to RTOs, given their intermediate position in the innovation system and their fundamental orientation to the transfer of technology to companies.

As stated in the introduction to this section, RTOs develop both inbound and outbound OI roles [16]. On the one hand, they offer knowledge and expertise inputs to other businesses (outbound), which is RTOs' main mission. This form of technology and knowledge transfer plays an important role in the innovation of clients' firms [6]. On the other (inbound), they rely on external partners, especially universities and other research partners for knowledge acquisition, capacity building, and to stay connected to the sources of scientific and technological developments [16].

RTOs, due to their nature and role in the Regional Systems of Innovation, have close ties with academia and industry, and work in an open collaboration environment, with knowledge flows that enter and leave the organization, which in practice is an OI model. In addition, the fact that companies are increasingly applying OI as an innovation strategy is reinforcing the role of OI in RTOs. Moreover, public administrations also promote, through R&D support programs, collaboration with other agents, which fosters OI in RTOs due to the impact of public funds on RTOs.

Additionally, RTOs consider OI as a key element in the achievement of their strategic objectives [9]: increase of benefits, improvement of development times, increase of innovative capacity, increase of R&D flexibility, or better access to the market. These objectives identified in the scope of the companies have not yet been studied for RTOs, nor the management approach of RTOs for OI or the related obstacles. Results regarding these elements are shown in the following sections.

3 Method

To explore the objectives and barriers of open innovation implementation in RTOs, an empirical study was performed based on a questionnaire addressed to managers in RTOs. The survey focused on the population described at the Spanish Ministry of Science, Innovation, and Universities database[1] regarding Innovation and Technology Centers (CIT database). In June 2018, the database contained 63 RTOs. Eliminating the non-active organizations, as well as the ones mainly orientated to sectors of low R&D intensity, the list of RTOs to study was shortened to 50 (target population).

The data employed in this research was obtained using a self-administered questionnaire filled in by the managers of the RTOs, mostly CEOs (43.24%) or other

[1]Directory of Innovation and Technology Centers. Spanish Ministry of Science, Innovation and Universities, accessed 28 June 2018, https://sede.micinn.gob.es/inforct/.

C-Level Executives (45.95%). The instrument was designed with a previous validation through personal interviews, and was based on scales (Likert 1 to 5) previously used in other research studies. Moreover, the management experience of respondents was high with 17.8 years of average experience for CEOs and 16.11 years of average experience for other executives.

Finally, 36 valid responses were obtained, which implies a ratio of 72% of the total population selected, which can be considered very representative.

4 Results

The heterogeneity of the RTOs analyzed is great, as reflected in the type of activity they develop (Table 1).

This heterogeneity affects the way RTOs understand the importance of OI strategy in their organizations. Thus, as observed in Table 2, the effect of public funding on the importance given to OI is greater for RTOs with a lower percentage of public funding.

In addition, when considering the management effort, those RTOs with the least public funding are the ones that show higher OI management practices. This may suggest that OI could play a role in the fund-raising mechanisms of RTOs, needed to complement public support. Figure 1 shows the average values for the "Open innovation management" construct.

Regarding the approach of RTOS when managing OI, the analyzed organizations are focused on the planning of the objectives and risks of implementation of OI and the measurement of the collaborations. The management of questions regarding the

Table 1 Spanish RTOs typology based on the percentage of activity based on under contract projects (percentage of total activity)

Range	Number
From 12% to 25%	10
From more than 25% to 40%	12
From more than 40% to 57%	11
From 70% to 75%	3

Table 2 RTOs open innovation importance and management

Percentage of public financing	Number	Open innovation importance[a]	Open innovation management[b]
10–30	9	4,05	3,02
30–50	14	4,00	2,71
50–70	13	3,75	2,57

[a]Likert scale 1 (Not important) to 5 (Very Important)
[b]Likert scale 1 (Not important) to 5 (Very Important)

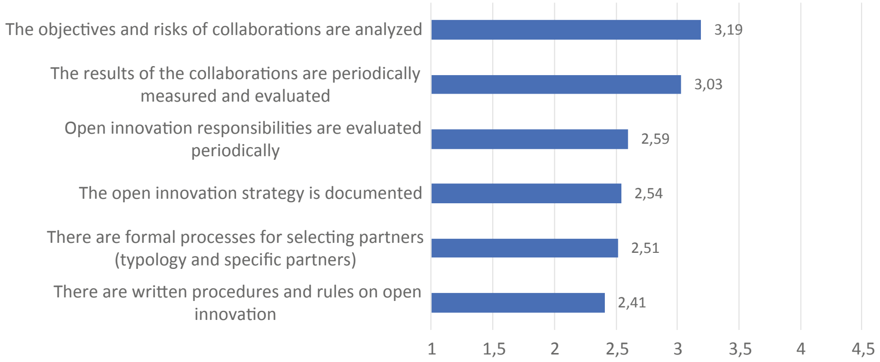

Fig. 1 Open Innovation Management in Spanish RTOs

establishment of formal processes, written procedures, and rules is not so important from their point of view.

Another element highlighted in the literature refers to the objectives that organizations seek when implementing OI. Thus, RTOs in this study underline objectives related to the response to the demand of their partners and customers, technological development (identification of new technological opportunities, exploring technology trends, and avoiding "reinventing the wheel"), the transfer of knowledge and technology, and the establishment of projects in cooperation (Fig. 2). These objectives corroborate those established by other authors [17]. However, some other objectives are not so important for RTOs: the improvement of scientific publications, or the efficiency of R&D projects (reduction of costs of R&D projects, reduction of risks of R&D projects, and the acceleration of R&D project development times).

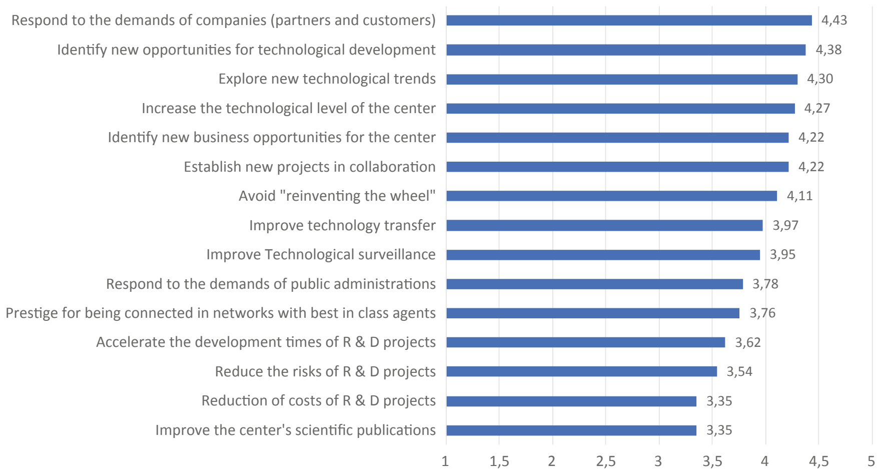

Fig. 2 Objectives when implementing OI in Spanish RTOs

Fig. 3 Barriers when implementing OI in Spanish RTOs

With these values and in the absence of a more detailed analysis, market needs and access to technology seem to be the two most important objectives for RTOs when developing an OI strategy.

Finally, RTOS also refer to certain obstacles when developing an OI strategy (Fig. 3).

Thus, RTOs point out that the most important barriers are those related to the management of cooperation, as well as those associated with knowledge management (existing and resulting knowledge management, property rights, and patents), and those associated with economic management (costs and financial aspects). Although barrier perception in RTOs shows similarities with the perception at companies [18], they differ in some aspects, like the higher importance that RTOs give to knowledge management (loss of know-how or the problems of exclusivity and confidentiality with multiple partners). On the other hand, RTOs feel management skills are the least important barrier, contrary to companies that feel this one as one of the highest barriers [18].

The importance of IPR management is also emphasized when analyzing the relationship between OI management performance and IPR management using simple linear regression. The model shows a value below the critical level (Sig 0.05), indicating that both variables are linearly related (R-value of 0,352). Besides, the value of R^2 indicates that 12.4% of the variability of the performance of OI management in RTOs depends on the IPR management implemented by the organization. These results suggest that knowledge management and intellectual property rights management are very important issues when implementing OI in RTOs. The reason for this is due to the position of RTOs in the innovation system, where continuous knowledge flows (in and out) affect RTOs, which in turn affects the importance of IPR management in generating value from such knowledge.

5 Conclusions and Further Research

Despite its growing popularity around the world, the concept of OI is still not widely studied in RTOs although they are paradigmatic actors of this innovation strategy. RTOs, due to their position in the innovation value chain, generate knowledge and transfer knowledge and technology.

By analyzing the responses regarding OI, it is clear that the nature of the RTOs has a great influence on OI implementation, and surely in other aspects that will be addressed in this ongoing research. The most important objective for RTOs to implement OI is linked to their will to better answer to the demands of their customers (companies), as well as their motivation to explore new technology opportunities. All these findings suggest that RTOs have different motivations when implementing OI than companies [18], more focused on the reduction of costs and the increase of efficiency on R&D projects. For RTOs, the improvement of scientific publications, the reduction of costs of R&D projects, the reduction of risks of R&D projects, or the acceleration of R&D project development times seem not to be so important.

Contrary to other studies analyzing OI in SMEs and big companies [19], the explored data shows that RTOs focus their barriers regarding the implementation of OI in aspects related to the economy of OI, and to the management of knowledge flows and IPR. This is expected due to RTOs' position in the innovation system, with continuous knowledge flows in and out of the RTOs and the important role IPR management has in extracting value from knowledge.

All these findings suggest that Spanish RTOs have different motivations when implementing OI strategy (demand driven versus technology driven) and that they are struggling to find IPR approaches that will make them be more confident when addressing OI. Additionally, this study shows that Spanish RTOs have a moderate level of OI management profile, with a focus on objective setting and performance evaluation, but with a weaker level of formal OI management procedures.

Further research will focus on how RTOs apply OI, identifying its application patterns and measuring the impact of OI application in RTOs' key performance results.

Statement on Compliance with Ethical Standards The Ethics Committee of the Faculty of Engineering of Mondragon University (ref. KO20191210–6) approved the entire procedure used in the research process. RTOs were informed about the process and data management policy through a presentation letter, voluntarily agreeing to participate in a research study by sending the fulfilled questionnaire. RTOs' data was also anonymized. The authors declare that they have no conflict of interest.

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On the Motivation of Funders When Financing Firms with Social Goals Through Crowdfunding Platforms

J. M. Fernández-Angulo, G. Morales-Alonso, Y. Núñez, and A. Hidalgo

Abstract The world is currently governed by the economic principles of capitalism, free trade economy, and private property. However, a new economic paradigm is shaking the foundations of the capitalist model: The Sharing Economy. An individual can now act as a funds provider through crowdfunding platforms, which he can do for extrinsic motivation (i.e. in exchange for equity or an interest rate). But intrinsic motivations can also be present through reward-based crowdfunding and crowdonation, in which the incentives for funding go beyond the extrinsic. A survey on 123 individuals who have acted as crowdfunders has been conducted. The results highlight the existence and importance of intrinsic motivators for crowdfunding with social goals.

Keywords Collaborative economy · Alternative financing · Third sector

1 Introduction

Sharing Economy refers to the ability to use idle resources for improving the match between demand and supply with respect to the match provided by the capitalist system [8]. There is an increasing consensus within the scientific community on the idea that this new phenomenon will change the pre-established economic model in the coming centuries [9].

Nowadays, the Sharing Economy is established in several sectors, where it is disruptively transforming a wide variety of business models, providing more sustainable and efficient ideas. Because of its global condition and its big potential, it threatens many traditional capitalist mechanisms. Revenues from the five key sectors where the Sharing Economy appears—travel, car sharing, finance, recruiting, and

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streaming of music and video—are expected to grow at about 35% per year, reaching more than $ 335 billion by 2025, which means a growth of about ten times faster the growth of traditional economy in these sectors [7].

Finance is among the sectors that are being disrupted, allowing new funding possibilities by means of individuals that act as financial actors (funds providers), supporting and investing in new ventures. Therefore, companies gain access to a new source of funding, the crowdfunding. Crowdfunding stands out as an alternative form of collective financing. It allows the crowd to support projects of any kind on a global scale.

In crowdfunding, the incentive for lenders is usually of an extrinsic type: the expected return of their investment. In this vein, the motivations to participate in the funding of social projects should be sought after. The aim of this research is to characterize investors acting on social platforms according to whether they are guided by extrinsic or intrinsic motivations, as well as to characterize how each type reacts to external influences. Lastly, research also seeks to discover how secondary parameters (such as age, investment frequency, and the amount invested) affect the motivations of the investors.

2 Theoretical Framework

The crowdfunding sector raised 34,400 M$ in 2015, with annual increases that doubled the total funds of the previous year. Thus, in 2012, the world raised $ 2,700 million, which increased to $ 6,100 million in 2013 and $ 16,200 million in 2014. Following this trend, it is expected to exceed $ 100,000 million by the end of 2019 [6].

The outlook for the next decade at a global level foresees that crowdfunding will continue to grow with rates as high as it has been until now. After the crisis, the existing low interest rates allow crowdfunding to continue growing in a consolidated way. According to a World Bank study [11], this growth will be heavily influenced by certain factors, such as the penetration of social networks, as well as the existence of support regulation and other cultural or technological factors. With all this, it is estimated that the total market potential for 2025 will be up to $ 90–96 billion per year.

There are four types of crowdfunding, namely (i) crowdinvesting, (ii) crowdlending, (iii) reward-based crowdfunding, and (iv) crowdonation, all of which are defined in the following. Crowdinvesting is an alternative financing method in which the investor receives equity in exchange of his funds, becoming a shareholder of the company in question. Crowdlending, on the other hand, are microloans offered by fund providers to entrepreneurs in terms of unsecured loans. Third, reward-based crowdfunding focuses on a pre-sale of a product or service, in which the sponsor deposits funds and in exchange, receives a reward. Last, crowdonation is donation-based microfinance used primarily by non-profit organizations or charities. Both crowdonation and reward-based crowdfunding can be identified as providing funds for social goals.

3 Methodology

Crowdfunding is a topic that has not been thoroughly addressed in the literature due to its recent nature, and for this reason, this research has been considered as an exploratory study. A questionnaire targeting a group of investors and potential users of the crowdfunding platforms has been developed, anchored on a Master Thesis realized in the School of Business and Economics of the University of Lund [10].

The focus of this study is on social crowdfunding, which is barely unexplored to date. We started building from the questionnaire designed by Van Wingerden and Ryan [10], to craft a final survey composed by 20 items. Out of them, 14 come from the mentioned previous questionnaire (in order to maintain the reliability of the scale), while the rest have been newly created for this study. All questions are formulated on a Likert 1 to 7 scale and have been randomly placed to ensure that the respondents did not observe the groups of factors that were investigated. Respondents were asked to rank the intensity with which they agree or disagree with the questionnaire statements.

The final questionnaire is composed of 20 items, divided as follows. Two items deal with the characteristics of the investor, namely asking for age and the extent to which the investor is familiar with crowdfunding. Seven items are related to investor motivations, replicated from the survey of the University of Lund but adapted from an original study on intrinsic and extrinsic motivations in participation in activities [4].

In order to obtain data on the influence of the other investors, the other seven questions replicated in Lund's research have been adapted from several studies to gather the required data. First, a study on the influence of the purchase of products was adapted to obtain a vision of the individuals influenced on their investment decisions. Secondly, a scale was adapted that measures to what extent the consumer has been influenced by the information presented in an advertisement [2].

For the collection of data, online questionnaires have been used through the Google Forms web application. Various methods of dissemination of the survey have been used. Among the most prominent are blogs and social networks, specifically LinkedIn, Twitter, WhatsApp, and Facebook. Data collection took place in spring 2017. After collection, several analysis methods were performed using the statistical software SPSS Statistics 2017.

In terms of the variables defined, 4 different items have been created to express the intrinsic motivations, while 3 are used for the extrinsic motivations, in accordance with Van Wingerden and Ryan [10]. The reliability of the measurement scale is then diagnosed by calculating Cronbach's Alpha, observing then the normality of the sample. Later, concrete tests are performed to find significant differences between variables. Since the sample does not follow a normal distribution, nonparametric tests will be used, which compare medians instead of means. When looking for relationships between two groups of responses, the Mann–Whitney U test is used, whereas if there are k groups of independent answers, the Kruskal–Wallis H test is used.

4 Results

A total of 153 respondents did the questionnaire in a period of 26 days. There was a discriminatory question that cataloged the answers according to their interest for the study, referring to how familiar the respondent is with crowdfunding. Among the 153 respondents, a number of 123 were familiar with crowdfunding, and they have been taken as the sample for this study. Of this group, 54 of them were investors in crowdfunding projects or had invested at some time, representing 35% of the total number of respondents.

The reliability of the scale has been sought after with the Cronbach alpha value for all the variables under study in the sample of 123 respondents. A value of 0.649 has been obtained, which calls for a good reliability of the scale in use. Following this, the normality of the sample was analyzed, using the Kolmogorov–Smirnov test, where a p-value lower than 0.05 is found and therefore the sample has a non-normal distribution. For this reason, nonparametric tests will be applied to do the analyses.

Regarding the descriptive statistics, in terms of the age of the respondents, it is important to note that 72.4% of them are under 35 years of age, with the average age being 29.1 years. It is then observed that the sample is especially displaced toward younger people, as expected by the environment in which the survey was disseminated.

In terms of frequency, 62.6% of respondents familiar with crowdfunding or investors have not invested any time in the last 6 months. Only 2.4% of the respondents could be considered habitual investors in the short term, having invested more than 6 times in the last half year. As for the amount invested, 43.1% invested between 1 and 5€, and 34.1% invested between 6 and 25€. There is also a decreasing trend as the amount invested increases (Fig. 1).

As for the questions related to motivation, the following descriptive characteristics are observed. Analyzing the extrinsic motivations, it is observed that the majority of respondents (58.8%) indicated that they do not finance a project just to receive a

Fig. 1 Frequency of use of the different crowdfunding types among the respondents

financial return, leaving only 25.5% of the respondents in favor with this affirmation. This is in line with the fact that only 26.1% of respondents believe that financial profitability is most important when financing a project. However, non-monetary incentives do not seem as influential as the non-financial nature of the respondents might seem, and only 22.2% of individuals agree that they only finance when they expect to receive a non-monetary incentive in exchange.

If the intrinsic motivations are studied, interesting characteristics of mentioning in the total sample are observed. 50.3% of respondents believe that helping someone reach their goal is more important than receiving a reward. Interestingly, the same percentage of people said they see financing a project as if it were a donation, leaving only 29.4% against this claim. 66.7% of people agreed that participating in the creation process by financing a project was a reward in itself while only 32% agreed that they fund for the fun it entails. In fact, the variable that analyzes being involved is the one with the highest average of all the variables studied (4.95), which shows the importance that investors give to this motivation.

In general, the data seem to suggest that crowdfunding participants were intrinsically motivated rather than extrinsically. If the means of the descriptive statistics that support intrinsic motivations are observed, it is observed that they are higher than the means of those variables that involve extrinsic motivations.

These aspects do not agree with some authors who affirm that once the extrinsic motivators are introduced, the intrinsic motivation decreases [1]. However, these trends are well known in the Human Resources domain. Likewise, they have also been observed in open source programming [5] or in investment decisions [3].

If the variables related to the influences of others are observed, interesting results of mentation are also observed. When making a decision to invest through crowdfunding, only 26.1% of respondents do not take into account the opinions or actions of other investors, although it is true that it is not an affirmation with an excessively high average (4.38), so it is understood that it is not a priority factor. While 50.3% of investors take into account the opinions and actions of others, 45.8% of respondents take into account the amount of funds they have received and that project. In addition, 42.5% prefer to finance projects that have received substantial funds from other investors recently, and 49.7% prefer to invest in projects that many other investors have. Being close to the target goal is also important, according to 46.4% of the surveyed population and only 17.3% of respondents are interested in investing in projects that have little funding to date. Regarding the campaign terms of the project, 41.8% prefer to finance a project when it is close to meeting its financing term, however, only 3.3% fully agree with this statement, so it does not it is a decisive factor in making the decision.

These trends are also analyzed by grouping respondents. A group is created dividing investors in those who invest in social projects and those who do not (see Table 1). As can be seen, there are significant differences within all the extrinsic motivational variables and three out of four intrinsic variables.

Table 1 Mann–Whitney U test results for the value variables with the SOCIAL grouping variable (Group 1: Investors in Social Projects; Group 2: Investors in Non-Social Projects)

	Int_1	Int_2	Int_3	Int_4	Ext_1	Ext_2	Ext_3
Mann–Whitney U	1406	1746	1194	1096	1288	1332	1226
Z	−1.871	−0.051	−2.992	−3.511	−2.487	−2.257	−2.824
Sig. (billateral)	**0.061***	0.959	**0.003**	**0.000**	**0.013**	**0.024**	**0.005**

5 Discussion, Conclusions, Limitations, and Further Research

The rise of the Sharing Economy has had a remarkable importance in the last years, and its repercussions across different economic sectors throughout the next decades will mark their future. The platform that supports this paradigm, the Internet of Things, is beginning to become a reality. Due to its collaborative nature, horizontal and open, it has great growing potential, partly because of the change of mentality among consumers, who step from "having" to "disposing of", allowing for the rise of the service economy.

Finance is one of the sectors in which the Sharing Economy has impacted in a disruptive manner, allowing for alternative financing sources, via the use of crowdfunding. Crowdfunding allows diversifying traditional financing methods and connecting people with parallel interests, allowing synergies to be made for the benefit of both parties.

In spite of the academic contributions made in the last years in the field of crowdfunding, the part of it that focuses on social contributions has received little attention. Social crowdfunding allows for a triple win-to-win, since (i) it helps promoters to carry out their social projects, (ii) provides good financial returns to investors, and (iii) profits the stakeholders that receive the positive impacts from these projects.

In this study, a questionnaire has been designed, aiming at shedding light on the motivations of the investors to participate in social crowdfunding. The results of this research are supported by 123 respondents. The data shows that, in terms of respondents' motivations when investing, there are two types of investors: those who use crowdfunding platforms hoping to receive monetary incentives in exchange, and those who use platforms that do not provide financial returns. The crowdfunding platforms in which it is expected to receive a financial return are those that are dedicated to crowdlending or crowdinvesting, while the types of crowdfunding in which this economic return is not expected are crowdonation and crowdfunding based on non-monetary rewards. That is, individuals who expect to receive a monetary incentive are statistically more motivated by extrinsic reasons such as financial return or financial profitability. In contrast, users who finance projects without expecting a monetary reward are significantly more motivated by intrinsic aspects such as helping someone or seeing their investments as donations.

In terms of how the attitudes of other investors influence respondents' decisions, it can be noted that, in spite of the existing differences in motivational incentives, these are not translated into the influence from other investors. In spite of the results provided by this study, it is not without limitations. First, a limited number of variables have been controlled, which does not allow to discriminate in terms of other factors which are known to be relevant, such as gender or purchasing power of the investor. Last, the lack of normality of the sample calls for analyzing the results with other tools, such as artificial neural networks.

Statement on Compliance with Ethical Standards The Research Ethics Committee of Universidad Politécnica de Madrid approved the protocol and procedure followed by the authors in this research work, by means of its declaration issued on January 31, 2020. All the data used for this study has been anonymized. The authors also declare that they have no conflict of interest.

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Blockchain and Smart Contracts: A Revolution

S. Fernández-Vázquez, R. Rosillo, D. De La Fuente, and P. Priore

Abstract Blockchain is currently one of the hot topics in academia and industry, mainly due to the implications that the implementation of this modern technology could have. This paper examines the peer-to-peer network that forms the blockchain, from its origin to the most recent developments and applications in various industries and sectors (mostly in supply chain management, energy, education, and medicine) as well as the different forms it can adopt, primarily through smart contracts. Some of the main issues of this technology are also addressed, mainly through the analysis of scale, security, and misbehavior. These are the major concerns regarding blockchain and smart contracts after its expansion in recent years. While the application of blockchain technology still faces many issues that must be addressed, it is through further investigation and investments that blockchain becomes a revolutionary technology. Although today it is far from being the solution to most of the challenges in many industries (logistics, education, and energy), its features set hopes for a bigger significance in the years to come.

Keywords Blockchain · Smart contracts · Ethereum · Bitcoin · Internet of things

1 Introduction

Blockchain has been one of the most talked-about subjects recently in the financial world. It was firstly created in 2008 with Bitcoin, an electronic peer-to-peer payment system allowing payments to be sent without the intermediation of financial institutions. This prevented the double-spending problem [28].

Blockchain's peer-to-peer network is linked by its nodes and has the properties of a distributed, transactional database. The information, once verified by each node in the network, is sent to the other nodes via their public keys [35]. A public key system is not something recent. In fact, it was in 1976, when Diffie and Hellman came up with the idea of asymmetric cryptography, bringing into play two kinds

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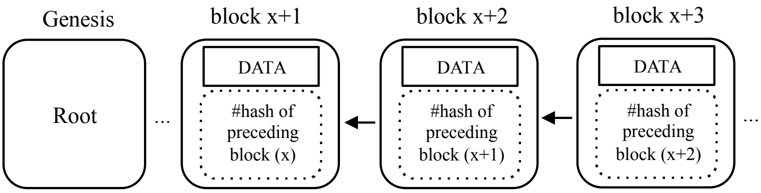

Fig. 1 This figure shows a simplified configuration of a chain of blocks, or blockchain. Each block has a unique identification hash that makes reference to its preceding block. Any user with a key (public or private) can access the chain of blocks at a certain point and have access to all the information exchanged in the system network

of keys: public and private keys. The principle behind the public key system was the possibility that two parties could communicate over a public channel using only publicly known techniques and creating a secure connection. Each party would send messages to the other enciphered in the receiver's public enciphering key (public key). In order to decipher this message, the other party would use its own secret deciphering key (private key) [10].

Public and private keys can only be used in combination with the other key in the pair, making the relation exclusive between both the keys. This pairing is possible, thanks to a mathematical relationship of the algorithms of the public and private keys. While the public key can be unrestrictedly shared, the private key needs to be kept safe and undisclosed [21] (Fig. 1).

Throughout encryption, every block of data is secured, thanks to the work of miners, who validate this information by solving cryptographic puzzles and reaching consensus [25]. Whenever a miner positively solves a puzzle, it is allowed to record a transaction. The miners earn Bitcoins through this process. The stronger the resources of this miner are, the higher the probability that the puzzle will be solved before the rest of the miners. Through this structure, miners are incentivized to contribute with their resources to the system, making the decentralized nature of Bitcoin possible [12].

Each miner has a copy of the blockchain when it joins the network and has information starting from the genesis to the most recent validated block [13]. The root of the blockchain receives the name genesis, which is hard-coded into the client software that supports the valid blockchain. The miner's main task is to solve the proof of work and produce the next corresponding block. A transaction will only be valid when a new block is added to the blockchain [20].

The fact that blockchain technology is asset-agnostic means that this technology is potentially capable of storing, recordkeeping, and transferring any type of asset [26].

Blockchain technology can transform the financial markets, thanks to its multiple advantages which are as follows:

1. Reduces complexity (especially in multiparty, cross-border transactions);
2. Improves the speed and accessibility of assets and funds in the end-to-end processing;

3. Decreases the requirements for settlement across multiple recordkeeping structures;
4. Increases transparency regarding transaction recordkeeping;
5. Improves network flexibility through distributed data managing; and
6. Reduces operational and financial risks [26].

One of the main reasons for the recent interest in distributed ledger (or blockchain) technology has been the suppression of a trusted intermediary or "middle man". This is possible due to the fact that these applications run in a decentralized fashion with the same level of certainty as those with a central authority would. The absence of this trusted intermediary means faster reconciliation among parties. Due to the heavy use of cryptography, the main characteristic of blockchain networks, authoritativeness, is brought through behind all the interactions in the network [7].

Nowadays, market players who preserve the integrity of the system act as a central ledger governing financial market infrastructures. Sometimes, and on behalf of its participants, these players manage certain risks as well. Blockchain technology could diminish the traditional reliance on this central authority (or intermediary) when transferring funds and other financial assets [4].

2 Smart Contracts

In recent years, blockchain has been developed in a broader fashion [24]. This has enabled, for example, the creation of smart contracts. The concept of smart contracts is not new. It was firstly introduced by Nick Szabo, which in 1994 defined these contracts as a "computerized transaction protocol that executes the terms of a contract" [33].

Smart contracts have the contractual clauses that govern them embedded into the hardware and software of each user (collateral, bonding, property rights, etc.). These clauses are considered as property, which diminishes the needs for a third party or central authority to govern these transactions [33].

Smart contracts can rely, for instance, on Ethereum, which allows users to create any system by simply coding the idea behind it [36]. Smart contracts, when used in Ethereum, have been found to be resistant to the double-spending problem, although adding a high degree of complexity [29]. Currently, the platforms that support blockchain's smart contract are Ethereum and Hyperledger [17].

When using Ethereum, smart contracts are coded using their own language, just as computer programs. Ethereum's consensus procedure, which details how the nodes of the network extend the chain of blocks, has the aim of guaranteeing the precise execution of contracts. One of the most important characteristics of this procedure is that a lottery takes place for all nodes to participate in order for a new block to be added into the chain of blocks. The computational strength of the nodes will determine which node wins this lottery. By means of an incentive mechanism, malicious nodes that could potentially win this lottery and add incorrect contract executions to the

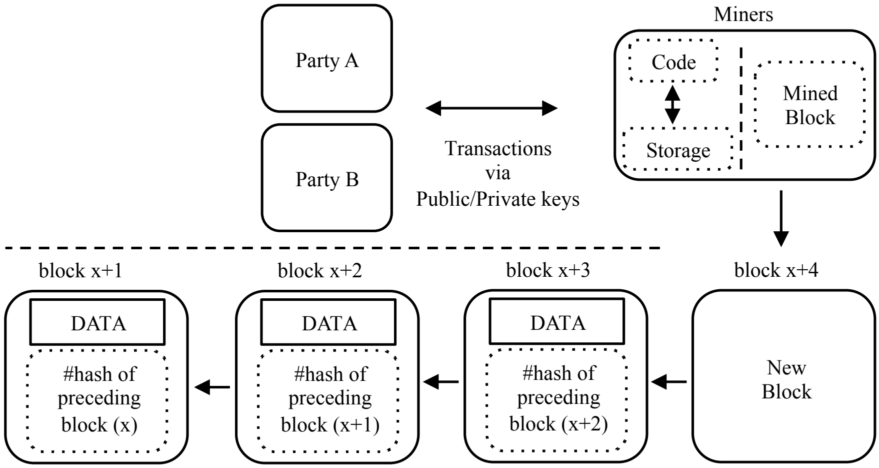

Fig. 2 This figure shows how a smart contract system works. On the bottom part, we have the blockchain. On the upper part, the parties involved make a transaction (for example, Party A sends units of currency X to Party B and receives units of currency Y). Parties exchange this information through their respective keys, and consensus of this transaction is reached through the work of miners. The transaction is only valid when a new block is created

node would be ultimately removed from the blockchain [3]. It is worth considering that, in order to satisfy all parties involved, contracts must be written to ensure fairness even when counterparties may try to cheat in arbitrary ways that could maximize their potential economic benefits [8] (Fig. 2).

There are two main types of smart contracts: deterministic and non-deterministic. The former depend exclusively on information on the blockchain to be triggered, while in the latter, an external party (also called Oracle) is needed in order to make effective decisions [27].

One of the main advantages of smart contracts is the high degree of customization of transactions in services that go all the way from financial services, health care, and energy resources [25], thanks to its flexibility [31]. The application of smart contracts has also been explored in public sector services, regarding taxable gains (such as dividends or profits) in countries where investors do not legally reside [19].

3 Challenges Facing Blockchain

There have been major concerns regarding blockchain and smart contracts after the former's expansion in recent years. There are currently three main areas where this technology faces continuous challenges:

- Scale: Due to the daily increase in the volume of transactions, the weight of blockchain becomes heavier. All the transactions taking place need to be stored in order to be validated. Right now, the blockchain processes about 7 transactions per second, due to block size restrictions and the time spent in order to create new blocks. This makes the processing of tens of thousands of transactions in real time extremely difficult [37]. A solution to this problem could be Bitcoin-Next Generation, a procedure aimed at scaling, which is robust and shares the same trust model as Bitcoin [11].
- Security: Even though blockchain is believed to be very secure as transactions are generated with keys and not with real identities, there are major issues concerning its security. The sequence of the activities that take place through smart contracts is extended through the entire network and recorded on the blockchain, being available to all users. Although creating different public keys can increase anonymity, the information concerning the transactions is publicly visible [22]. Cryptographic models such as Hawk [22] or platforms such as Corda [15] could help mitigate this risk.
- Misbehavior: The Bitcoin protocol is based on the honesty of its miners. If a group of miners with big mining power takes control of the network, the system stops being decentralized and becomes controlled by the conspiring group. This group could, for example, forbid transactions from being recorded. There is evidence that shows that miners behave strategically, forming groups. Because rewards are given away randomly, forming groups allows miners to work together to find the solution to the puzzle, sharing the reward [11]. One solution to this problem, also known as the Byzantines General Problem which deals with loyal and disloyal generals (in our case, miners) [23], is the Practical Byzantine Fault Tolerance (BFT), which is an algorithm that, in the presence of attacks, does not return bad replies [6]. Another solution is the modification of the instructions in the protocol when other parties in the network misbehave, although this has to be done with care [2].

4 Discussion

Blockchain has the potential to become a source of innovation in many fields over the next few years. In supply chain management, for instance, blockchain can improve visibility, optimization, and demand. The technology can be used in logistics, identifying fake products, easing paperwork, facilitating the product's tracking (for example, food tracking), or connecting the Internet of Things (IoT) devices [18].

In the energy sector, a large number of established energy companies are involved in blockchain projects, which clearly shows a deep interest in this area. However, the long-term value will depend on the investment in big-scale projects, which are currently at the early stage of the development phase. Some of its most important challenges, which are scalability, speed, and security, could be solved by means of the Energy Web blockchain, which can be scaled up to thousands of transactions per second [1].

In education, for instance, a blockchain-based distributed record of academic effort and reputation would provide a secure record of educational accomplishments that could be accessed and distributed to all academic institutions [32]. The trajectory of the educational achievements of students would be added by teachers into the blockchain [9]. A similar case would happen for professionals in the academic world, who would claim the authenticity of their academic accreditations via the proof of blockchain [16].

In medicine, research is being made in the direction of a shared key between patients and doctors. Using a shared key, the patient's data would be stored in a blockchain through encryption, being secure and accessible only to the parties involved [34].

Another application of the decentralized architecture of blockchain points toward the one used for purchase and rental contracts. As a device-to-device communication protocol, the work results in a cost-efficient, secure, and smart contract-based application [30].

5 Conclusions

While some consider that blockchain technology is not fully matured, others consider it to be overhyped, as its application produces outcomes that in most cases could be attained using traditional alternatives [14]. Some scholars point out that Bitcoin is an infrequent case where practice could be ahead of theory [5].

It is clear that, while the application of blockchain in many industries is being developed, the technology still faces certain issues that must be addressed. Further investigation and improvement will help blockchain overcome issues such as scalability, security, and misbehavior. Though today it is far from being the impeccable solution to challenges in many industries (logistics, education, and energy), its features set hopes for a bigger significance in the years to come.

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A Conceptual Approximation Toward Occupational Safety and Health Within the Servitized Industry 4.0

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Abstract Present highly dynamic manufacturing environments call for adaptive and rapidly responding Occupational Safety and Health systems within the new technology-dependent production models. Emergent trends of Servitization and Industry 4.0 tend to become widely recognized and accepted in the industrial branches. The same way, the more sophisticated tendency is emerging. The Servitization of Industry 4.0 is regarded as another promising trend of manufacturing firms' transformation of business models. So this servitization-based growth in product-based firms is one of the most active research domains; it may be prone to different interpretations and a variety of conceptualizations. It suggests the new paradigm shift of management of Occupational Safety and Health (OSH) as the change will trigger new human-to-human and human-to-machine interactions and the new occupational risks will surface. This article provides an approximation to the conceptual framework of the convergence of Occupational Health and Safety and the Servitization of Industry 4.0, based on the scoping literature review, as well as it moots future areas of the research domain. Furthermore, it provides details of the principal types of the Emergent OSH approach in servitized Industry 4.0.

Keywords Industry 4.0 · Occupational safety and health · Product-service systems · Servitization · Servitized industry 4.0

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1 Introduction

The digitalization of manufacturing companies often generates new challenges such as how to not only offer better products but also capitalize the firm infrastructure and resources. This transformation tends to reconfigure the socio-technical relationships with customers and providers, as well as generates new opportunities for innovation with information technologies (IT) applied to the Smart Factory [1]. Hence, manufacturing companies need to adapt their production systems to be able to respond to the required changes in processing functions, production capacity, and dispatching of orders. In parallel, in order to satisfy customer expectations and gain a competitive advantage on the market, industrial firms have developed services that either complement or integrate the manufactured products. All of these changes bring increasing pressure on the aspects related to Occupational Safety and Health, in particular when emergent business and production models are considered. So, one can consider the OSH as a relevant factor of effective and sustainable transformation of the production systems of manufacturing firms. Although the importance of this phenomenon is widely recognized, the new approaches toward the holistic transformation of manufacturing companies are still at a very early stage.

It has been long recognized that Industry 4.0 will bring deep changes within the production and the increase of new challenges directly related to automation, digitalization, and autonomous equipment. Industry 4.0 can be defined as two possible approaches toward smart manufacturing [2]: output- and input-driven. The output approach is centered on the change in the operating framework and is also called the application pull. The input approach, the technology pull one, aims at the increasing relevance of mechanization and automation in industrial practice and use. The technology push approach is also closely related to cyber-physical production systems and networks. The technology itself serves as an enabler of the profound transformation. All of this is intended to meet more efficient processes, adding value to increasingly individualized products, and supporting managerial decisions with enriched, predictive data [3]. Industry 4.0 is considered a new industrial scenario in which cyber-physical and intelligent systems can create value along the industrial processes [4, 5].

Considering that the recent models of Industry 4.0 or Smart Manufacturing claim to introduce the Internet of Things and servitization concepts into manufacturing [6] and generate the so-called "cyber-physical systems" (CPS), where the physical systems are combined with the digital items in order to communicate and control themselves [7, 8], this stage of "smartization" of industrial environments becomes the source of vast opportunities for new forms of hybrid industrial business models [9].

Accordingly, the increasing service orientation of manufacturing companies [10, 11] alongside the digitalization of processes establishes the relation between industry servitization and Digital Transformation focusing on the value creation for the hitherto product-based business models [12] and product-service systems (PSS) [10, 13]. Providing a product accompanied by a service not only may enhance the flexibility in production [14] but also can change the market benchmarking of manufacturing firms pinned in the tangible resource dependence [15].

It is widely agreed that technology is the basis for the modernization of manufacturing firms and due to the digitalization of the industry, the rapid progress of a service-driven economy takes place even in the product-related branches [16]. Smart servitization or "smartization" through the interconnected intelligence, automatized processes, and data transformation makes possible the advanced product-related services that can be offered by manufacturing firms [17]. As many experts consider digitalization as the necessary condition for many servitization approaches, it is widely accorded that the rise of services and the ICT-based transformation of industry come together [18].

Both industrial trends, servitization and Industry 4.0, have become the objects of diverse studies [19, 20] and some conceptualization of consequence. However, till now there is still a lack of a robust bridge between the Servitization of Industry 4.0 and the resulting perspective change of Occupational Safety and Health within. In this article, we provide a new conceptual convergence perspective on the OSH in the context of servitization in Industry 4.0 which can facilitate strategists and researchers a better understanding of the scope of the required policy change and we propose further research lines. The importance of aligning human (knowledge) capital and corporate servitization and/or Digitalization strategy with the OSH performance is becoming supported by an emergent research evidence [21]. Therefore, this research aims to propose the conceptual framework of OSH approaches within the servitized Industry 4.0 according to different stages of the convergence of servitization and Industry 4.0 in the manufacturing industry.

2 The Convergence of Servitization and Industry 4.0

During the recent two decades, research on servitization in manufacturing firms has been conducted from different perspectives: industrial services [22], high-end types of product-related services [23], Service Infusion [24], PSS modularization [25], or being considered as a stage of the industry evolution [26]. Moreover, existing contributions were often focused on a generic level of service transformation in product-based firms. Pertinently, [27] argue the lack of inter-disciplinary approaches to research on servitization, being the domain fragmented into three research streams: sustainability-centered Product-Service Systems (PSS), Solution Business focused on operations management and industrial marketing, and Information System-related Service Science.

Many scholars consider the current approach to servitization still limited and as [20] argue, the contributions prescribing how to servitize manufacturing companies are the acknowledged need. Servitization covers the transformation in which manufacturing firms are increasingly changing their value propositions by offering services [28]. To be able to carry on this transformation, new additional capabilities, cultural–structural reorganization and improvement in effectiveness and efficiency of industrial operations are usually required [29]. Furthermore, [30] determine that the consideration of both the business model and organizational change is required to meet the challenges of a wide range of organizational and environmental contexts of any manufacturing firm. Hence, the service-based strategy must be closely aligned with the manufacturing capabilities and competencies to enter into the market with a viable product-service offering.

In parallel, the Industry 4.0 challenges have arisen very rapidly both from a strategy point of view and on a production operations basis. Recent studies on Industry 4.0 [31] argue the positive input of the cyber-physical systems [32], digitization [33], and Industrial Internet of Things (IIoT) [34] to the paradigm shift of the manufacturing business model. Similar concepts surface concerning emergent Industry 4.0-based capabilities linked to cloud manufacturing, predictive analytics, or augmented reality [9]. Therefore, manufacturing firms that understand how this shift in a business model relates to the necessity of new capabilities and how it will change their internal operational processes are likely to implement effective strategies of their products and processes.

This strategy–capability alignment is also the core issue when Industry 4.0 implementation is considered [35]. Even so, the literature on servitization and Industry 4.0 nexus limits the scope of the shared area to the Digital Transformation perspective or collateral effects of servitized technologies embedded in the final products (Smart Products) within the Industry 4.0 strategy [36]. Some authors have posed the question of the contribution of specific digital tools to servitization, such as remote monitoring [37], cloud computing [30], big data [38], Internet of Things (IoT) [39], and predictive analytics [40]. The IoT, sensor technologies, and data analytics underpinning Industry 4.0 can, for example, lead to providing services of intelligent monitoring of a manufacturing plant and its maintenance.

However, the deep implications of servitization and Industry 4.0 for the value creation in manufacturing firms have made the scholars consider different aspects of both trends' implementation worth noticing. The studies aimed to analyze the present and potential connections between these two fields have been developed [40–43]. Hence, [4] propose a common framework that divides servitization into manual services, digital services, and Industry 4.0-related services, even if the conceptualization of servitization in Industry 4.0 is still lacking a more structured approach.

An overall view of industrial servitization pathway [44] in particular the Product-Service Systems raises interesting opportunities for the manufacturing firm to meet customer needs and make the organizational transition more smooth and seamless. The benefits of PSS encompass gains not only for the customers but also for the provider itself, as PSS reshapes the supply chain, manufacturing processes, maintenance, and operational procedures [45]. Nevertheless, the approach that considers PSS and servitization as a part of Industry 4.0 argues for the digital platforms as a common environment for service offering [4] along with digital feedback for manufacturing processes [36].

On the other hand, Smart PSS [46] can be considered as the intersection between PSS (as one of the servitization streams) and Industry 4.0. [12] view smart PSS as the paradigm for a new service-oriented manner of Industry 4.0. In this paradigm shift, the core technologies of Industry 4.0 and network capabilities are largely accepted as a major enabling factor of the business model transformation [47]. Hence, the human aspects of smart PSS development (technology-push manufacturing processes and customer-centered service design) must be considered. To meet workers' capability, health, and safety, the redesign of operating processes will be required, including the shift in the scope of the OSH dimensions and the adoption of a hybrid approach based on different sets of resources and capabilities.

3 An Emergent Occupational Safety and Health Approach Within the Servitization of Industry 4.0

Frank et al. [4] supports the statement that servitization of Industry 4.0 is an emergent trend and both approaches can coexist and support each other. The most important contribution of the work by [48] is that OSH in the Industry 4.0 context requires significant input from ergonomics and human factors research. This could be based primarily on considerable advantages associated with cyber-physical systems. The authors emphasize the major role of ergonomists and engineers in the design and the operation of new systems and processes as well as in the downsizing of undesirable effects brought by industrial paradigm shift [49].

The digital products of manufacturing firms can be classified according to their hybridity (a combination of digital and physical elements), smartness (capacity to sense), connectivity (ability to enter into networks), servitization (product-service systems), and the product ecosystem (online or offline) [50]. In this regard, the Industry 4.0-related services [40] that emerged from the Digitalization-based servitization can link these two perspectives and reveal the qualified personnel intensive approach of the manufacturing company. The authors propose the set of digital capabilities required to deliver new services related to Industry 4.0 as well as the necessity to combine them with the new adjusted OSH policy.

By tradition, the OSH in the manufacturing firms focuses on safety and prevention within the interaction with physical artifacts and industrial equipment. On the contrary, interactions with tangible objects decrease in the Industry 4.0 environments to give rise to long-term synergies between humans and machines [5], with digital technologies as both the bridge and the interface [25]. Manufacturing companies can focus on different needs they may have when they prioritize the implementation of good OSH management. However, in particular when Industry 4.0 and servitization concerned the workers' participation and engagement to carry on the effective measuring workplace risk, implementing the robust framework for the OSH management [5] is a game-changing factor.

Within the Industry 4.0 servitization, in particular smart PSS perspective, the OSH can be aimed mostly to develop a whole new set of technologies and service capabilities and adapt the organizational structures and production processes so that they reflect the cyber-physical nature of services [51]. What is more, by taking over the internal and external customers' support, servitized Industry 4.0 manufacturers have to take into account the risks inherent to digitalization, automatization, and virtualization [52]. Furthermore, those risks are related to not only the workers in an industrial plant but also those potential risks associated with providing services based on Industry 4.0 technologies.

In this work, the early stage conceptualization of OSH of servitized Industry 4.0 is pretended. This conceptualization [53] aims to become an abstract model of emergent workplace risk prevention and occupational safety management strategies within the volatile servitized Industry 4.0 environments. This matches with [54]'s focus on how to proceed with understanding a new problem by analyzing related concepts considered in former research. The theoretical perspective used to build the first approximation to the conceptual framework of Occupational Safety and Health within Industry 4.0 servitization is introduced in Fig. 1. We considered three dimensions of approximation to the OSH in servitized Industry 4.0 manufacturing firms: strategic/operational capabilities, servitization level, and Industry 4.0 adaptation level.

The necessity to consider together the strategic/operational capabilities, servitization level, and Industry 4.0 adaptation level arises from the holistic integrative focus of the analysis of significantly complex systems such as the servitized Industry 4.0 manufacturing firms. Within the context of these firms, all three dimensions are both interconnected and interdependent but to propose the specific strategy as the OSH one, it is required to delimit 3D areas according to the level of each of them. However, the higher level of Industry 4.0 or of servitization does not signify a more

Fig. 1 A conceptual framework of OSH within the servitized Industry 4.0 (*Source* authors' own elaboration based on Torrecilla-García et al. [55])

favorable situation for the company, in particular, in face of the OSH policy. Consequently, it can be argued that a sophisticated business model of industry required a specific set of strategic and operational capabilities to be able to respond to the challenges of the hybrid approaches and reach the competitiveness and productivity improvements alongside the more effective OSH strategies.

The relevant output of the integration of servitization and Industry 4.0 perspective into the OSH strategy and processes emphasizes the servitized manufacturers' need to undertake new or different responsibilities within the wider context: a business, technology, process, and person intertwined one. Within this wider context, we identify four main challenge areas that servitized Industry 4.0 manufacturers should consider in order to allocate adequate efforts and resources.

Based on the conceptual framework, we develop the first approximation [56] to the classification of emergent OSH approaches as shown in Table 1.

By adapting the reference framework of the operations strategy presented in different researches, the four novel approaches have been proposed and characterized. The major challenge for the correct classification lied in the precise differentiation of the most relevant operational/strategic capabilities. The first approach, called initially *Nascent strategy-oriented OSH perspective along the Servitization and Industry 4.0 implementation,* requires a very specific perspective of OSH from the bottom line and the alignment of a new service-based strategy with existing manufacturing capabilities and competencies.

The second one, *Adaptive, strategy-oriented, Industry 4.0-related Servitization OSH perspectives,* is closely related to companies with advanced strategies of Industry 4.0 and servitization but limited capabilities, in particular strategic ones. This situation forces these firms to look for new ways to adapt current resources and internal policies to develop and enhance the transition from the traditional OSH perspective toward the OSH scope based on the integration of CPS with the smart PSS approach.

A further one is an approach of *Smoothing process-centered OSH perspective along the Servitization and Industry 4.0 strategy progress.* The embedded operational capabilities of the firm allow gradual and adjustable placement of adequate OSH strategies when servitization and Industry 4.0 implementation processes come together. Digitalization marks a shift in thinking about the human–machine risk perception and subsequently risk prevention when digital or user-centered services related.

Finally, in the case of optimal levels of all three dimensions—what could be considered the servitized Industry 4.0 organization—the approach of *Optimized efficiency-oriented OSH perspective within the servitized Industry 4.0 manufacture* may be considered as a strategic tool both to improve the occupational safety and to increase the efficiency of all production processes including the OSH. Strategic capabilities-centered servitization is carried out through automatization, virtualization, or digitalization. Hence, new workplace hazards arise as well as the OSH needs to provide easy on-demand adjustment possibilities.

We summarize that the OSH policy can be considered as a facilitation factor of the efficient implementation of the servitized Industry 4.0 strategy if the mentioned

Table 1 An emergent occupational safety and health framework in servitized industry 4.0

Emergent OSH approach type	Main characteristics	Framework source references
Nascent strategy-oriented OSH perspective along the Servitization and Industry 4.0 implementation	New service-based strategy aligned with the manufacturing capabilities and competencies	Xu and Duan [32]
		Li et al. [57]
	Technology-push manufacturing processes and customer-centered service design	Moeuf et al. [35]
	Information System-related service approach	Romero et al. [52]
	Original bottom line OSH perspective	Kowalkowski et al. [10]
Adaptive, strategy-oriented, Industry 4.0-related Servitization OSH perspective	Transformation of manufacturing production systems	Frank et al. [4]
		Dolgui et al. [58]
	Strategic capabilities-centered servitization through automatization, virtualization, or digitalization	Fargnoli et al. [25]
	PSS modularization and digital platform interfaces	Wiesner et al. [45]
	OSH scope transits from CPS to smart PSS approach	Podgórski et al. [49]
Smoothing process-centered OSH perspective along the Servitization and Industry 4.0 strategy progress	New service-based strategy aligned with the manufacturing capabilities and competencies	Visnjic et al. [41]
	Technology-push manufacturing processes and customer-centered service design	Rymaszewska et al. [12]
	Information System-related service approach	Martinez et al. [13]
	Original bottom line OSH perspective	Coreynen et al. [44]
		Marilungo et al. [47]
Optimized efficiency-oriented OSH perspective within the servitized Industry 4.0 manufacture	Transformation of manufacturing production systems	Frank et al. [4]
		Ardolino et al. [40]
	Strategic capabilities-centered servitization through automatization, virtualization, or digitalization	Kamp et al. 2017
	PSS modularization and digital platforms interfaces	Mueller et al. [5]
	OSH scope transits from CPS to smart PSS approach	Durugbo [29]

strategy is explicitly grounded on the premises of correlation between operational/strategic capabilities, servitization grade, and Industry 4.0 level. However, the aforementioned emergent approach approximation requires the further research as well as needs to be contrasted with real OSH strategies of servitized Industry 4.0 manufacturing firms.

4 Conclusion and Future Work

The servitized Industry 4.0 based on smart connected systems and servitization is gradually becoming the new stage of the evolution of manufacturing companies that want to broaden their sources of revenue streams and compete on a wider market with different rules than raw materials cost and productivity. The human factors provide a stepping stone for the companies not only to be able to implement correctly the servitization and Industry 4.0 but above all also to carry on the adequate OSH strategies in that new volatile but still industrial environment.

The transition to both services-related and Industry 4.0 business models involves significant challenges that render a substantial impact on the OSH policy in manufacturing firms. The perspective shift of OSH in servitized Industry 4.0-related manufactures requires consistent alignment of strategic/operational capabilities, servitization processes, and Industry 4.0 adaptation within the business models and operational policies of companies. In order to show the relevance of integrative perspective and interdependence between the OSH policy and Industry 4.0 servitization, this paper addresses the gap in this field by developing a preliminary conceptual framework that includes four emergent approaches applicable in manufacturing firms. Therefore, this research determines that there are differences among the OSH approach in correlation to the levels of capabilities' intensity, servitization, and Industry 4.0 implementation degree.

With regard to a different grade of implementation of servitized Industry 4.0, we infer that as Servitization and Industry 4.0 level increase the OSH strategy takes an important role in effectiveness and productivity metrics. So, it can be said that the emergent approaches of OSH within the servitized Industry 4.0 become an even more relevant factor of competitive advantage for manufacturing companies. On the other hand, the OSH policy implementation, adjusted along the transformation toward Industry 4.0 or servitization, requires a new bottom line risk and occupational hazard prevention perspective.

The contribution of this paper lies in a scoping review of existing research on servitization and Industry 4.0 from the prism of emergent requirement related to the OSH policies. The present proposal of the conceptualization of the four types of new OSH approaches is clearly focused on the operational and strategic capabilities that the company has at its disposition or need to acquire. The proposal seems sound, as it synthesizes the existing research evidence and confronts it with the OSH management in manufacturing companies.

Notwithstanding the former, as an initial conceptual study, this research mainly looks at the general strategic aspects, while many other factors of OSH in servitized manufactures should be taken into account in the future as well. In particular, the empirical evidences leading to a robust model of OSH policy implementation in servitized Industry 4.0 manufacturing firms are required. It is also pertinent to seek to understand how the holistic perspective of the smart PSS can shape the new horizons of efficient OSH strategies in manufacturing firms. As yet, the approach relies on conceptual justification and requires further in-field validation. However, nowadays the empirical validation of the proposal provides another challenge in the face of a scarce number of manufacturing firms that can be classified as servitized Industry 4.0 companies.

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Additive Manufacturing Disruption in Manufacturing Sector—Spanish Evolution in the Last Triennium

L. Isasi-Sánchez, J. Morcillo-Bellido, and A. Durán-Heras

Abstract Additive Manufacturing technology, also known as 3D printing, has become, in the last few years, the most disruptive technology for the whole manufacturing sector. Spain, which is a well-positioned country in manufacturing activities, mainly in what concerns to parts, automotive, aerospace, and defense sectors is, and would have to be in the future, trying to detect and react to the main impacts of this technology on the manufacturing industry. In this work, we seek to deepen the knowledge of how additive manufacturing (AM) is affecting and transforming the Spanish manufacturing industry, and how fast this process is going to continue from the current moment. The acquired knowledge and the obtained conclusion will enable us to better understand the main strategic axes that all the stakeholders should consider in the future. One of the main contributions of this research work is the fact that the relevant business and organizational conclusions have been obtained from a global survey including all the major stakeholders: machine tool manufacturers, machining and forming service providers, and AM expert organizations.

Keywords Additive manufacturing · AM · Disruption · Future evolution · Flexible manufacturing

1 Introduction

Since Chuck Hull invented Stereolithography (SLA) in 1986, additive manufacturing (AM) is well known in the manufacturing sector. The foundation of the 3D system, Mr. Hull's company, was one of the facts that meant the "big bang" of one of the most important manufacturing sub-sectors that has not stopped growing since that time. And it is specifically over the last decade that most of the involved parties have been showing a huge interest in the subject [1].

AM contributes enormously to the current industry and to the Industry 4.0 Manufacturing concept since it adds value to all the processes, including the supply chain,

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and is called to revolutionize some aspects like ecology, sustainability, etc. [2–5]. AM allows the production of complex and integrated designs in much simpler processes, nearly no material waste, high geometry flexibility, and more other aspects that constitute a real "revolution" of the manufacturing sector and its business models. However, on the other side, the industry is realizing that many other aspects, some of them absolutely new, would have to be taken into consideration. Among the most relevant, the following could be listed: overall business will move from a pure product-manufacturing scenario to a more service-oriented one, increasing "made by you" effect, legal and intellectual property challenges, etc. Consequently, from a business and operations management point of view, there seems to be a clear need to switch from a traditional "sector" approach to a more global "interconnected scenario" one [6–9] (Fig. 1).

Considering all that is mentioned above, it could be concluded that, nowadays, all the involved stakeholders have not found a consensus about the way and the speed with which AM is going to affect the manufacturing activities and operations. The following two are the main reasons for this fact:

- AM has an extreme "multivariable" character that makes it really difficult to predict what are going to be the variations of all of those variables within short, medium, and long terms and, consequently, what are going to be the final impacts over the industry.

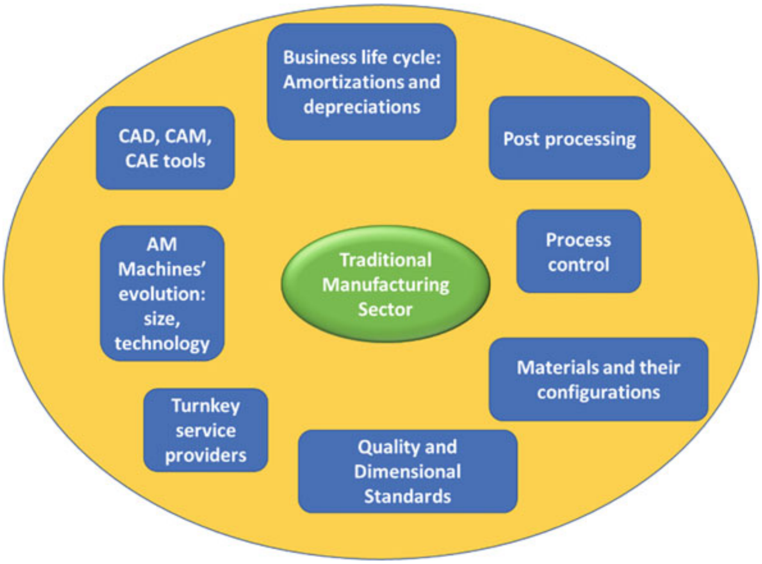

Fig. 1 With respect to the traditional manufacturing sector, some aspects whose impact is growing will become key into the future AM ecosystem. Own elaboration

- Lots of resources must still be invested in the future, in order to discover and develop key technological aspects, highlighting all of them, the available materials and their preparations, and the depositing technologies of the machines.

Currently, and according to the International Monetary Fund, Spain occupies the world's 14th largest economy, based on 2018 GDP data [10], accounting for its industrial sector, for an average of 15% of GDP [11]. In total, the main subsectors (automotive, defense, machinery and equipment, railways or other assimilated activities) could be estimated to represent a global turnover of 10,2 km€, and around 338 thousand workers, most of them being highly skilled and qualified.

Consequently, AM's impact and influence on the Spanish manufacturing sector is an extremely important aspect to be taken into consideration by all the business-related companies, when analyzing, defining, and crafting their strategies for the future.

2 Research Study Methodology

The present work began 3 years ago, and its two main objectives were the following ones:

- To detect singularities of the Spanish machining sector and its main shareholders, identifying analogies and differences with respect to other more advanced markets like the US, Sweden, UK, etc.
- To quantify, over time, the evolution of the AM and its influence in Spain.

Three main phases were identified as crucial to achieve the objectives. These are the following:

1. Detailed interviews with the main executives of stakeholders' relevant companies. A total of six interviews were performed, including a machine tool manufacturer, two machining services' providers, one technology center specialized in industrial design and production (non-profit entity), one manufacturer of printers, and one big corporation that at that time had just incorporated AM to its portfolio, as one of the future strategic directions.
2. In-depth analysis of the interviews to identify and validate the main disruptive aspects to be considered during the monitoring process of the AM impact evolution over the industry. Those aspects were used to create the online interview. The online conducted survey, directed to most representative focus-group corporations, related to AM in a direct or indirect way. Two waves have been performed, one on Q1 2016 and the other on Q1 2019, to verify the evolution over the last 3 years.

Fig. 2 Spanish AFM cluster configuration (Courtesy of AFM)

2.1 Sampled Companies

With the main purpose of having as much representativeness as possible of the survey results, the main searching direction was through the AFM cluster, which is the Spanish main representative cluster for advanced and digital manufacturing interest. The cluster integrates four industrial associations: AFM (machine tools and advanced manufacturing technologies), ADDIMAT (additive manufacturing and 3D printing), AFMEC (manufacturing and mechanical engineering), and ESKUIN (hand tools and industrial supply). As a whole, the cluster represents around 400 companies that directly employ more than 12,500 employees, with a turnover above 2,5 M€.

Although just 72% of the total 43 contacted companies in 2016 were part of the AFM cluster, all the rest were suppliers, customers, or R + D entities related to, at least, one of the associated ones (Fig. 2).

The initial wave of online interviews, performed in 2016, was completed by a total of 43 companies, 31 of which were directly related to the AFM cluster. In the second wave, performed in 2019, a total of 42 companies have replied, 32 of which were directly related to the AFM cluster. 64% of the 2016 wave respondent companies have also responded to the 2019 wave, but the relative weight of the different roles (manufacturers, service providers, etc.) has been maintained wherever possible.

3 Main Disrupting Aspects of AM

In the last two decades, lots of research papers have been published, trying to identify the main influencing aspects of AM on the industry. Good summaries can be found in [12–16], and specifically [17]. However, it still seems to be early to reach a good consensus among all the stakeholders.

What is undeniable is that the emergence of AM and its increasing development is going to greatly affect the whole industry, not only in production and manufacturing aspects, but also in the rest of the value chain, including the maintenance and service activities, once the goods have been produced and delivered, and not only in what concerns to operative aspects, but also when considering strategic ones [18, 19] and [13] (Fig. 3).

In order to tackle the problem in a structured manner, the main identified aspects, from phase 1 of our methodology, have been classified into two categories:

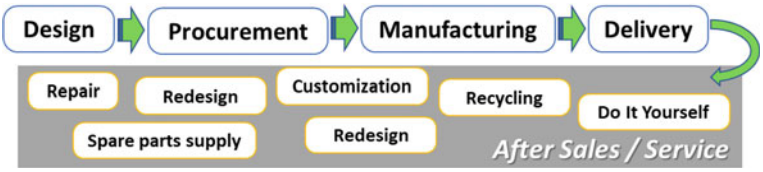

Fig. 3 AM affects in a global manner the industrial sector, at both production and after-sales activities. Own elaboration

Technical: Materials, difficulty to select the ideal technology (metal extrusion, metal jetting, binder jetting, etc.), post-processing (mainly in what concerns to shape and dimensional tolerances, and surface finishing), and simulation (with a specific focus on parameter selection).

Business management: Digitalization process, lack of enough competence, lack of enough skilled and trained human resources, standardization deficit, process robustness and scalability, productivity and cost (mainly for big parts and/or series), legal regulations (intellectual property, liability, etc.), amortization periods, distributed activities [20], customer satisfaction [21], and global risk management.

4 Survey Results

In the following pages, the quantitative results of the survey, with the evolution from Q1 2016 to Q1 2019 are presented (Table 1).

Within this 3-year period, the whole AM-related business turnover evolution of the companies of the survey can be roughly estimated, as a weighted average growth, around 29%. This means that some of the following results should be considered relative to this increase.

5 Conclusions

From the previous results, some important conclusions for AM Spanish activities can be obtained.

- Many of the companies that had started their operations related to AM technology, businesses, supply chain, or divisions before 2016 have increased their activities and their investment, and are convinced that even being quite a diffuse scenario, AM would be considerably important for their future.

Table 1 Quantitative summary of the main factors that have been analyzed in the survey period (from Q1 2016 to Q1 2019)

	2016	2019	Variation
For how many years has your company been directly involved in AM activities?	7,50	10,20	35,9%
What % or your last year turnover is due to AM income?	59,1%	68,0%	15,0%

	2016	2019	Variation
With which of the following materials are your AM activities related ?			
Metal	43,9%	45,2%	3,0%
Plastics and polymers	37,2%	39,2%	5,4%
Ceramics	9,0%	7,7%	-14,5%
Others (including composites)	9,9%	7,9%	-20,1%

	2016	2019	Variation
What is the geometric complexity of the parts your company is working on?			
Very high	39,8%	41,8%	5,0%
High	35,3%	37,9%	7,6%
Medium	24,5%	20,3%	-20,7%
Low	0,0%	0,0%	0,0%
Very low	0,4%	0,0%	0,0%

	2016	2019	Variation
Among the following technologies, what is the % of use of your company?			
SLS	18,9%	18,8%	-0,6%
DMLS	17,1%	17,7%	3,8%
EBM	7,1%	6,2%	-13,3%
Material Jetting	9,8%	10,5%	7,6%
Sterolitography	11,0%	10,8%	-2,5%
Direct Deposition	5,1%	6,1%	20,7%
Binder Jestting	7,2%	6,0%	-16,8%
Sheet lamination	1,0%	0,6%	-39,8%
Material extrusion	15,6%	15,6%	0,3%
Others	7,2%	7,7%	6,5%

(continued)

- Taking into consideration the main AM technical aspects and concerns, there seems to be a long way to go before reaching an agreement about the manufacturing technologies and processes that will consolidate and succeed in the mid- and long-term future.
- However, the current trend of the manufacturers of AM machines and hardware is clearly oriented toward metal applications, and the ones that seem to be consolidating are SLS, DMLS, and material jetting.
- AM batches seem to increase the number of parts and the geometric complexity, and the viability of manufacturing larger parts has also increased (even if, in terms of their relative weight over the total number or parts, the ones over 350 × 250 ×

Table 1 (continued)

	2016	2019	Variation
Which of the following applications are the most important for your company, in terms of revenue %?			
Aero & Space	19,2%	19,0%	**-1,3%**
Industrial components	20,2%	24,2%	**20,3%**
Automotive	13,3%	16,1%	**21,2%**
Medical & Dental	13,3%	11,5%	**-13,5%**
Defense	8,2%	5,0%	**-39,2%**
Education	7,9%	7,7%	**-2,0%**
I+D	10,9%	8,2%	**-25,0%**
Others	7,0%	8,3%	**17,7%**

	2016	2019	Variation
What is the size of the parts your company is working with?			
< 100x75x75	10,1%	12,2%	**20,6%**
> 100x75x75 and < 150x100x100	14,9%	16,9%	**13,6%**
> 150x100x100 and < 250x200x200	20,1%	19,5%	**-3,1%**
> 250x200x200 and < 350x250x250	31,1%	30,8%	**-0,9%**
> 350x250x250 and < 500x350x350	19,0%	16,0%	**-15,9%**
> 500x350x350	4,8%	4,7%	**-3,3%**

	2016	2019	Variation
What is batch size of the AM manufactured parts in your company?			
< 15	51,7%	45,8%	**-11,3%**
15-50	15,1%	18,5%	**23,0%**
> 50	33,3%	35,6%	**7,2%**

	2016	2019	Variation
From you point of view, what are the main limitations for AM developement?			
Lead time	13,7%	12,3%	**-9,7%**
Part size	17,2%	14,5%	**-15,3%**
Manufacturing capacity	26,3%	27,5%	**4,5%**
Superficial finishing	42,8%	45,6%	**6,5%**

250 have decreased). Besides this, superficial finishing and the post-processing works remain nowadays the main limitations from a technical point of view.

- At the present moment, AM is far from dominating the manufacturing activities of the industrial business. But nevertheless, some important and interesting information about its development for the future has been obtained from the survey, and this might be useful for involved companies that are in the process of crafting their strategy for this area.
- An especially important aspect to highlight among all those that have been obtained from the present work is the fact that, in Spain, industrial and automotive areas seem to be the ones that are growing more in AM, while AM's role in defense seems to be decreasing.

Statement on Compliance with Ethical Standards The Committee of Ethics in Research of Universidad Carlos III de Madrid has considered the circumstances of the article "Additive Manufacturing Disruption in Manufacturing Sector—Spanish Evolution in the Last Triennium". In view of the documentation submitted, the Committee has agreed to report favorably on the article as both the scientific paper and its preparatory research activity meet the needed ethical and data protection requirements (ref. CEI20_002_ISASI_Luis). The authors also declare that they do not have any conflict of interest.

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Operations Research

Optimization of Water Supply Network Design Based on a Tabu Search Algorithm

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Abstract The optimal design of a water supply system is essential to minimize costs as well as to maximize the sustainability of the infrastructure. Moreover, most future problems related to its operation and possible extensions can be significantly reduced at the design stage. The network performance is subject to laws of flow balance and energy conservation, which represent non-linear constraints. Furthermore, the pipe diameters, which have to be chosen from a commercial catalog, are discrete variables. Consequently, it is a non-linear mixed-integer problem whose resolution is not trivial. For this type of problem, metaheuristics are suitable resolution methods because of their abilities to explore the search space in order to find an optimal solution. In this study, a tabu search algorithm is used to design the well-known Alperovits and Shamir's network. Although the global optimum is not reached, the efficacy of the proposed method is fully demonstrated. The results are similar to those achieved by other metaheuristics and the resolution times are considerably shorter. Therefore, it is expected to obtain better results in future studies in which larger networks are designed.

Keywords Water supply network design · Tabu search · Metaheuristics · Optimization

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1 Introduction

A water supply network is an infrastructure responsible for bringing drinking water to consumers. Currently, the population is growing, specifically in urban areas. This causes new challenges regarding the construction and enlargement of this utility. The design and building of extensions of such water supply networks is a hard and expensive task. Therefore, efficient planning may result in substantial cost reduction.

The optimal design of a water supply network is a problem in which the demand of a set of consumer points must be covered with specific conditions of pressure and flow. Generally, network characteristics are previously established as well as consumers' geographical locations and the connections between them, representing the future pipes' settlement. Moreover, the demand of each consumer area is usually estimated using the population growing estimation and the *per capita* consumption. Consequently, the problem is the election of the pipes' diameters, which have to be chosen among a commercially available set, while technical and demand requirements are fulfilled.

2 State of the Art

As previously stated, the intrinsic characteristics of hydraulic systems and the discrete nature of some of their variables make this problem a non-linear mixed-integer problem. One of the first attempts to solve it was by implementing a method named linear programming gradient (LPG) which decomposes the original problem into two subproblems, one linear and another one non-linear [1, 2]. It is an iterative process in which the flows are fixed and then, the pipes are divided into various segments with different diameters. The main problem of this methodology is that some segments take a diameter in more than 95% of their lengths and a different one to the rest, which is unrealistic. The other approach is to use linear programming taking the diameters as continuous variables. Once the problem is solved, they are transformed into similar commercial diameters [3]. However, these transformations could suppose the loss of the optimum.

To face this challenge, metaheuristics emerged as methods capable of treating diameters as discrete variables and working with non-linear constraints. For this reason, they can solve this non-linear mixed-integer problem more realistically. Metaheuristics are iterative processes that explore the search space to find the global optimum. Although it is not always found, satisfactory solutions are usually achieved in a short time. These methods try to emulate phenomena as behaviors of humans or animals or other natural processes. They can be classified according to their basis. Some of them are based on populations, as the genetic algorithm (GA), the particular swam optimisation (PSO), or the memetic algorithm (MA). While others are based on solutions and their trajectories, as the simulated annealing (SA) or the tabu search (TS).

Recently, several authors have applied metaheuristics to plan the design of water supply networks. For instance, SA and GA are used to solve the problem achieving significant improvement in the quality of the solution and the resolution time [4]. PSO was chosen to address the problem using a model whose objective function included penalty costs [5]. Meirelles et al. [6] have recently used the same algorithm but adding to the general objective of minimizing total costs, the benefits of energy production that would involve the installation of recuperators in the network. This makes sense when the study network is located in an area with large slopes.

Another option is to solve a model which includes penalization costs for reliability. The solutions reached by these models are, in general, branched networks that are a bit more expensive but much more reliable. GA [7] and a metaheuristic based on the behavior of ant colonies [8] have been used to assess the aforementioned model.

To the best of the authors' knowledge, the resolution of this problem using tabu search has been treated in the scientific literature only by Cunha and Ribeiro [9]. In our study, new criteria, as the use of different initial solutions or the neighborhood generation process, are applied to improve the previously achieved results.

3 Mathematical Model

Water distribution network design models seek to minimize the network deployment costs. A common strategy is to add penalty terms in the objective function or constraints for non-compliance with certain network requirements as pressure drop, water velocity, or reliability.

In this study, the traditional model, which does not include any penalty terms, is chosen and some requirements are included as constraints. The sets, the data, and the variables are defined in Tables 1, 2, and 3. The pipes are represented by arcs and the consumer points by nodes.

The complete model is detailed below.

$$\text{Min Total costs} = f(\emptyset_{1k}, \emptyset_{2k}, \ldots, \emptyset_{Ak}) = \sum_{j \in A} C\left(\emptyset_{jk}\right) \cdot L_j \quad (1)$$

Table 1 Sets of the model

Set	Definition
N	Nodes set (both consumers and source node)
I_i	Set of input arcs homing node i. $\forall i = 1, \ldots, N$
O_i	Set of output arcs leaving node i. $\forall i = 1, \ldots, N$
A	Set of all arcs as the union of the two previous sets
M	Set of loops
K	Available set of commercial diameters

Table 2 Data of the model

Data	Definition
d_i	Nodes set (both consumers and source node)
E_i	Set of input arcs homing node i. $\forall i = 1, \ldots, N$
L_j	Set of output arcs leaving node i. $\forall i = 1, \ldots, N$
$C(\emptyset_{jk})$	Set of all arcs as the union of the two previous sets
$h_i{}^{\min}$	Available set of commercial diameters

Table 3 Variables of the model

Variable	Definition
$\emptyset_{jk}$	Diameter $k \in K$ assigned to arc j chosen among the set of commercial diameters. $\forall j = 1, \ldots, A,$
q_j	Flow in the arc $\forall j = 1, \ldots, A,$
hi	Pressure in node $\forall i = 1, \ldots, N$
H_{jk}	Pressure drop in the arc $\forall j = 1, \ldots, A$

$$\sum_{\forall j \in I_i} q_j - \sum_{\forall j \in O_i} q_j = d_i \forall i = 1 \ldots N \tag{2}$$

$$\sum_{\forall j \in M} H_{jk} = 0 \forall m = 1 \ldots M \tag{3}$$

$$h_i = h_{i-1} - H_{jk} \forall i = 2 \ldots N,\ j \in I_i \tag{4}$$

$$h_i \geq h_i^{\min} \forall i = 2 \ldots N \tag{5}$$

$$\emptyset_{jk} \in K;\ q_j \in R;\ h_i \in R \tag{6}$$

The final objective of the model is to find the optimal diameters of each network pipe that minimizes the total costs (1) while satisfying a series of technical limitations [5]. Furthermore, the diameters, which are the main variables, are discrete because they have to be chosen from a set of commercial ones. The network performance is subject to laws of flow balance (2) and energy conservation (3). The pressure of each node is calculated by the pressure of a linked node less the pressure drop in the arc which connects both nodes (4). Moreover, they all must be equal or higher than a minimum operating pressure, $h_i^{\min}$ (5). The pressure drops are calculated using the Hazen–Williams Eq. (7) where C is the roughness coefficient depending on the pipe material, α is a parameter which depends on the measurement units, and p and γ are empirical constants whose values are 1.852 and 4.87, respectively. It must be noted that the Hazen–Williams equation is utilized once the diameter has been assigned to the arc j, connecting this variable to the technical pressure equations.

$$H_{jk} = \alpha \cdot \frac{L_j \cdot q_j^p}{C^p \cdot \text{Ø}_{jk}^{\gamma}} \tag{7}$$

Finally, the nature of variables is established in Eq. (6), with R being the set of real numbers.

4 Tabu Search Algorithm

Tabu search (TS) is a metaheuristic firstly introduced by Glover in 1986 [10]. The main characteristic that differences it from other metaheuristics is the use of short-term memory. The search space is created by possible changes or movements of the current solution. When a new solution is achieved, the movement that caused it takes the attribute “tabu”, being a prohibited movement during a certain number of iterations. This process tries to avoid solutions being trapped in local optima, which is one of the major challenges of metaheuristics, by allowing the temporary worsening of the solutions.

The algorithm works with solutions in the form of lists. Each element represents the diameter assigned to each arc. The neighborhood structure is built through the decrease of one diameter unit to the next one in the commercial catalog. It also includes short-term memory and an aspiration criterion which allows attaining a new solution despite taking a tabu movement if this new solution improves the best attained solution. The problm studied in this work requires two different evaluation functions. The first one performs the hydraulic simulation of the network. If a solution is hydraulically non-valid, it is rejected and saved in a list in order to avoid checking the same solution more than once. Additionally, a mechanism that generates new solutions when a neighborhood is full of non-valid solutions is included.

The second function evaluates the total cost of the hydraulically valid solutions. The whole process is summarized in Fig. 1, and the number of iterations of the process is previously set to a maximum.

5 Case Study: Alperovits and Shamir’s Network

The designed methodology has been tested in Alperovits and Shamir’s [1] network. It has been considered as a relevant case study to analyze the optimal water network design from the beginning to nowadays. This network consists of 2 loops, 7 nodes, and 8 arcs (see Fig. 2). The water is supplied by a single source node and the circulation is entirely done by gravity, which means no impulsion is required. Figure 2 also shows the data which define the network. Elevation (E_i) is in metres and demand (d_i) in

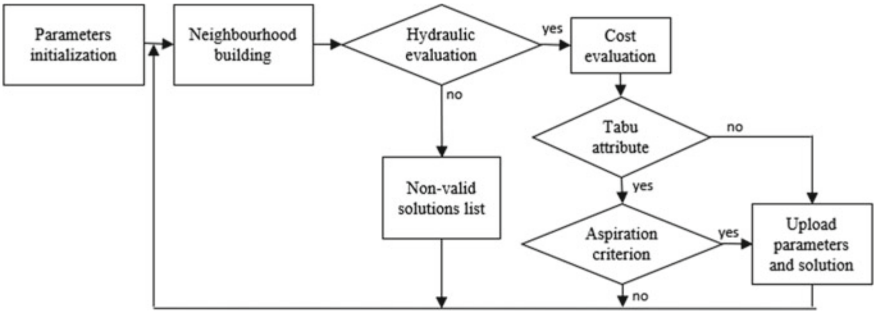

Fig. 1 Designed tabu search algorithm

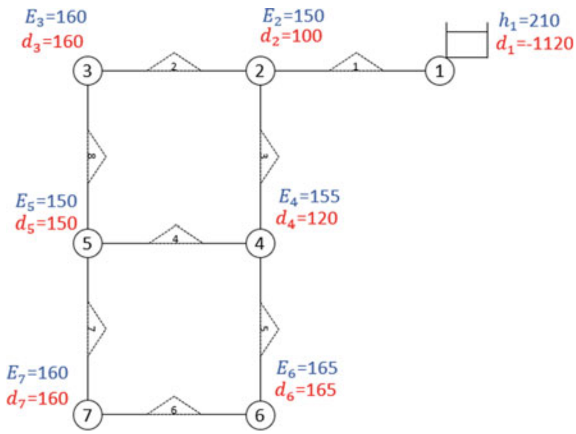

Fig. 2 Layout and data of the water supply network

m^3/s. The elevation of the source node corresponds to its pressure (*h1*). Finally, the length of every arc is 1,000 m.

In addition, 14 diameters are available, each one with a specific unit cost (see Table 4). The acronyms m.u. represents monetary units which are arbitrarily created. Measurement units of pipe length are in inches, as in the original paper, and its corresponding value in SI units, metres.

Table 4 Catalog of diameters and their unit costs

Diameters	in	1	2	3	4	6	8	10
	m	0.0254	0.0508	0.0762	0.1016	0.1524	0.2032	0.254
Unit costs (m.u.)		2	5	8	11	16	23	32
Diameters	in	12	14	16	18	20	22	24
	m	0.3048	0.3556	0.4064	0.4572	0.508	0.5588	0.6096
Unit costs (m.u.)		50	60	90	130	170	300	550

The number of arcs together with the number of available diameters generates a search space composed of 14^8 = 1,475,789,056 $14^8 = 1,475,789,056$ possible solutions. The minimum operating pressure in every node has been fixed to 30 m, and it is a constraint of the model.

6 Results

Python is the software used to develop the algorithm and test its results. In order to simulate the network and to analyze if the hydraulic requirements are reached, the WNTR library [11] was employed. This Python package allows defining water networks as well as simulating their performance. The non-linear problem is internally solved by the Newton–Rapson method. The use of this library has made it possible to explore different solutions iteratively in a short time.

The algorithm has been implemented from two different initial solutions. Solution A is the worst possible solution whose cost is 4,400,000 m.u. and all pipes have the biggest available diameter. This is an unacceptable solution because the pressure in the nodes would be insufficient. Solution B is a hydraulically valid solution with a cost of 498,000 m.u.

Once the algorithm is calibrated (the initial solution, the tabu size, and the stop criterion), multiple simulations are made, reaching, in most cases, a solution whose cost is 420,000 m.u. The characteristics of this best attained solution are presented in Table 5. The pressure requirement is achieved in all nodes, except in node 1 that is the source node, a reservoir (and it is not required). Moreover, it can be noted that two arcs have almost no flow.

The use of metaheuristics has made discrete solutions to prevail over continuous ones. Table 6 shows several results attained by different authors and the solution type. The solution obtained in this study does not improve GA results but resolution times and procedure complexity are considerably reduced. It is expecting that this approach will attain better results for bigger networks.

Table 5 The best attained solution

Arc	1	2	3	4	5	6	7	8
Diameter (in)	20	10	16	1	14	10	10	1
Flow (m^3/s)	0.311	0.102	0.181	0.000	0.147	0.056	0.075	0.000
Node	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
Pressure (m)	0.00	55.96	30.87	46.56	32.48	30.80	30.90	

Table 6 Solutions of Alperovits and Shamir's network found by other authors

Method	Authors	Minimum cost	Sol. type
PL	Alperovits and Shamir [1]	479,525	Split-pipe
PL	Kessler and Shamir [2]	418,000	Split-pipe
GA	Savic and Wlaters [12]	419,000	Discrete
SA	Cunha and Sousa [4]	419,000	Discrete
GA	Matías [7]	419,000	Discrete
TS	Cunha and Ribeiro [9]	420,000	Discrete
PSA	Suribabu and Neelakantan [5]	419,000	Discrete
MA	Baños et al. [13]	419,000	Discrete

7 Conclusions

The purpose of this study was the design, development, and validation of a tabu search algorithm to solve the water distribution network design problem. The optimization of this design is sought by adding new criteria to the metaheuristic. Obtained results are clearly in line (error equal to 0.2%) to the ones attained by other authors for Alperovits and Shamir's network. Furthermore, using the designed tabu search together with the WNTR library, the problem is solved in a very short time. Hence, this library has fully demonstrated to be a really useful tool to solve the non-linear mixed-integer problem iteratively. This has allowed testing different configurations and conditions of the hydraulic system.

Future work may include the resolution of larger and more realistic networks using this tool in order to demonstrate the good performance of the designed methodology in these cases.

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Review of Symmetry-Breaking Options on Mathematical Programming Models with Rolling Horizons Procedure

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Abstract The rolling horizons procedure is widely used both in industry and in scientific research for the resolution of mathematical programming models. It allows reducing the size of the models to be solved in the times allowed with the available computational capacities. It takes into consideration the closest information with less uncertainty. But programming models can have symmetries, when they have variables that can be **permuted** without changing the structure of the problem. These symmetries increase the search spaces for possible solutions, increasing the need for computation and presenting alternative solutions with equivalent results in the objective function. The symmetry can generate different solutions with equivalent values in the objective function but that can imply very different results in the long term with the rolling horizons procedure. This paper presents the proposed actions to symmetry break that have been applied to the rolling horizons procedure. The work provides the different proposals identified to break the symmetry.

Keywords Supply chain management · Rolling horizons · Symmetry · Mixed integer linear programming

1 Introduction

The rolling horizons procedure is a frequent tool in industry and academic environments [7, 35]. Practical application is identified in inventory management, production planning, scheduling/sequencing, plant location, machine replacement, cash management, capacity expansion and wheat trading/storage [5]. Its use can support decisions in uncertain environments and transform the resolution of a long-horizon problem into a sequential resolution of short-horizon problems [9, 17, 26, 30, 31, 39]. But it is a heuristic method, where it should be said that the best planning operations proposals that are obtained on each rolling horizon are not necessarily the same

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planning operations proposals that would be found in the solution of the entire time horizon [4].

The rolling horizons are a representation of the industrial reality [7]. Companies make decisions about the operations planning from forecasts and orders, their ongoing situation, and the available capacity [16]. The information is usually updated in the following periods along with the results of the planned planning. The new information available may have variations within the expected ranges (stochastic tools, fuzzy, sensitivity analysis can be used to simulate it), or totally unexpected (require contingency plans for accidents or catastrophes) or higher than forecast ranges but expected (reactive plan in real time together with preventive actions could be used). This new information allows updating the planning for the following periods, by modifying the previous plan or launching a new planning recalculation [24]. The companies recalculate their planning according to information updates, although they try not to make changes in the near periods, in order to reduce the nervousness or planning instability and costs [32]. The competitiveness of the company lies in the balance between its operating costs and its ability to react to changes.

These problems frequently have symmetries in their mathematical programming models. Alternative solutions can be generated with similar results in the objective function. Variables that can be exchanged without changing the structure of the problem [1]. These symmetries slow down the search algorithms of the best solution to the objective function that complies with the modeling constraints. The symmetries increase the options that the branch and bound algorithms must solve [33]. The symmetry in a problem increases the search space size for the algorithms. Equivalent solutions can be exchanged [3], where different solutions are proposed for the same objective value [38]. This may make it more difficult to demonstrate the optimality of the problem solutions and, therefore, increase the computation time [25]. Jans [13] showed that eliminating the formulation symmetry can be useful to accelerate computational times. It reduces the amount of search needed to solve the problem [10]. Margot [18] comments that breaking symmetry can turn a computationally intractable problem into one that is easily solved.

In the procedure of rolling horizons in mathematical programming models, symmetry can become especially relevant. The different solutions within the allowed tolerance or calculation time can imply large differences in the following planning horizons. The proposed solutions for the model can vary significantly from one computer equipment to another.

To the best of our knowledge, we have not found a review of the literature on the treatment of symmetry when using the rolling horizons procedure. Therefore, a systematic review of the literature on measures to avoid symmetry in models with the rolling horizons procedure is proposed.

The rest of the paper is structured as follows: first, a short description of the review methodology is introduced; second, a brief discussion of the results is presented; finally, the paper ends with the conclusion and future works.

2 Review Methodology

The review has been carried out following the systematic literature review protocol presented and used by Marín et al. [19] and Rius-Sorolla et al. [28, 29].

The steps proposed are as follows: set the goal, select type of reference and database, search filter and manage reference, extract information of selected reference, and write the report.

Therefore, it uses a transparent procedure, to find, evaluate, and synthesize the results of relevant research. The procedures are explicitly defined in advance to ensure that the exercise is transparent and can be replicated.

Our goal is to identify actions to avoid symmetry in the application of the rolling horizons procedure.

The search was carried out on selecting the references that contain the terms "symmetry" and "rolling horizon" in the database of *Scopus* and *Web Of Science* (WoS) with access from Universitat Politècnica of València. The extracted works have been those that deal with both concepts. A snowball strategy has also been applied to the first identified references in order to include other related jobs. In Table 1, the publication of the reviewed references can be identified.

3 Results

According to Margot [18], the main approaches to deal with symmetries in integer linear programming are symmetry breaking inequalities, perturbation, fixing variables, and pruning of the enumeration tree. It also can be reformulated the problem so that it has a reduced amount of symmetry, or even none at all [10].

The actions identified to break the symmetry are:

- Add new restrictions to order equivalent elements [12, 14, 22, 25]. If a product can be done on several machines, it is established that it should be done in the first machine. Lexicographic perturbation Eq. (1),

$$x_i \leq x_{i+1} \, \forall i \tag{1}$$

- Sort the machines according to some natural logic, such as varying the setup costs per machine, or decreasing the total costs per machine or decreasing resources capacity, or with a weighting factor in the objective function increasing parameter values with product index [8, 13].
- Set new restrictions that avoid those undesired solutions, without eliminating feasible solutions [6]. One way is by setting variables to reduce the feasible solution space [21, 34, 36, 37]. A binary variable is fixed on some periods, as can be seen in Eq. (2).

$$\delta_t = 1, \, \forall t \geq t_s \tag{2}$$

Table 1 Publication of the selected references

Publication	References
International Journal of Production Research	4
Computers and Operations Research	3
Informs Journal on Computing	2
International Journal of Production Economics	2
Transportation Science	2
Annals of Operations Research	1
Computers and Chemical Engineering	1
Computers and Industrial Engineering	1
European Journal of Operational Research	1
Expert Systems with Applications	1
International Journal of Electrical Power & Energy Systems	1
International Journal of Healthcare Technology and Management	1
International Journal of Innovative Computing, Information and Control	1
International Journal of Sustainable Engineering	1
Journal of Marine Science and Engineering	1
Journal of Rail Transport Planning & Management	1
Lecture notes	1
Management and Production Engineering Review	1
Mathematical Problems in Engineering	1
Modern Physics Letters B	1
Nuclear Physics B—Proceedings Supplements	1
Operations Research	1
Transportation Research Part C: Emerging Technologies	1
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- Give continuity with the previous period, like if the oven was working in the previous period, the setup is eliminated [23], as can be seen in Eq. (3).

$$Z_{yt} \leq Z_{y(t-1)} \; \forall y, t > 1 \tag{3}$$

The actions identified in the systematic literature review attempt to break the symmetries produced by equivalent demands in different products [3], by the existence of equivalent resources in the models, such as parallel machines [2, 8, 11, 13] or a combination of both [38] or routes with equal costs [15].

4 Conclusion and Future Work

This work presents the results of a systematic literature review on actions to break the symmetry in models that apply the rolling horizons procedure.

It highlights the importance of breaking symmetry in order to avoid unwanted solutions or speed up the resolution process. The identified symmetries focus on demands related to equivalent products and operations that can be performed on equivalent resources. The identified symmetries relate to product, resources, operations and time indexes in the mathematical programming models [27].

The actions identified to break the symmetry have been grouped into four categories. And they are those that give a lexicographic order, varying the parameters of the model to establish a differentiation and setting variables in certain conditions to eliminate undesired solutions and restriction between periods to give an order.

Future research should be done to extend the symmetry breaking action to another index as the time relative index of the rolling horizons procedure. In addition, a specific pruning option could be developed for the rolling horizons procedure.

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Local Search and Initialization in the Firefly Algorithm: Performance Analysis in Solving the Flexible Job-Shop Scheduling Problem

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Abstract Hybrid metaheuristics are becoming a widely used alternative to solve some combinatorial optimization problems such as the Flexible Job-shop Scheduling Problem (FJSP). The inherent complexity of this type of problem requires methods that can find near optimal solutions in a reasonable computational time, since exact methods may be impractical in the real industry because of their exhaustive nature. Here is where metaheuristics, which have been proved to be very time-efficient in providing *quality* solutions, play a key role. Nevertheless, they also present some shortcomings like premature convergence and local optima stagnation. Hybrid versions are commonly used to avoid these issues and increase its search capability. In this paper, we conduct a comparative study of the performance of the Firefly Algorithm and two variants, one improved with an initialization phase and another that integrates both this initialization and multiple local search structures, in solving state-of-the-art FJSP instances. The study demonstrates how local search and initialization can notably enhance the performance of the algorithm.

Keywords Firefly algorithm · Local search · Initialization

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1 Introduction

Combinatorial optimization problems have been the focus of many scientific research because of their complexity and practical importance in a wide variety of fields, and different algorithms have been developed for their resolution. These algorithms can be classified as complete and approximate algorithms [1], the former being algorithms that ensure to find the optimal solutions.

Nevertheless, when the problem is NP-hard [2], complete algorithms require an impractical amount of time, and thus approximate algorithms (i.e. metaheuristics) are the alternative commonly used in the real world. Approximate algorithms cannot guarantee to find the optimal solution but they notably reduce the amount of time required to provide good solutions [1].

The Job-shop Scheduling Problem (JSP) is "not only NP-hard, but it also has the well-earned reputation of being one of the most computationally stubborn combinatorial problems (…)" [3], and hence it is a problem that elicits interest in areas like planning and managing of manufacturing processes or operations research. In the JSP, there is a set of jobs that has to be performed and each job consists in a set of operations that must be processed in exactly one machine and the operations are subjected to precedence constraints. The goal of the JSP is to find a sequence of the operations that optimizes certain criteria, e.g. minimize the completion time, minimize the total machines' workload, etc.

The Flexible Job-shop Scheduling Problem (FJSP) is an extension of the JSP in which, in addition to the sequencing, a further decision level is required, the assignment: the operations that make up each job can be processed by any machine from a given set of compatible machines, and thus it is required to assign each operation to one machine. This fact makes the FJSP even more complex than the JSP.

Many approaches have been proposed for the resolution of the FJSP, especially (meta)heuristics algorithms. To name a few within the most relevant ones, Brandimarte [4] described a hierarchical approach for the FJSP, solving separately the sequencing and the assignment problems, both tackled by a tabu search (TS) algorithm. TS was also used by Mastrolilli and Gambardella [5] where, additionally, two neighborhood functions are introduced. Kacem et al. [6] presented a hybrid approach combining evolutionary algorithms and fuzzy logic for solving the FJSP with multiple objectives. In Pezzella et al. [7], a genetic algorithm (GA) with different strategies for initializing the population and for the selection and reproduction of the individuals is presented. Regarding constructive metaheuristics, particle swarm optimization and ant colony optimization has also been applied for this problem (see [8, 9], respectively).

In this paper, we present a comparative study of the performance of different versions of the firefly algorithm (FA) in optimizing the total completion time (makespan) in the FJSP. With this purpose, we have developed a standard discrete version of the FA, another version in which some strategies to generate the initial population are used, and one hybrid version in which, together with this initialization, multiple local search procedures are integrated to increase the performance of the algorithm. These three versions have been tested with multiple state-of-the-art FJSP instances, providing a detailed analysis of the results.

The rest of the paper is organized as follows. In Sect. 2, a general description of the FJSP is provided. In Sect. 3, we describe the discrete version of the FA, the initialization procedure, and the local search strategies. The computational results of the tests and the comparative analysis are summarized in Sect. 4. Finally, Sect. 5 closes the paper with the conclusions obtained in the study.

2 Problem Definition

In the FJSP, there are n jobs, consisting each job J_i $(1 \leq i \leq n)$ in a sequence of n_i operations and m machines. An operation O_{ij} ($i = 1,2, \ldots, n$; $j = 1,2, \ldots, n_i$) needs to be performed on one machine m_{ij} from the set of available machines M_{ij}. Each machine $k \in M_{ij}$ requires a certain processing time (P_{ijk}) to perform an operation O_{ij}.

Some assumptions are made: an operation cannot be interrupted (a_1); there are precedence constraints defined for any pair of operations within a job (a_2); machines are independent of each other (a_3); there are no precedence relations between jobs (a_4); transport and set-up times are already considered in P_{ijk} (a_5); and each machine can process at most one operation at any time (a_6).

The mathematical model could be given as follows:

$$\min f = \max_{1 \leq k \leq m} (C_k) \tag{1}$$

subject to

$$C_{ij} - C_{i(j-1)} \geq P_{ijk} X_{ijk},\ j = 2, \ldots, n_i; \forall i, j \tag{2}$$

$$[(C_{hg} - C_{ij} - P_{hgk}) X_{ghk} X_{ijk} \geq 0] \vee [(C_{ij} - C_{hg} - P_{ijk}) X_{hgk} X_{ijk} \geq 0], \forall i, j, h, g, k \tag{3}$$

$$\sum_{k \in M_{ij}} X_{ijk} = 1, \forall i, j \tag{4}$$

$$X_{ijk} \in \{0, 1\}, \forall i, j, k \tag{5}$$

Equation (1) ensures the minimization of the objective, the *makespan* (i.e. the maximal completion time of all the jobs). Constraint a_2 is ensured by Inequality (2) and constraint a_6 by Inequality (3). Equation (4) indicates that, for each operation, only one machine can be selected. Equation (5) is the binary decision variable (“1” if operation O_{ij} is assigned to machine k, “0” otherwise).

3 Firefly Algorithm

The firefly algorithm (FA) is a swarm intelligence algorithm inspired by the social behavior of the fireflies. The fireflies use their flashing lights to attract others with predation or mating purposes. It was originally developed for solving continuous optimization problems by Yang [10].

The main aspect of the FA is the association of the fireflies' light intensity with the objective function of the optimization problem. It is assumed that the firefly brightness (I) determines its attractiveness (β), both being in turn linked with the encoded objective function [11], the makespan in this study. If the aim is to minimize an objective, the objective function value of a firefly at a position x can be inversely associated with its brightness $I(x) \propto 1/f(x)$.

Fireflies are initially spread over the search space and each position stands for a solution to the optimization problem. At each iteration of the algorithm, the fireflies will move toward the brighter ones (i.e. for minimization problems, solutions with lower objective function value) within a certain region of the search space, depending on their distance and visibility. The fireflies' movement driven by its brightness, plus a random movement component, allows efficiently exploring the search space. A more detailed explanation of the original FA can be found in [10, 12].

This section is focused on the discrete version of the FA, which is required for the FJSP. The main aspects of the FA that need to be adapted are the representation of the solutions, the calculation of the distance, and how the movement is performed. The discrete approach presented in this paper is based on [11].

Solution Representation and Decoding. Each solution of the problem is obtained from two different vectors, one for each FJSP subproblem. The Sequencing Vector (SV) indicates the sequence of the operations and each job number J_i appears n_i times. The Assignment Vector (AV) denotes the machine assigned to each operation, an item AV[i] being a machine index. Both vectors have a length equal to the total number of operations, $\sum_{i=1}^{n} n_i$. Figure 1 shows the decoding of a solution from its AV and SV.

First, SV gives the sequence of the operations. The jth operation of J_i (O_{ij}) corresponds to the jth time a job index J_i appears. Then the machines m_{ij} assigned for each operation O_{ij} are obtained from the AV. The combination of these two vectors provides the final solution of a firefly: $\{(O_{11}, M_1), (O_{12}, M_1), (O_{31}, M_3), (O_{21}, M_1), (O_{32}, M_2), (O_{33}, M_3), (O_{13}, M_4), (O_{22}, M_2), (O_{23}, M_3), (O_{24}, M_1)\}$.

Measurement of the Distance Between Two Fireflies. The distance between the SVs of two fireflies can be carried out as the minimum number of swaps required

AV	1	1	4	1	2	3	1	3	2	3
	O_{11}	O_{12}	O_{13}	O_{21}	O_{22}	O_{23}	O_{24}	O_{31}	O_{32}	O_{33}

SV	1	1	3	2	3	3	1	2	2	2
	O_{11}	O_{12}	O_{31}	O_{21}	O_{32}	O_{33}	O_{13}	O_{22}	O_{23}	O_{24}

Solution:

(O_{11},M_1) (O_{12},M_1) (O_{31},M_3) (O_{21},M_1) (O_{32},M_2) (O_{33},M_3) (O_{13},M_4) (O_{22},M_2) (O_{23},M_3) (O_{24},M_1)

Fig. 1 Solution representation and decoding

Table 1 Distances and movement

P	AV = [2 4 3 1 3 1 4 4 1 2]	SV = [1 2 2 3 1 2 1 3 3 2]
P_{best}	AV = [2 1 3 4 1 1 4 4 1 2]	SV = [1 3 2 2 1 2 1 2 3 3]
d_{av} and d_{sv}	{(2,1), (4,4), (5,1)}	{(2,4), (8,10)
$\lvert d_{av} \rvert$ and $\lvert d_{sv} \rvert$	3	2
$\beta(r)$	0.53	0.71
rand ∈ [0,1]	{0.34, 0.17, 0.76}	{0.09, 0.82}
Mov. β-step	{(2,1), (4,4)}	{(2,4)}
Position after β-step	2 1 3 4 3 1 4 4 1 2	1 3 2 2 1 2 1 3 3 2
Position after α-step	2 1 3 4 3 1 4 4 2 1	1 3 2 2 1 1 2 3 3 2

to bring one SV closer to the most attractive one ($|d_{sv}|$). For AV components, the distance is the number of non-corresponding items in the sequence, known as the Hamming distance ($|d_{av}|$). Table 1 shows how both distances between the AVs and the SVs of two fireflies (P and P_{best}) are calculated.

Fireflies' Movement. The movement of the original FA is divided into two not interchangeable steps: First, the β-step and then the α-step. The β-step is an insertion and pair-wise exchange mechanism used to bring the AV and SV of a firefly closer to the global best firefly. The β-step consist in the following sub-steps: all necessary pair-wise exchanges in SV and insertions in AV are found and stored in d_{sv} and d_{av}, respectively; the distances $|d_{sv}|$ and $|d_{av}|$ are stored in *R*; the probability $\beta(r) = \beta_o/(1 + \gamma r^2)$ is computed; a random number rand ∈ [0,1] is generated for each element of d_{av} and d_{sv}; and then the corresponding insertion/pair-wise exchange is performed if $Rand \leq \beta$. The α-step is a swapping mechanism in which two non-equal element positions are chosen at random and swapped. Table 1 shows how the different steps of a firefly movement are performed, with $\beta_o = 1$, $\gamma = 0.1$, and $\alpha = 1$.

3.1 Initialization Module

In order to study how the initial population can impact the performance of the FA, we have implemented an initialization module. This module aims to initially locate the fireflies in promising areas of the search space instead of doing it randomly. The initialization rules explained below are the same used in the GA of Pezzella [8] who, in turn, follow the *approach by location* of Kacem et al. [13].

For AVs, two different rules are used: Ar_1 and Ar_2, both considering the processing times and the machines' workload. Ar_1 works as follows: the minimum processing time P_{ijk} is selected, and the machine k is assigned to the operation O_{ij}. Then all the columns corresponding to machine k are updated with P_{ijk}, and the process is repeated until all the operations have been assigned to a machine. Ar_2 works similarly but, before starting, all rows (i.e. operations) and columns (i.e. machines) are randomly shuffled. Then, instead of selecting the minimum of the table, the minimum P_{ijk} of the new first row is selected, then the minimum of the second row, and so on, updating the columns as it was explained for Ar_1. The advantage of Ar_2 is that different assignments can be obtained in different runs of the algorithm.

For SVs, the well-known sequencing dispatching rules, the Most Work Remaining (MWR), and the Most number of Operations Remaining (MOR) are applied. In addition, to enhance diversity, some of the initial SVs are randomly generated.

3.2 Local Search Module

To enhance the search performance of the FA and to avoid common problems of the metaheuristics such as premature convergence or local optima stagnation, we have introduced several local search procedures into the algorithm. These local search (LS) strategies are based on the neighborhood structures used in the variable neighborhood search (VNS) algorithm presented in [14].

LS Strategy 1. Two element positions of the SV are selected at random and swapped, ensuring that no precedence constraint is violated. This is repeated multiple times depending on the total time of operations.

LS Strategy 2. A random operation is selected from the AV, and a different machine of the set of available machines for that operation is assigned, randomly as well. This step is repeated depending on the total time of operations. It can be noticed that LS strategies 1 and 2 are very similar to the α-step of the discrete FA.

LS Strategy 3. Two jobs are selected at random, and the positions of all its operations are swapped maintaining the precedence relations within each job, while the machine assignments remain the same.

LS Strategy 4. One operation assigned to the machine with the maximal workload (e.g. the sum of the processing times of the operations assigned to that machine) is randomly selected, and then it is assigned to the machine with the least workload, if possible. If not, it is assigned to any random available machine.

LS Strategy 5. One random operation assigned to the machine spending the maximum time to complete its assigned operations (equal to makespan) is selected, and then it is assigned to the machine spending the minimum time, if possible. If not, it is assigned to any random available machine.

4 Results and Comparative Study

This section describes the computational study conducted to compare how differently the FA performs with the initialization and the local search. We implemented three different versions of the FA: a standard discrete FA (V_S), another version integrated with the initialization module (V_I), and one more version with both the initialization and local search modules (V_{LS}). The algorithms were implemented in Python 3 and the tests were run on an Intel Core 7 2.1 GHz PC with 8 GB RAM memory.

Table 2 shows the average results (*Cmax*-Av.), the best results (*Cmax*-Best), and the average and best relative time of 30 runs of the three FA versions (V_S, V_I, and V_{LS}) for six different FJSP instances. Nxmxn_i stands for the number of jobs (n), the numbers of machines (m), and the total number of operations (n_i). Large instances were selected for the study because it is where more differences in the performance of algorithm's versions exist. Behnke and Geiger [15] provide a detailed explanation of the instances, from where we took the best-known results (BKR). *Av.Rel* and *Best.Rel* were calculated as $(tVx-tVs)/tVs$, tVx being the time spent by version x ($x = V_I$, V_{LS}) in reaching the maximal numbers of generations allowed (Max_{Gen}), which is the termination criteria. The parameters of the FA are number of fireflies $nf = 200$,

Table 2 Comparative study

				Cmax		Time	
Instance	*n* x *m* x *ni*	BKR	Ver	Av	Best	Av.Rel	Best.Rel
Mk1	10 x 6 x 55	40	V_S	50.4	48	–	–
			V_I	47.7	46	0.007	0.118
			V_{LS}	43	42	−0.008	−0.050
Mk3	15 x 8 x 150	204	V_S	246.5	231	–	–
			V_I	243.6	237	−0.127	−0.227
			V_{LS}	219.7	**204**	−0.255	−0.264
MFJS2	5 x 7 x 15	446	V_S	474.43	456	–	–
			V_I	460.96	**446**	−0.002	0.014
			V_{LS}	453.33	**446**	−0.026	−0.017
MFJS3	6 x 7 x 18	466	V_S	549.4	507	–	–
			V_I	530.4	497	−0.003	−0.005
			V_{LS}	497	**466**	−0.030	−0.035
Kacem 2	10 x 7 x 29	11	V_S	24.9	***21***	–	–
			V_I	14	13	−0.002	−0.004
			V_{LS}	11.96	**11**	−0.012	−0.008
Kacem 3	10 x 10 x 30	7	V_S	20.6	18	–	–
			V_I	8.03	**7**	−0.006	−0.004
			V_{LS}	8	**7**	−0.009	−0.008

$Max_{Gen} = 50$, $\beta_o = 1$, $\gamma = 0.1$, and $\alpha = 1$. For the initialization module: $Ar_1 = 20\%$, $Ar_2 = 80\%$, MWR = 40%, MOR = 40%, and random = 20%.

It can be noticed how V_{LS} notably and consistently outperforms V_S and V_I (Table 2), both in average and best values, reaching the BKR for almost all the tested instances. It was expected since V_{LS} is the most complete version, using both the initialization and local search modules. Nevertheless, what catches our attention is that the time spent by V_{LS} is almost the same or lower than for V_S and V_I. As a preliminary hypothesis, we believe a possible reason is that the more different the fireflies are, the more computational time for the distance calculation and movement is required. Hence, when applying local search, many solutions are neighborhood solutions of others, and the distance between them is very low, requiring less time to compute it and perform the movement. Another explanation may be how we apply the local search to the firefly's population. To each solution from the first $nf/2$ set (better fireflies), we randomly apply one of the LS strategies. But, at each iteration, the second $nf/2$ (worse fireflies) is renewed with solutions obtained after applying one of the LS strategies to the best solution obtained so far, and thus half of the population are neighborhood solutions of the best one (more focused in the exploitation), while the other half is used for the exploration of promising areas.

5 Conclusions

It is common to look for improvements in the efficiency of metaheuristics algorithms by adding some kind of problem-specific strategies or knowledge. This allows to better explore the search space obtaining quality solutions to the optimization problem in a shorter time. In this work, the original Firefly Algorithm was enhanced with an initialization phase and some different local search procedures for solving the FJSP, aiming to analyze how these two upgrades affect its performance. With this purpose, we have explained and implemented three different versions of the FA—the original discrete version, another version with an initialization phase, and one more version with both the initialization and the local search modules—and compared them in the resolution of some middle- and large-sized state-of-the-art FJSP instances.

Computational results confirmed that the most complete version, the one that starts the search from solutions obtained from the initialization phase and that uses the different local search strategies during the search, consistently outperforms the other two versions, reaching the best known results in most of the tested cases. Future work will be focused on expanding this study to more FJSP instances and on studying further techniques to speed up the algorithm.

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Adoption of Life-Cycle-Based Methods for Improving Product-Level Circularity: An Analysis from the Perspective of Stakeholders

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Abstract In recent years, many companies have incorporated environmental management practices aimed at reducing the environmental impact of their products throughout their life cycle. Considering the adoption of this perspective necessary, many companies have adopted various tools, techniques, or methodologies at the operational level and, even at the strategic level, with the support of even the public administrations, among other actors. Nevertheless, the process is not simple and the lack of practical knowledge of previous cases makes the process difficult and costly. Consistent with this point, the objective of the research focuses on the development of an exploratory analysis of the fundamental drivers, key aspects of the process, and the most relevant results of the adoption of life-cycle-based tools and methods for environmental management of manufacturers held in the Basque Country, a leading region in Spain in terms of GDP per capita with a strong and high-tech industrial base. Results show improving a company's image in the market seems to be a fundamental motivation, but there are other internal and external drivers, such as the possibility of increasing the value of products, environmental awareness, and increase competitiveness of companies themselves. The main difficulties were the acquisition of the necessary environmental information from suppliers, the need to adopt new working tools, techniques and methods for environmental impact assessment, and rethink operational and strategic processes to include environmental aspects, and the commitment of all the personnel involved. Overall, the results of the adoption process are

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positive and companies were satisfied. Stakeholders highlighted improvements in safety, quality, and innovation of products and the company image. Nonetheless, stakeholders claim a greater environmental commitment by public administrations is necessary, though they seem to be taking steps forward.

Keywords Product design · Environmental sustainability · Life-cycle thinking · Circular economy

1 Introduction

In the last decades, the behavior of our society with respect to the environment and how we approach the environmental problem has evolved. Since the ability of the planet Earth to meet the needs and ways of life of an ever-growing population is not sustainable, our awareness of this problem has grown.

In the industry, paradigms on sustainable development have been developed, such as "industrial ecology" or "cleaner production", among others. Among the implications common to all of them, the need for therational exploitation of natural resources is highlighted, as well as a limitation of emissions at a level, at least, in line with the regeneration capacity of the Earth. To address this issue, many more or less specific and complex tools, techniques, and methods have been developed and designed to be integrated at different levels in the company, around concepts such as eco-design. Precisely, according to Papanek [1], design is the most powerful tool with which a human being shapes everything he employs and surrounds him, among other things to the environment (and, by extension, to society itself).

Design presents products as sources of environmental problems. It also implies that organizations are responsible not only for environmental damage due to their own physical activities, but also for a broader range of environmental interventions throughout the product chain. The adoption of the life-cycle perspective includes the indirect environmental impacts of an organization's activities [2]. It also implies trying to take preventive measures, in order to reduce environmental impacts in all phases of its life cycle, from obtaining materials and components for processing to its disposal, reuse, or recycling. The main challenge for companies is related to the optimizations of the interactions among product design, manufacturing processes, and other life-cycle activities [3]. The environmental factor is considered as one more requirement as other factors like cost, safety, or quality, without compromising the sustainability of the company [4].

On the other hand, eco-design projects require that all the agents involved in the project collaborate. In order to achieve the objectives, changes are needed in the way of carrying out projects, but a series of guidelines and support tools are also necessary [5].

There are several methodologies and tools developed with the aim of successfully undertaking eco-design projects and, even, the integration of eco-design at an operational and strategic level [5, 6].

Despite the wide variety of tools, techniques, and methods, mostly theoretical examples are available, without the support of the practical application by companies [7, 8].

Considering these aspects, the research work has been focused on the analysis of the adoption of environmentally sustainable design and development methods of manufacturing companies from the Basque Country, Spain, a region that hosts one of the main eco-design hubs in Europe. Likewise, the impact of the adoption process on the company's management system, operational processes, and business results has been analyzed.

2 Literature Review

Companies interested in improving the environmental performance of the product and, therefore, of their activities must integrate specific support tools for operational management and, even, at a higher level, for strategic management in a dynamic process of continuous incremental improvement of environmental performance; otherwise, they will be specific improvements of limited scope [9].

The products offered in the market are so diverse that it is not possible to establish a series of specific eco-design actions applicable to all cases. Each product is conditioned by a series of limiting factors, which depend both on its type and the designer/manufacturer and the market where it will be put up for sale. Likewise, not all products generate the same environmental impact, neither at the same stages of their life cycle, nor for the same reasons [10].

In the process of implementing eco-design, the actions to be carried out in the company can be very diverse, depending on the objectives of the company, the characteristics of its products, the resources available, the level of integration of the eco-design to be achieved, etc. [11–13] (see Table 1).

Eco-design must be integrated into the design and management processes of the company, as it is a process. Therefore, it is necessary to consider management tools, strategy tools, communication tools as well as complementary tools for the design process, such as creativity tools and decision-making support tools [3, 15–19].

For these reasons, in recent years we have witnessed the development of numerous methodologies aimed at addressing the keys to the successful integration of eco-design into a single tool [3, 17].

Most of these eco-design tools and methodologies are mostly adaptations of the traditional methods and tools used in the product development process [20].

Among them are the environmental management standards, for example, ISO/TR 14062:2002 (ISO, 2002) or IEC 62430: 2009 (ISO, 2009), based on processes of continuous improvement of ecological and economic indicators of a product, and based on the systematic integration of the environmental variable in the strategies and practices of the company from the life-cycle perspective [3, 15].

The methodologies differ in the scope, the quality of the results, and the time required to apply them, but their application is scarce [15, 19]. Even when they are

Table 1 Techniques for the integration of environmental sustainability in product development

	Level 1	Level 2	Level 3
	Strategy	Tactics	Operations
Implementation levels	• Development and establishment of the environmental strategy • Focus: corporate level • Users: Top Management	• Tactical decisions taking into account the product life cycle and interrelationships • Focus: development process • Users: Product Manager	• Practical concepts to integrate the ESD in the process of developing traditional products • Focus: development process • Users: designers
Features	• Objectives of the company toward environmental sustainability • Manageable and simple to apply	• Environmental performance taking into account the entire product life cycle • First stages of the product development process • Manageable and simple to apply	
	Top-down approach Δ↓	Bottom-up approach Δ↑	
Tools for Environmentally Sustainable Development (ESD)	(1) Environmental benchmarking (2) Environmental strategies (3) Action plans and environmental champions (4) Integration into the structure of the organization (5) Environmental education programs (6) Environmental audit (7) Environmental management systems	(1) ESD Process Statement (2) Communication systems (3) Advanced Environmental Systems (4) Life Cycle Assessment (5) Environmental accounting (6) Multicriteria evaluation criteria	(7) Concept indicators (8) Deployment of the Environmental Quality Function (E-QFD) (9) Method of environmental failures and evaluation analysis (E-FMEA) (10) Concepts-matrix: MET, EPLC… (11) Checklists (12) Creativity techniques

Source Compiled from Kara et al. [14] and Bovea and Pérez-Belis [15]

applied, most of the times they are not systematically applied in companies due to their complexity, the time required for their application, and the lack of knowledge on environmental issues [15, 18].

3 Methods

In this exploratory research, a set of in-depth interviews were developed in three successive phases with 24 professionals from different fields related to the integration of the life-cycle-based environmentally sustainable product design practices in industrial companies. The election of this qualitative methodology was due to the possibility of comparing the different perspectives of the stakeholders about the adoption of eco-design and development practices with a life-cycle approach in the industry.

Before the study, semi-structured in-depth interviews with 11 professionals following guide notes based on several case studies of the literature were carried out [5]. The aim of this pre-test was to improve the guidelines verifying the information collected in the literature and the inclusion of new elements and life-cycle-based methods on sustainable product design highlighted by these professionals.

In the second step, the professionals selected were 9 leaders of eco-design projects belonging to companies of four industrial sectors (chemical, electrical–electronic, capital goods, and furniture), 5 auditing companies, 4 consulting firms, 2 academics, 3 public institutions, and one member of an industry eco-design cluster. We tried to draw up a group taking into account several aspects highlighted by Habidi [21], for example, the degree of affectation to the consequences of the research object, the degree of subjectivity, the degree of motivation, the level of knowledge about systematizing, measuring and acting on the constant improvement of the implementation, and management of environmentally sustainable product design practices in companies and other factors, such as the cost of displacement, proximity, and organizational considerations.

In the first round of interviews, it was tried to keep a flexible guide in order to be able to integrate new points into the study. In the second round with a shorter and less flexible guide, the participants assessed these new aspects.

To measure each item, different scales were created from 1 to 7 taking into account the pre-test and the responses of the interviewed professionals. In the following section, the median and range of each item are shown.

4 Results

In general, companies seek, above all, to improve their economic results, although they also understand that it is essential to comply with environmental legislation. In the study, it is highlighted that the final product manufacturer needs to communicate the environmental qualities of its product (added value of eco-design) to obtain a green image (see Table 2). The reinforcement of the marketing strategies is cited by the managers as one of the key aspects, for the integration of environmental criteria in the strategic plans with similar valuations among small, medium, and large companies.

Table 2 Main motivations of stakeholders to support the adoption of eco-design tools and methods

Stakeholders	Motivation	M[1]	R[2]
Managers	Possibility of economic return	5,5	1
	Company image	6	0,25
Design and development dept	Possibility of increasing the added value of work	6	1,25
	Environmental awareness	5	1,5
Suppliers	Possibility of benefiting from the improvements	4	1,25
	New alternatives, new market niche	5	1,25
Dealers	Possibility of benefiting from the improvements	4	2
	Requirement of the main customers	4,5	1
Public administrations	Compliance with sustainability objectives	5	1,25
	Increase in the competitiveness of the local company	5,5	1,5
Customers	Reduction of costs in use	4	1,5
	Environmental awareness	4	1,25

[1]M: Median.[2]R: Range
Source Put together by the authors

Among the obstacles that hinder the adoption of eco-design tools and methodologies, the members of the group mention several (see Table 3). Among others are the requirement of implementing new tools and methodologies in the work routine, the external support needed, the lack of market incentives, and the added costs.

Companies also have difficulties in obtaining necessary environmental information about materials, components, and systems (see Table 4). For some of the managers, this problem represents one of the most important that companies face. However, this is not shared by suppliers.

Likewise, the belief that eco-design products increase internal costs seems to be a generalized problem. The members believe that sometimes there is a lack of

Table 3 Causes that imply the slowdown of the adoption of eco-design practices

Causes	M[1]	R[2]
Bureaucratization of internal processes	4	2
Absence of market incentives	6	2
Need to reduce costs	6	1
Thought that there will be an increase in technical, economic, and human costs	5	0
The reduction or elimination of public supports (via subsidies)	5	1

[1]M: Median.[2]R: Range
Source Put together by the authors

Table 4 The most difficult obstacles to overcome during the process of adopting eco-design methodologies and tools

Obstacle	M[1]	R[2]
Initial investment need: staff training, procedure development, certification, etc	4,5	1,25
Obtain the necessary environmental information about materials, components, and systems	5,5	1,5
Difficulty in applying a methodology for the identification and evaluation of aspects	4,5	1,5
Need to implement new tools and methodologies in the work routine	5	0,5
Need for external support to guide the adoption process	5	1
Get the commitment of all the personnel involved, from management to pawns	5	2

[1]M: Median.[2]R: Range
Source Put together by the authors

Table 5 Influence or impact in the different phases of the life cycle on the cost of eco-designed products

Phase	M[1]	R[2]
Obtaining materials and components	4,5	1,5
Design and development	4	1
Manufacturing	4	0
Distribution	3,5	1,25
Use	2,5	1,25
End of life	3	0,5

[1]M: Median.[2]R: Range
Source Put together by the authors

knowledge about the implications of eco-design. For example, they do not agree on whether operating costs increase globally. They admit a probable increase, mainly in the phase of obtaining materials, substances and components, in the phase of design and development of the product, and in the manufacturing phase, that is, in the initial phases of the life cycle of the product (see Table 5).

Asked about the most used eco-design tools among companies, the members of the group do not agree on the preponderance of any of them over the rest (see Table 6). It is possible to think that companies demand tools to be able to assess the

Table 6 Level of use of the main eco-design tools

Tools	M[1]	R[2]
Software LCA	3,5	3,25
Energy simulation software	1	0
Guidelines	2,5	3,25
Recommendations for product certification systems (eco-labels, Energy Star…)	4	3

[1]M: Median. [2]R: Range
Source Put together by the authors

Table 7 Influence of the adoption of methodologies and tools at the operational level

Aspect	M[1]	R[2]
Introduction of new technologies	6	2
Work processes	6	2
Health/Safety at work	4	2
Stock rotation	3,5	1

[1]M: Median.[2]R: Range
Source Put together by the authors

environmental behavior of a product, but none of these tools predominates over the rest.

Other elements that facilitate the adoption of methodologies and tools at an operational and even strategic level are the support of associations, clusters, or public bodies.

The improvement of motivation among personnel in the area of design and product development is another of the most outstanding aspects (see Table 7). In addition, the companies know and control better the process of product design and development. Systematically, eco-design practices seem to be a factor with a positive influence on the introduction of new technologies in the activities of companies (see Table 7).

Regarding the product (Table 8), the experts assure that the adoption of eco-design tools allows the achievement of environmental improvements in various phases of the product's life cycle and the improvement of the quality and safety of the products. For example, in the chemical sector, companies obtain more efficient and safe products for people, and also for the environment.

The systematic practice of eco-design has helped to improve the image of the company and, even, anticipate future environmental legislation (see Table 9). Nevertheless, sales of products do not grow especially, although the proportion of sales of eco-designed products does.

As can be seen in Table 10, the managers are particularly satisfied with the new life-cycle approach and the adoption of eco-design practices at the operational and strategic levels. In a way, it might be expected, since it is a process that depends on their decision and their leadership.

The public administrations are also satisfied with the adoption of eco-design practices, and they consider that it improves the competitiveness of companies and even

Table 8 Influence of the adoption of eco-design practices on the product

Aspect	M[1]	R[2]
Quality and Safety	6	1
Innovation	6	1
Cost at factor prices	5	1
Sales margin	4	1

[1]M: Median.[2]R: Range
Source Put together by the authors

Table 9 Influence of the adoption of eco-design methodologies and tools on business results

Aspect	M[1]	R[2]
Sales growth	4	0,5
Productivity	4	0,25
Economic profitability	4,5	1,25
Market share	4	1
Internationalization	5	0,5
Company image	6	0,5
Customer needs compliance	5	1,5
Environmental communication	6	2

[1]M: Median.[2]R: Range
Source Put together by the authors

Table 10 Level of Satisfaction of the main stakeholders

Stakeholders	M[1]	R[2]
Managers	6	0
Design and Development dept. Employees	6	1
Suppliers	3,5	1,75
Dealers	4	2
Public administrations	6	2
Customers	4	1

[1]M: Median.[2]R: Range
Source Put together by the authors

contribute to the environmental strategy of the territory. Then, it seems possible to talk about the contribution to sustainable development, although it has obviated the social component in that statement. On the contrary, their attitude shown seems different, according to other members of the panel. They denounce a lack of government leadership in the development, implementation, and support of initiatives that promote green markets.

5 Conclusion

This research has addressed the study of the process of adoption by industrial companies of tools, techniques, and methods to improve the environmental performance of the product from a different perspective, from the stakeholders, with the aim of exploring other aspects of the process that could be key for success.

Companies have diverse internal and external drivers. Improving the company's image in the market is the most highlighted motivation, but it is linked with the possibility of achieving environmental recognition. The possibility of increasing the value of the products and environmental awareness of the company, and increase of the competitiveness has been pointed out too.

The adoption process is not free of difficulties. Obtaining environmental data on materials, substances, or components has initially been one of the most difficult problems to overcome. Besides, the belief that eco-design practices increase the internal costs seems to be a generalized problem, but the interviewees considered that, in many cases, it is due to the lack of knowledge of the companies.

In general, they agree that, eco-design practices integrated at operational and strategic levels, contribute to improving key factors of the products or services such as quality, safety, and energy efficiency in the use phase or generation of less waste at the end of life. These improvements generate an innovative and green image of the companies. Managers seem to be satisfied with the adoption of eco-design practices, mainly due to achievements of improvements in safety, quality, and innovation of the products and the company image.

Nevertheless, to strengthen the motivation for adopting life-cycle-based eco-design methods, the implication of the public administrations is considered necessary. In this respect, the declaration of a climate emergency for a carbon-neutral Basque Country in July 2019 could be an important step.

Besides, recognition systems that, allow consumers to distinguish a product with better environmental performance from a worse one, should be promoted and current legislation should be improved and updated. Otherwise, the economic criteria will continue to be imposed on the environmental criteria.

The limitations of the study mainly are focused on the methodology used, which is eminently exploratory. As a result, the study serves to raise another series of questions that should be analyzed in depth. Among others, on methodologies aimed at facilitating the integration of eco-design practices in the daily management, the integration and internalization of life-cycle-based eco-design methods, and its influence on economic and environmental performance in companies, because they are key aspects to change in favor of a sustainable business model in companies.

Conflict of Interest The authors declare no conflict of interest.

Author Contributions All the authors contributed to the study conception and design. Naiara Uriarte-Gallastegi, Beñat Landeta-Manzano, Germán Arana-Landín, and Patxi Ruiz-de-Arbulo-López performed material preparation, data collection, and analysis. The first draft of the manuscript was written and commented on previous versions of the manuscript by all the authors. Likewise, all the authors read and approved the final manuscript.

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Statement on Compliance with Ethical Standards This manuscript has been prepared within the framework of research whose design, development, and dissemination plan of the results are in accordance with the "Regulations of the University of the Basque Country (UPV/EHU) for the Protection of Personal Data" (accessible at www.ehu.es/babestu) and in accordance with Regulation (EU) 2016/679 of the European Parliament and of the Council of April 27, 2016, on the protection of individuals with regard to the processing of personal data and the free movement of such data, as it has been certified by the Committee on Ethics in Research and Teaching of University of the Basque Country (CEID), with ref. no. TI0190.

All participants (internal and external to the UPV/EHU) and the companies, associations, or public or private bodies to which they belong were informed at the beginning of the study of the points included in article 13 of the RGPD, including the right to exercise the rights of access, rectification, suppression, opposition, portability, and limitation of processing in the UPV/EHU.

Likewise, the participants were duly informed with general information about the research project: objectives and scope of the research, duration of the project, methodology, funding organizations, security considerations and anonymity in the treatment and safeguarding of personal and company data, expected results of the study, and dissemination of results and publication policies. In this respect, research results and manuscripts prepared for dissemination contain only data processed in aggregate form, and were shared with participants on an individual basis for approval before publication. No personal data or opinions were shared at any time, or those of participating companies, associations, or public and private bodies.

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Identifying and Analyzing Operations Management Strategic Problems in Home Care

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Abstract Home care encompasses medical-related care performed by health professionals at patients' homes and non-medical care (cleaning, bed-lifting, cooking, etc.) delivered to people who cannot accomplish these actions autonomously at their own homes. The operations management literature has studied home care mainly as a variant of the well-known vehicle routing problem with time windows (VRPTW). Yet, other strategic, longer term problems related to operations management have not received as much attention. We explore the (still) limited literature on home care operations management strategic problems and give guidance for potential research.

Keywords Home care operations · Long-term problems · Strategic problems

1 Introduction

Home care is experiencing growing attention from the operations management scientific community. The main reason underlying this interest is the increase of home care patients in many countries. For instance, according to OECD [15] between 2011 and 2015, 14 European countries[1] experienced a 20% combined surge (from 4,5 to 5,4 million patients). In these countries, the most notable growths, in absolute terms, occurred in Spain (from 520,000 to 860,000 patients) and Switzerland (from 250,000

[1]Estonia, Finland, Germany, Hungary, Italy, Latvia, Luxembourg, Netherlands, Norway, Portugal, Slovak Republic, Slovenia, Spain, Sweden, and Switzerland. The rest of the European countries are not included because either the 2011 or the 2015 figure is not available.

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to 340,000 patients). Population aging, smaller families, and urbanization are behind the demand rise. Furthermore, planners devise and manage caregivers' routing and scheduling assisted by specific software, in which optimization algorithms, developed by operations management researchers, may be implemented so as to improve resource utilization. Finally, from an economic point of view, home care could be cheaper than hospitalization or nursing homes.

The operations management literature has explored home care operations mainly as a static short-term routing and scheduling optimization problem, i.e. assigning caregivers to known and certain patients' requests of service and deciding upon service starting times to optimize a given objective function (for instance, to minimize the total distance traveled). Little attention has been paid to strategic problems. This paper analyzes long-term operations management problems in home care, and points to potential research directions.

2 Strategic Operations Management Problems in Home Care

We have reviewed articles and conference papers whose goal was to find and categorize home care operations management problems [1, 5, 7, 9, 11, 12, 14, 17]. Typically, home care problems are classified according to the time horizon of the decisions to be made. This paper is specifically based on Matta et al. [12]. Their classification contains strategic problems (1–5-year time horizon), tactical problems (up to 12 months), operational problems (up to several months), and detailed operational problems (up to several days). Due to the objective of this study, we focus exclusively on strategic problems.

This section is organized as follows: every identified problem is defined and the literature on every specific topic is further examined, extending our review from problem-identifying to problem-specific articles. Finally, potential research directions are sketched.

2.1 Global Demand Forecasting

It refers to the expected annual patient care volumes. Demand is a major concern for home care organizations, due to its intrinsic uncertain nature.

Literature Review. Only one article on demand forecasting has been identified [10], which presents a deterministic model to forecast the evolution of the number of patients in home care and other care services in British Columbia. The forecasted events are: patients entering any of the care services, switching between them, or abandoning definitively the care system. The main variables are: age, health status, and income. It does not include patient location forecasting.

Future Research Directions. Not only the total number, but also the location of future patients is relevant for Home Care organizations. No paper has attempted location forecasting. We suggest two probabilistic approaches:

- Individual-based method: to calculate, for every time period, the individual probability of a person entering or exiting the home care system, based on his/her characteristics (age, income, etc.). This approach would need data and exact home location on all populations of the studied area and projections on demography and individual's characteristics. The longer the forecasting period, the higher the error (potential patients may change residence, new residents arrive, etc.). Simulations should be conducted and analyzed.
- Region-based method: the studied area would be divided into smaller regions. For every smaller region, relevant variables would be gathered (total population, age pyramid, average income, etc.). A statistical model, based on relevant variables, may compute, for every time period and region, the number of entering and exiting patients. The location would be probabilistically random within the smaller region. Data needs are lower, but also is accuracy. Simulations should be conducted and analyzed.

2.2 *Capacity Planning*

It answers the question of how many caregivers, at an aggregate level, and of which type (skills, contract type, etc.), the home care organization needs in the long run. It also includes selecting, at a general level, which services will be delivered by internal resources and which will be outsourced.

Literature Review. We have not found any paper specifically devoted to capacity planning in home care.

Future Research Directions. The capacity planning problem must consider the caregiver's fixed salary because generally a great proportion, if not 100%, of this salary is fixed. Some routing and scheduling papers take it into account (see, for instance, Yuan & Fügenschuh [18]), but their short-term nature limits the applicability for capacity planning. We suggest developing a method that jointly optimizes routing, scheduling, and capacity for long periods, taking as an input the demand forecast. The method must propose the number of caregivers, contract type, skills, working hours, and services to be outsourced. We suggest a heuristic approach, aimed at minimizing the sum of salaries, since the problem is NP-Hard.

2.3 *Facility Location*

It consists in determining the number and location of operational centers across the region which is to receive home care.

Literature Review. Du and Sun [6] propose a discrete-time model with differentiated types of services and caregivers. Its main problem variables are (i) when to open an Operational Center, (ii) in which of the possible locations, and (iii) when to start providing, if at all, each of the possible kinds of services from each Operational Center.

Future Research Directions. This problem is of low importance because in many settings, visiting tours can start and end at each caregiver's home (neither starting nor ending at any Operational Center). Facility location is a well-known topic: models from contexts other than home care can be adapted (for a review, see [13]).

2.4 *Districting*

It refers to disaggregating geographic areas to provide the service. Home care companies tend to partition large areas into smaller districts to simplify resource assignment, managing each district independently [12].

Literature Review. Districting has been widely studied to establish political optimal areas, and in other contexts, such as sales territories partitioning [2, 8], but has been barely applied to home care. Common starting hypothesis in home care districting, based on Benzarti et al. [2], Benzarti et al. [3], Blais et al. [4], and Gutierrez-Gutierrez and Vidal [8] are:

- Indivisibility of the basic units: Basic units are pre-established geographic areas which are grouped to form districts. The number of districts is a specific number m set by the problem maker.
- Respect of administrative boundaries: Districts must be formed by units from the same administrative area (for instance, the same municipality).
- Maximum total service time difference among districts: This is to be obeyed to avoid workload imbalances. Generally, the condition is expressed in deviation from the mean service time of all districts.
- Maximum number of caregiver changes: When a home care organization is pursuing a continuity-of-care policy (caregiver–patient assignments are permanent, that is, all services to a given patient are always performed by the same caregiver), districting for the first time or redistricting necessarily leads to changes of caregivers–patients assignments. Benzarti et al. [2] present a model in which the total number of those changes is upper bounded.

Problem variables represent to which district every basic unit is assigned. As for objective functions:

- Blais et al. [4] tackle the problem with a weighted multicriteria function to be minimized composed of two terms: the first is a measure of the distance between basic units, and the second a function by which a penalty is incurred whenever the workload (comprised of caregivers' travel time and service time) of a district lies outside certain arbitrary margins from the average.

- In the first model of Benzarti et al. [2], the objective is to minimize, in absolute value, the maximum difference between each district's workload and average workload; in the second model, the objective is to minimize the weighted sum of the maximum difference between each district's workload and average workload plus the maximum travel time between basic units within the same district. A third model proposes a single criteria objective function to minimize the maximum travel time between basic units of the same district.
- Gutierrez-Gutierrez and Vidal [8] is the only paper, to the best of our knowledge, aimed at providing a Pareto frontier by using several objective functions with variable weights. The first function measures the travel time between basic units within the same district, whereas the second one comprises the sum of the difference, in absolute value, between each district's workload and travel time as compared to the average.

Future Research Directions. Basic units' boundaries are always imposed before optimization. Hence, research on defining those boundaries seems promising. Likewise, the number of districts is usually imposed. Only in Gutierrez-Gutierrez and Vidal [8], the problem is solved for different numbers of districts. This practice should be generalized.

Large districts provide more possibilities to optimize routing and scheduling, despite increasing complexity. However, these economies of scale, arising from large districts, may come to an upper bound: a district might reach a size above which significant gains are no further possible. Testing this hypothesis and, if certain, calculating this "right" size for different home care settings (for instance, high and low populated areas) may be a valuable guide for home care organizations.

2.5 Fleet Selection and Sizing and Fleet Assignment

Fleet Selection and Sizing refer to define who is responsible for transportation to, from, and between visits (the organization or the staff) and to select the transportation modes (private, public transport, etc.) so as to balance cost and speed. Fleet assignment consists in assigning vehicles to staff for transportation (when vehicles are owned by the home care organization).

Literature Review. We have not found any paper specifically devoted to this problem. Some routing and scheduling papers include the option of setting, before optimization, which transportation means is used by each worker, (see, for instance, [16].

Future Research Directions. Two circumstances are important in this regard: (i) no paper treats transportation mode as a problem variable and (ii) new modes are rapidly entering the urban transportation market, either as a "Mobility as a Service" (MaaS)

Table 1 Suggested research directions on operations management strategic problems for home care

Problem	Suggested research directions
Global demand forecasting	(1) Patient location forecasting: individual-based/region-based
Capacity planning	(2) Heuristic methods that provide the number of caregivers, type of contract, skills, outsourced services, etc. Forecasting models are used as input
Facility location	(3) Apply facility location models from other contexts to home care
Districting	(4) Definition of basic units' boundaries (5) Apply solving procedures for different number of districts (6) Calculate the "right" district size
Fleet selection and sizing and fleet assignment	(7) Develop models that suggest the appropriate number and type of owned transportation means (8) Include, in routing and scheduling models, the use of MaaS as a problem variable

Source own elaboration

(Such as bicycle, scooter, motorbike, and car sharing) or as private means, such as electric bicycles and small electric scooters. These modes can provide a cheap and reliable alternative for caregivers' travels. We propose two research topics:

- Ownership of means by the home care organization. A method can suggest an appropriate number of each type and assign it to specific caregivers or specific routes.
- Even though this is not a strategic problem, let us highlight here that including, in short-term routing and scheduling methods, the possibility of using MaaS appears to be a valuable future contribution.

3 Summary

Eight potential research directions for operations management strategic decisions on home care have arisen from our analysis, which are displayed in Table 1.

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Supply Chain Management

Additive Manufacturing in the Aerospace Industry: Impact on Purchasing Process

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Abstract Additive manufacturing (AM) has become an important tool in manufacturing companies that seek to improve their competitiveness by adapting their manufacturing processes to their customer requirements. In this study, the authors seek to deepen the knowledge about the disruptive potential impact of additive manufacturing (AM) implementation in aerospace sector purchasing processes. During the study it has been analyzed the changes on the purchasing processes, activities, and cost-related issues, when aerospace companies decide to change from their traditional manufacturing models to one new manufacturing model based on AM adoption. Result analysis allow authors to infer quite several relevant changes in terms of purchasing function definitions, investments, and costs involved which could be relevant to consider before AM implementation is decided by aerospace companies.

Keywords Additive manufacturing · Aerospace industry · Aerospace purchasing

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1 Introduction

Additive manufacturing (AM) is a term used to define the process of building new products by adding successive thin layers of material [1]. In 1972, Ciraud launched the first technology that can be considered as a precursor to its modern-day counterpart [2]. Although there are drawings and diagrams of this specific process, there is no evidence that he was able to physically execute it. In the early eighties, Hideo Kodama and Alan Herbert launched the first devices that worked using a technology called "3D printing", which would subsequently be referred to a more comprehensive way as "additive manufacturing" [1, 2]. A few years later, in 1986, Charles Hull developed the "stereolithography machine", considered the first device capable of producing and making 3D parts [3]. The process also should include the proper design of an IT model based on 3D computer-aided design software (CAD) and tools for the production of the model using 3D printing technology.

The main applications of AM are: (i) "rapid prototyping", perhaps the most mature application [4]; (ii) "small batch production", applicable in situations where a single unit or a very limited number of them should be manufactured [5]; and (iii) "on-demand manufacturing", 3D printing can support a simpler and shorter supply chain, meaning that a number of geographically distributed printers could meet local demands while significantly reducing transport costs and order-to-delivery lead times [6]. The disadvantages of AM versus subtractive manufacturing processes, for instance, include (i) the limited volume of products that can be executed, (ii) the limited choice of materials used in making those products, and (iii) limitations on the type of product finishing or color [7].

In terms of future applications [7], AM could be extended to (i) consumer electronics products, toys, and jewelry; (ii) automotive industry, mainly for prototyping, but customized solutions are widely predicted for the near future; (iii) medical and dental solutions, which is currently considered a key market, with more than half of hearing aids and orthotics already being produced using 3D printing; and (iv) aerospace, reducing the buy-to-fly ratio due to the possibility of replacing heavy components with elements made of titanium and nickel. In addition to these highly relevant applications that are already in place, other immediate applications are being developed in completely unrelated fields, for instance, in the food industry [8].

Although the development of this technology is still fairly new, according to authors such as Kietzmann et al. [9], the estimated market value of 3D printing products and services in 2017 had reached USD 3.7 billion and this value is expected to double by 2020. It is important to highlight that this technique is considered to be one of the four main pillars of Industry 4.0 and the aerospace industry is one of the pioneers in the use of AM, exponentially improving the quality of current deposition aerospace manufacturing techniques. AM is now a process with highly disruptive potential in this industry.

For example, at the end of 2015, Boeing introduced more than 20,000 original parts built applying AM technology [10]. Original parts (OP) are those used for the production of a new aircraft, while spare parts are used to manage aircraft service support during its life cycle. These 20,000 pieces were non-metallic (mainly plastic-based parts). Meanwhile, Airbus has also been installing thousands of non-metallic parts in its airplanes since 2014.

Moreover, the first two titanium metal brackets using AM were introduced on Airbus production lines in 2014, and were both introduced in the A350 model, making a breakthrough step forward [11]. According to the Airbus Group (Airbus Press release), the company has achieved several benefits adopting this AM technology (i.e. reducing the cost by 50–55% in one piece and 30–35% reduction in the other) not only on the cost side but also on the design cycle reduction.

2 Objective and Study Methodology

The research is trying to understand to what extent additive manufacturing development and application in aerospace sector companies could influence industry supply chain performance, with a special focus on their purchasing process. The purchasing process is extremely important in the aerospace industry due to the high value of outsourced and purchased materials, operations, and equipment [12].

This study belongs to research that will have different phases and includes different scenarios, combining in-house and outsourced manufacturing of OP aircraft. In this preliminary scenario, the research will be focused on the consequences of the purchasing process when AM is applied to in-house manufacturing.

Published research has tried to describe some benefits of AM in supply chain management [13, 14]. Additional studies sought to understand the main benefits of this technique within the aerospace supply chain industry by (i) reducing inventories, (ii) increasing reaction speed, and (iii) reducing lead times. Even some authors have managed to perform small simulations to compare "traditional supply chains" with AM-based supply chains [15, 16] in order to infer performance improvement difference.

This study goes further and aims to understand the current and future applications of AM technology as a factor that could strongly transform the aerospace industry supply chain by influencing its purchasing process. The authors have based this research on these sources: (i) a detailed review of the published literature, especially focused on recent research; (ii) the direct involvement of one of the authors in the direct leadership of the purchasing process of a top aerospace company, especially on some of the projects that have been analyzed for this research (action research). According to Coughlan and Coghlan [17], action research could bring extra insight into the research due to the specific nature of the matter, and finally (iii) the authors also tried to get valuable knowledge from some field experts who could bring extra veracity and reliability. This part was performed using semi-structured surveys, based on in-depth interviews to gain insight into good industry practices. Five in-depth interviews (personal interviews) were managed with senior executives currently working in two major aerospace companies. Of course, the interviews have been done based on semi-structured questionnaires, and always guaranteeing that the information would only be used for academic research and always managed as an aggregated database.

3 Additive Manufacturing Influence on Aerospace Supply Chain

In the aerospace supply chain, over one thousand companies contribute to the manufacture of a specific aircraft. Any large aircraft is built in its final assembly line, where major structural building blocks are supplied directly. Building blocks arrive from either internal manufacturing plants or some major external supplier. These major suppliers act as risk and revenue sharing partners, participating starting from the initial program launch. Each supplier that delivers parts to the final manufacturer is considered Tier 1 of the process. Those who deliver parts directly to the Tier 1 supplier are considered Tier 2, and consequently, those who deliver to Tier 2 suppliers are considered Tier 3 suppliers. To give an idea of the magnitude of the process, an A380 airplane incorporates 2.5 million different part numbers, of which 70% are sourced from 1,500 suppliers [13]. Purchasing and supply management have thus become one of the key success factors for manufacturing an aircraft [18]. It requires an important dedication of resources, one of the main operating risks, and in a certain sense, it will condition the company's strategy. The main functions involved in the aerospace supply chain within the purchasing process could be described as follows (Table 1).

Table 1 Roles and responsibilities of the main purchasing functions

LEVEL A – Strategic Purchasing:
Responsible for leading the commercial negotiations and the value for money performance, defining the purchasing strategy throughout all aircraft projects, contract management.
LEVEL B – Operational Purchasing:
Accountable for supplier industrial performance. Supports the daily operations, follows up all the deliveries, manages the release of purchasing orders.
LEVEL C – Logistics Control:
Specifically dedicated to logistics and warehousing. It keeps in close contact with the forwarding companies, manages the warehouses and performs the incoming inspections.
LEVEL D – Purchasing Quality:
Oversees supplier quality performance. Level D is accountable for the suppliers' process control, performing audits and industrial capacity assessments, validating quality of the goods.
LEVEL E – Purchasing Coordination:
Ensures the coordination between all purchasing functions. Implement processes, manages the prioritisation of tasks, as well as information distribution.
LEVEL F – Supplier Development:
Works across the board with the other purchasing functions, developing strategic suppliers by applying lean tools.

Source authors' elaboration

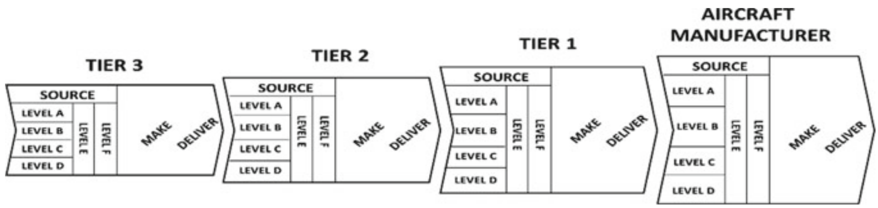

Fig. 1 Purchasing functions manufacturer and supplier. *Source* authors' elaboration

These six functional levels could be found in every department of any company in the aerospace industry, perhaps with different names but with similar functions. It should be noted that any supplier with whom a buyer deals would have its own corresponding purchasing department, with the same functions defined. Figure 1 below summarizes the purchasing processes of a company and its suppliers.

The consequences of adopting a potentially disruptive manufacturing system like AM and its impact on the complex management structures of the supply chain, and more particularly on the main process like Purchasing, require an in-depth analysis, which has not been done so far. Out of the six levels described here, this paper focuses on the first four, from Levels A to D. Levels E and F provide across-the-board support to Levels A to D and have less exposure to any manufacturing technology change.

4 Impact of AM on Original Parts Purchasing Process. Analysis and Discussion

This research looks to analyze how the adoption of AM technology influences the purchasing process when parts are internally manufactured, both using traditional manufacturing and AM. In the below example (Fig. 2), the case of a metallic part that is currently produced internally by the aircraft manufacturer using the conventional manufacturing process is shown. This is compared with a scenario in which the part is produced internally using AM. Being an internally produced original part (OP), the purchasing processes are very focused on the procurement of the components, as well as the purchasing of the machinery and tooling.

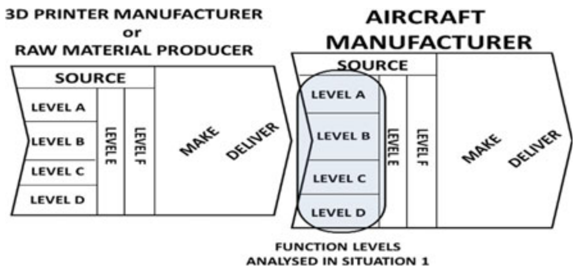

Fig. 2 From traditional manufacturing to AM. *Source* authors' elaboration

Prior to the adoption of AM, the Level A function only participates in the negotiation of specific tools and production support equipment. This negotiation takes place once at the beginning of the project launch, and there are many suppliers willing to manufacture these parts (with little bargaining power). When AM is adopted, the Level A function becomes responsible for purchasing new machinery to adapt to this new technology, it leads negotiations with the 3D printer manufacturers. Although this does not imply a radical change in its functional role, it will require technological knowledge. The work will be similar in terms of workload, but different in terms of technical expertise. It will require new skills and training to properly negotiate the machinery purchasing contract.

Prior to AM adoption, the Level B function is mainly occupied with recurring purchases of base material for production. Suppliers are generally large heavy-duty forged metals corporations that are stable in their day-to-day operations and even able to absorb some of the fluctuations in commodity prices. Price fluctuations can be very high, and it is the biggest challenge that faces Level B. The move to AM requires a change of suppliers, namely powdered metal or consumable yarn suppliers, depending on the type of additive process used. As they are generally smaller suppliers, their capacity to absorb cost variations when raw material prices change drastically can be expected to be lower, meaning that there will be fluctuations in raw material final costs. On the other hand, since AM is a production process that optimizes the use of materials, the inventory will probably be reduced, making it easier to manage.

Table 2 Impact on purchasing functions

LEVEL A	Without AM	With AM	Impacts
Commercial negotiations **Contracts management** **Purchasing strategy**	Tooling purchasing	3D printers purchasing	Training needed No relevant change
LEVEL B	**Without AM**	**With AM**	**Impacts**
Purchasing orders **Delivery follow up** **Inventory management**	Materials/components purchasing WIP management	Raw materials purchasing	Easier inventory management Higher variability production direct costs
LEVEL C	**Without AM**	**With AM**	**Impacts**
Logistics management **Wharehousing** **Incoming inspections**	Space management	Less space management	Less space needed Less people Less cost
LEVEL D	**Without AM**	**With AM**	**Impacts**
Process control and deviations **Audits/assessments**	Process control of raw material	Process control of consumable yarn or material dust	Training needed No relevant change

Source authors' elaboration

Level C is mainly involved in the logistics and storage of recurring materials. Considering that one of the greatest benefits when implementing AM is the reduction in the amount of resources used, Level C will be positively impacted, as it will require a lower volume of material, which will mean less storage space, a smaller number of people, and a decrease in stock maintenance. The Level D function is concerned with process control and is responsible for the purchased product. Generally, the base material manufacturers follow very robust production processes, with a very small number of deviations, so quality control has a relatively low weight in this scenario. Both prior to the adoption of AM and after applying it, Level D is responsible for the quality of the base material purchased. Whether in powder form, consumable thread, or conventional forging, an increase in the number of issues should not be experienced (as shown in Table 2).

5 Conclusions

In the specific analyzed scenario, based on the consideration that an aerospace company decides to move from an in-house and traditional manufacturing model to additive manufacturing, it could be inferred that the impact on the purchasing process is mainly perceived on the way of working changes and a purchasing function task refitting. This means that just to introduce this change, theoretically simple but with complex implications, a clear plan and roadmap should be drawn, involving all relevant people involved. The different purchasing levels described in the study would require training to become familiar with the new techniques and their new way of working.

The scope and responsibilities of the main purchasing identified levels would be significantly reduced. This means a huge reduction in the number of references to purchase and in the number of suppliers to deal with.

Purchasing cost drivers (including work in progress, logistics, and the amount of space required) will all be reduced. An optimization of inventory management and lower logistics costs are expected, and a higher standardization of the products to be supplied would probably generate additional savings.

These changes will mean not only an optimization of the company operating margins, but also a remarkable reduction in the need for direct human resources in the aircraft manufacturer purchasing function. Furthermore, the effect on the Tier 1 supplier's purchasing function could be even greater. Vertical integration of the purchasing function could also happen, and the consequences will be studied in future research. Despite previously described consequences, the purchasing team would generally continue to purchase manufacturing equipment and materials for production as usual.

Based on this analysis, it is possible to infer that the purchasing function could be simplified with the application of AM within the aerospace sector, and costs would be reduced. The aerospace supply chain would become shorter, prepared for a breakthrough lead times reduction. All these drivers could bring subsequent benefits such as lower inventories and less capital employed. The total integral cost reduction could be relevant if the potential reduction in human resources is considered.

Statement on Compliance with Ethical Standards The Research Ethical Committee of Universidad Carlos III de Madrid approved the entire procedure followed by the authors in the research (ref. CEI2019_ 014_Morcillo_Jesus). The data has been anonymized. The authors also declare that they have no conflict of interest.

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Addressing Structural Complexity in Facility Location

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Abstract The focus of this work is the problem of locational complexity in the supply chain (i.e. the complexity emanating from the proliferation markets) that results from natural growth, multi-market, and market overlapping strategies. Notwithstanding, it is widely agreed among practitioners that this proliferation damages supply chains, rendering them less efficient; there is still a need for a mechanism for incorporating a measure of structural complexity in optimization models that may help on the design of less-complex networks or, alternatively, in the rationalization of oversized ones. In this work, we propose an extension to the K-Median problem that takes into account the complexity of the resulting network.

Keywords p-median · Complexity · Network design · Location · Supply chain

1 Introduction

In recent years, supply chain complexity has been frequently referred to as the source of inefficiencies that, by generating hidden costs, erode firms' capacity for generating profit [4, 11, 16]. Using the words of Saeed and Young [20], complexity can be understood as "the systemic effect that numerous products, customers, markets, processes, parts… have on activities, overhead structures, and information". This notion can be narrowed down for defining structural complexity as the pervasive effect of the proliferation of products, distribution channels, and markets. This kind of complexity stems from strategic choices and grows as an organization adds products and/or increases

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the number or diversity of interactions among them, for instance, by moving into new geography, serving a new customer, or opening a new manufacturing location [13].

Locational complexity arises from the firms'—frequently mislead—perception of a need of serving several markets (multi-market strategy), or to be present wherever their competitors are (market overlapping strategy). A discussion of this phenomenon in the banking sector can be found in Fuentelsaz [10]. As a consequence of this, firms proliferate production, distribution, and retail facilities, expanding their network well beyond the limits of profitability and "keep expanding until their chains begin to collapse under their own weight" [8].

Most authors consider that the most efficient mechanism for reducing complexity is eliminating sources of operational complexity that do not add value (AT [15]. Indeed, Saeed and Young [20] found that all companies that have capably managed complexity have used elimination to a degree. Regarding locational complexity, the advice is the same: "stop opening new stores" [8], and stay close to your customer but not too close [12]. It is not hard to list companies that have faced the need of reducing their network in order to survive in the marketplace. For example, in British retail, Debenhams announced the need of closing about 50 stores (The Guardian, 25/10/2018, and Marks and Spencer announced that it will close 17 stores in 2019 (BBC News, 15/01/2019; in the UK banking sector, by June 2018, 2900 branches had been closed over a three-year period (BBC News, 15/06/2018).

Although there is an important body of literature addressing the problem of supply chain complexity, most of the available work focuses either on the design of alternative measures for complexity [9, 21, 14, 5], or on the analysis of product-driven complexity [1, 3, 6, 18] while locational complexity has only received limited attention (e.g. [2]). Moreover, the lack of consensus in an operational measure of complexity has prevented the development of optimization models aimed at reducing the complexity in already oversized systems, or at avoiding its emergence during network design.

The main objective of this work is to illustrate the importance of taking into account complexity issues on location design, in particular, because of their impact on profitability. Additionally, we understand that oversized distribution networks are not typically the consequence of a one-time network design decision, but the result of subsequent expansions. Based on a measure for supply chain structural complexity introduced by Ruiz-Hernández, Menezes, and Amrani [19], we propose a mechanism for introducing complexity into the locational decision process. The objective is to provide a framework that takes into account complexity-induced costs for identifying the optimal number and location of facilities to be open. Additionally, we develop an algorithmic approach for network rationalization that allows us to address the problem of complexity when it is a consequence of natural growth.

2 Methodology

To solve a facility location problem, an objective function must be optimized subject to certain constraints. These types of problems are typically combinatorial problems where a cost´s function (due to serving the demand from a set of nodes or facilities) must be minimized. The purpose of a typical location problem could have two different objectives. On the one hand, a given number of facilities must be located maximizing the demand covered, and on the other hand, the total demand in a region must be satisfied by finding the optimal number of facilities and their location (see, for example, [7]).

The structural complexity measure developed by Ruiz-Hernández, Menezes, and Amrani [19] has been employed in this work. This measure is based on the concept of entropy. In this section, we present the *K-Median Complexity-Bounded* problem, a modified version of the well-known *p-median* problem that includes a complexity parameter in its formulation.

The measure for structural complexity is built around a collection $\wp$ of triplets *{SKU,Market,Channel}* that completely characterize the products' family in a firm's supply chain. Each of these triplets has associated a probability value ω_i that represents the proportion of total revenue generated triplet $i \in \wp$. With these elements, the structural complexity of a system $\wp$ is given by the equation

$$C_p(\omega) = \sum_i \omega_i \log_2\left(\frac{1}{\omega_i}\right), i \in \wp \tag{1}$$

It has been proved that function $C_p(\omega)$ satisfies the following properties:

1. $C_p(\omega)$ is continuous and concave in ω.
2. If $|\wp| = 1$, then the system´s complexity is zero, i.e. $C_p(\omega) = 0$.
3. C_p Attains a maximum when $\omega_i = \omega$ (where$\omega = \frac{1}{|\wp|}$) for all$i = 1, \ldots, |\wp|$. Such maximum is equal to $log_2(|\wp|)$.

2.1 *The K-Median Complexity-Bounded Problem*

The optimization objective is to find the optimal number and location of facilities, and the way the demand is allocated among them, in order to maximize the firm's benefit when taking into consideration the cost of complexity. The optimization problem is given by

$$\max_{S \subset N:|S|=K} Z^K_{Plex} = \sum_{k \in S} R^{(k)}\left(1 - \alpha C_p^{(k)}\right) - \phi K \tag{2}$$

where

$$R^{(k)} = \sum_{i \in \mathcal{N}_k} (r - \gamma d_{ik}) W_i, k \in S \tag{3}$$

is the profit obtained from facility k; and α is a constant that accounts for the effect of complexity in facility k's profit and must satisfy

$$\alpha C_p^{(k)} < 1, k \in S \tag{4}$$

The set of demand nodes is given by $\mathcal{N}$; the set of open facilities is given by $S \subset \mathcal{N}$; the set of nodes allocated to facility $j \in S$ is represented by $\mathcal{N}_j$. Parameter W_i, represents the weight of demand node $i \in \mathcal{N}$; ϕ is a fix facility opening cost; r represents the revenue per unit sold; α is a complexity-related profit loss factor; γ is a generic transportation cost; and $\omega_i = W_i / \sum_{i \in \mathcal{N}} W_i$ for all $i \in \mathcal{N}$.

Due to the non-convexity, non-linearity, and the heavily combinatorial nature of the objective function, we propose an algorithmic approach aimed at attaining network configurations whose objective function value is close to the one of the optimal *K-Median Complexity-Bounded* problem. This approach is based on evaluating different network configurations, characterized by a set of facility locations S' and their corresponding collection of allocation sets $\mathcal{N}^{|S'|}$, on the *K-Median Complexity-Bounded* objective function (2). The value of each of these configurations is represented by $Z^{\text{Plex}}\left(\mathcal{N}^{|S'|}, S'\right)$.

The rationale behind our approach is illustrated in Fig. 1. The upper curve represents the value of the solution to the *K-Median* problem, i.e. the profit that would be obtained from the optimal K facilities if complexity did not exist. The lower curve represents the actual profit observed in the firm's books. This curve reflects two costs, namely the (unavoidable) cost of complexity and the (avoidable) cost of ignoring the existence of hidden complexity costs. This curve is obtained by applying the $Z^{\text{Plex}}\left(\mathcal{N}^{|S'|}, S'\right)$ function to the network configurations given by the solution of median problems corresponding to different values of K. Finally, the dashed line

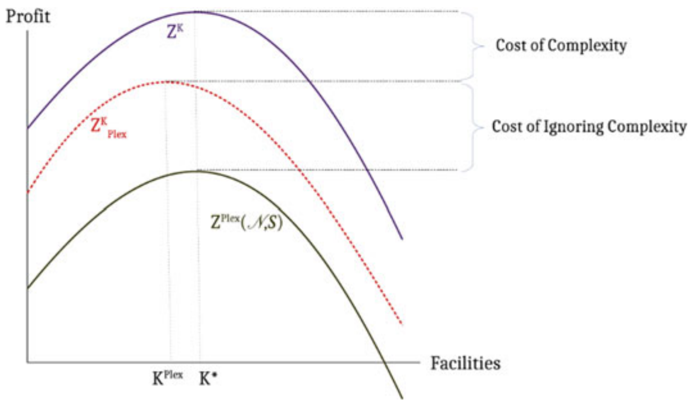

Fig. 1 The cost of complexity in facility location

represents the profit that could be observed in the firm's books if complexity is accounted for during network design. The distance between this line and the top one represents the cost of complexity. Notice that the optimal number of facilities prescribed by the Z_{Plex}^{K} formulation does not necessarily coincide with K*.

Based on the proposed algorithmic approach, we analyze two different situations. We first address the problem of designing a network of facilities taking into consideration the impact of structural complexity. In the second, we analyze the problem of reducing an oversized network by means of strategically reducing the firm's presence in certain non-profitable markets.

2.2 Designing a Low-Complexity Network

Standard location models do not take into account the hidden costs of channel and market proliferation. This often results in an oversized network whose profitability is typically overestimated due, mainly, to ignoring those costs. In order to address this problem, we propose a strategy that builds on a given solution for the *K-Median* problem, $\left\{S^K, \mathcal{N}^{|S^K|}\right\}$, by reassigning demand nodes to different facilities (exploiting the trade-offs existing between increased transportation costs and reduced complexity penalties), and then solving *1-Median* problems around each of the available facilities after demand reallocation.

The value of K is determined by sequentially solving *K-Median* problems until the value of the corresponding $Z^{Plex}\left(\mathcal{N}^{|S^K|}, S^K\right)$ is maximized. Once this solution is obtained, the procedure reassigns the demand nodes across the different facilities based on the total shipment cost from each node to its second closest node.

2.3 Reducing Complexity in an Existing Network

It can be argued that locational complexity is not always a problem from the network design. Locational complexity may be caused by changes in the original network, such as network expansions aimed at increasing revenue [8]. We refer to this as *natural growth.* The multi-market and market-overlapping strategies followed by banking institutions during the last decade of the past century and the early years of the current one are a good example of this behavior. Firms are able to leave certain markets (unprofitable markets) in order to reduce complexity and concentrate their services in the most profitable ones (although firms are usually unwilling to abandon certain markets under the idea that lost sales will affect profit negatively). In order to address this issue, we propose an algorithmic network rationalization strategy, based on sequentially removing nodes when the resulting reduction in complexity contributes to an increase in profits. This strategy exploits simultaneously savings in transportation costs obtained from withdrawing from a certain market, and the positive effect on profits due to the associated reduction in complexity.

3 Numerical Experiments

To analyze the proposed algorithms, we conduct several numerical experiments on some networks designed over the 125 largest cities, with more than 50,000 inhabitants, in Spain, France, and Italy (excluding islands).

Preliminary results suggest that the proposed algorithms improve results in general, i.e. larger profits can be reached by both the reallocation of demand nodes across facilities (plus the subsequent re-centering) and the removal of inefficient demand nodes.

The improvement routines outlined in the previous section show higher improvements in profit for large values of the complexity cost parameter α. The values have been calibrated based on the empirical results obtained by Menezes and Ruiz-Hernandez [19]. Our results also suggest that the larger the transportation costs, the higher the potential impact on the profit of a network rationalization strategy. Some results are shown in Tables 1 and 2 for illustrative purposes. Table 3 shows the results obtained using the complexity reduction technique in a network whose optimal size using the *K-Median Complexity-Bounded* problem is 6 facilities.

The results of the strategy followed for designing a new network (Tables 1 and 2) show that demand reallocation can have a positive impact on profits by attaining a more even distribution of complexity among the different distribution centers. The positive effect is larger when the transportation costs are higher and when the impact of complexity on profits is also higher.

Table 1 Experimental results for a new network, $Tr.Cst = 33.3$ cts/km × ton

α	K	$Z(\mathcal{N}, S^K)$	Z^K_{Plex}	Improv (%)
0.040	7	16194.76	16427.87	1.44
0.050	7	15494.87	15727.40	1.50
0.075	11	13811.09	14120.16	2.24
0.100	12	12257.31	12715.39	3.74

Table 2 Experimental results for a new network, $Tr.Cst = 8.3$ cts/km × ton

α	K	$Z(\mathcal{N}, S^K)$	Z^K_{Plex}	Improv (%)
0.040	5	17131.03	17210.32	0.46
0.050	6	16331.94	16419.19	0.53
0.075	8	14465.94	14684.96	1.51
0.100	11	12683.99	13136.66	3.57

Table 3 Experimental results for complexity reduction in an existing network of 6 facilities

Tr. Cst	α	Elimin nodes	$Z(\mathcal{N}, S^K)$	Z^K_{Plex}	Improv (%)
2 €/km × ton	0.125	25	8500.31	8634.11	1.57
	0.150	61	6917.61	7498.67	8.40
33.3 cts/km × ton	0.125	8	10262.97	10283.04	0.20
	0.150	55	8374.05	8759.38	4.60
8.33 cts/km × ton	0.125	7	10527.37	10540.18	0.12
	0.150	54	8592.51	8964.00	4.32

Table 3 results show that by eliminating demand nodes, the savings in transportation cost and reduction in complexity are, in most instances, enough for compensating the lost revenue resulting from abandoning certain markets. As expected, the higher the transportation costs and the cost of complexity, the larger the benefits attained from reducing market share. Starting from a 125-node network, results indicate that large reductions in network size can still have a positive impact on profitability (up to 8.4%), supporting the idea that shrinking the network is an efficient mechanism for reducing location-related structural complexity.

4 Conclusions

The objective of this manuscript is to take the first step in incorporating the notion of structural complexity in facility location problems. In particular, by incorporating a measure of complexity that roots in the Theory of Communication and aims at reflecting the effect in profits of the proliferation of products, markets, and channels, we propose an extension to the *K-Median* problem for the locational complexity problem. This extension results in a highly combinatorial non-linear optimization problem that can hardly be solved to optimality by standard techniques. For this reason, we propose a couple of algorithmic approaches aimed at addressing the problem of locational complexity from two different points of view: during network design and for an already existing network. The first problem targets the design of distribution networks where the impact of complexity is limited, avoiding the unnecessary proliferation of facilities. The second starts from an already existing network and seeks to reduce the impact of complexity by eliminating certain demand nodes. In both cases, experimental results show that reducing complexity has a positive impact on profitability.

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Application of a Methodology for the Management of Risk in a Pharmaceutical Supply Chain

N. Anich and M. Mateo

Abstract The supply chains of a business are designed to respond to a variety of clients' and customers' requests. Given the increasing complexity of the chain management, nowadays it is also important to design them in order to face different kinds of customers and also different kinds of risk to satisfy their requests. We have developed a methodology to redesign a supply chain including decisions to balance the performance indicators and the possible risks. The paper describes the application of the first steps in this methodology for the distribution of pharmaceutical products to customers, from hospitals to pharmacies. The result is a diagnostic of points with higher risks in the supply chain, to focus the changes in the redesign.

Keywords Supply chain management · Design · Risk · Methodology

1 Introduction

In recent years, the increasing expectative of customers has led to changes in the supply of goods. According to Chopra and Meindl [9], the organizations involved in the direct or indirect way in the satisfaction of clients' requests are integrated into the supply chain (SC). Usual entities in a chain may be external suppliers; distribution centers (DC), or demand areas [14]. The supply chain management (SCM) deals with the planning and management of all activities involved in the acquisition, conversion, and distribution to move products or their components up to the customers. Moreover, besides the flow with destination the customers, each day the reverse logistics are achieving more importance.

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Several events (which can be set in different classifications, for instance: meteorological or geological events, like earthquakes; geopolitical, as a consequence of government decisions…) may affect the global supply chains. This can be transformed into risks that break the regular flows. Their management is studied in the SCRM, Supply Chain Risk Management [17].

Simultaneously, the changes in society and business have brought uncertainty in the markets, a global competition with competence firms, longer times and distances in supply chains, customization of products or shorter lifecycles. Kaplan and Garrick [13] already formulated some questions that a firm responsible had to face: What can go wrong? What are the risks? What are the consequences?

Progressively, companies are adapting their business models to face a higher number of supply chain interruptions, changes in the capacity constraints, some quality problems, etc. Therefore, they should study risks, understood as a combination of events and consequences [1, 11]. The methodology here proposed and applied on a specific supply chain pretends to help managers in this way, to redesign a supply chain in order to manage different ways of risks. Some works have faced the design [6, 12], but any for redesign, whose starting point is the current chain. This is the main difference with previous papers as, in our case, data can be obtained from reality and planned changes can be defined. Moreover, for the redesign we introduce some usual tools in management, like the strengths, weakness, opportunities, and threats (SWOT) analysis.

The application of the methodology is framed in the pharmaceutical sector. Clients may be divided between private, such as pharmacies and private health institutions, and public health institutions, whose demand comes from public auctions and long-term contracts. This research summarizes the first steps in the so-called methodology for redesign the chain taking into account the risk and its associated elements. The result is a diagnostic of the points in the chain to pay attention in order to reduce risks.

The paper is organized as follows. In Sect. 2, a brief introduction to Supply Chain Risk Management is given. Section 3 introduces the methodology with the corresponding 7 steps; the application to the pharmaceutical distribution is done through Sect. 4. Finally, Sect. 5 provides the conclusions and the future work to be developed.

2 Supply Chain Risk Management

A supply chain configures a network of organizations through different links, in the different processes and activities that produce value in the form of products and services for the consumer [10]. This complex adaptive system depends on the number of nodes in the chain, their location, and the set of interrelationships, and will lead to chains of different degree of complexity [8]. The risk may be the probability of occurrence of an event or threat, which is independent of the consequences [3, 5]. The threat in an event is an external factor of risk that affects the chain.

This event has uncertainty, since there is no exact information on the appearance instant or the magnitude, scope, and duration. The consequences of the disruption will be directly related to the chain attributes of vulnerability and resilience. The consequences may have multiple dimensions, to be expressed in economic, material, system states (active/passive), and others [2].

Many researchers have sought answers, through models, to the challenges caused by the changes and the necessary redesign of the chain. They have proposed mainly the maximization of efficiency, effectiveness, or responsiveness. Effectiveness is defined as the ability to deliver the right product, in the right place, at the right time, in the right conditions and packaging, in the right amount, with the correct documentation, for the right user, while in front of a demand the ability to quickly assess and take into account needs is necessary [7]. Nevertheless, in general, the models developed for the design of the chain try to solve particular situations [6].

3 Methodology for Supply Chain Risk Management

Many methodologies for supply chain design cannot address all types of chains with their particular issues. Moreover, they do not differ between a design, starting from an idea and put in practice, and a redesign, whose starting point is the current chain, and this brings differences from a methodological focus, which have not been addressed [6, 12, 14]. As a result, we propose a methodology for supply chains which are running and have as objective the continuous improvement in adaptive terms to scenarios of uncertainty. According to Mateo and Anich [15], several characteristics of this methodology are as follows:

(a) As the objective is the redesign, it starts from a priori solution and changes must be proposed on it.
(b) A hierarchical top-down approach is used, where in the first stages the objective is to obtain the information of the actors and processes. In the redesign, the processes and activities take on more relevance than the actors involved.
(c) Reverse logistics will be also considered.
(d) The mathematical models are one of the possible elements related to the design of the chain and must be placed in an appropriate frame.
(e) This methodology considers recursive stages, i.e. the periodic evaluation of the participant units, objectives of the supply chain, and links between these units that define the underlying structure of the network.

This methodology is composed of the following seven steps [15]:

1. Definition of the object of the SC (according to the dominant actor), an environment analysis (competence, clients, or laws, among others), and the formulation of objectives. It is important to segment the markets, and consider simultaneously the initial and the potential markets.

2. Definition of the existing SC, as a priori design. According to Corominas et al. [12], this will be done at several levels (the macro, the meso, and the micro) through the M-graph, the m-graph, and the μ-graph.
3. Definition and/or evaluation of the model of SCM and the strategic coherence of the SC (reality versus objectives). Two kinds of tools may be used: some economic indicators as, for instance, orders delivered on time over total orders; other analysis usual in business, like strengths, weaknesses, opportunities, and threats (SWOT).
4. Study of the customers and the possible scenarios of demand. The objective is to determine the demand (based on historical data) by types of customers and channels of distribution. An analysis on demand risks will permit to evaluate possible scenarios.
5. Identification and evaluation of risks in the supply chain, by determining current and latent threats. They will be sequenced according to impacts: ABC classification of the threats. Finally, it is necessary for the determination of risk prevention policies to prevent emerging threats; risk mitigation policies to reduce the impact of these threats; and risk recovery policies to limit the time when the system is not in the usual state.
6. Analysis of the redesigned chain, final state, using optimization if possible (multicriteria context and looking for an improvement in the degrees of vulnerability and resilience against possible disruptive events).
7. Evaluation of the accomplishment of objectives. If the requirements and objectives fixed in step 1 are not satisfied, go back to step 5 (change policies for risk detection and mitigation) or step 1 (change objectives).

4 Application to a Pharmaceutical Supply Chain

4.1 Definition of the Object

The supply chain to be evaluated corresponds to the distribution of pharmaceutical products in Chile. The distributor has a high pressure from customers, since they require short delivery times and a lot of flexibility in orders. At this moment, more than 750 active ingredients (i.e. medicines) are sold, provided by more than 80 domestic and foreign suppliers. The products must reach the different points of sale, classified into three different channels or types of clients: retail or pharmacy, private health, and public health (Table 1). The delivery points are more than 1100, divided into 396 pharmacies for retail sale, 61 for private health institutions, and 650 for public health institutions.

The distributor manages different lists of products according to each channel, which implies that a list may have common products with the rest or not. In addition, the distributor develops its own brand. Nowadays, it has registered more than twenty products which are manufactured in different countries over the world (Brazil, India, or Germany, for instance).

Table 1 Definition of the three different business channels in the pharmaceutical supply chain

Business channel	1. Retail sale	2. Private health sector	3. Public health sector
Type of client	Private pharmacies of the health system	Private institutions of health	Institutions of the public health system
Type of product	Medicines for individual consume	Mix of medicines for individual and massive consume	Medicines for massive consume
Objectives	Availability and response times	Right delivery quantities in a short time	Efficiency (low prices and low costs)

4.2 Definition of the Existing Supply Chain

The following step describes the architecture of the SC for the three different business channels of the company, through a set of graphs (the macro, meso, and microstructures for each business). In this paper, we only provide the respective graphs Figs. 1 and 2 for the two first structures and the first kind of clients. Instead, the third structure has too big dimensions to be included here.

From a macropoint of view, the M-graph (Fig. 1) is formed by procurement and distribution activities (P), the users or consumers (U), the collection of products in poor conditions (C), the recycling (R), and return to supplier or send to a special depot for active ingredients (D).

Next, the meso structure corresponds to relations between the classes of elements contained in each vertex of the M-graph, where a class is the set of elements (that are not necessarily and probably identified in this stage) capable of executing a transformation of inputs into outputs. Therefore, the meso structure of the chain, built for each of the three different businesses, determines the type of relationship with suppliers, storage and delivery characteristics, types of collection and reprocessing.

From the vertex P (Fig. 1), there are five types of relationships with suppliers (Fig. 2): manufacturing own products (P1), strategic alliances with some national suppliers, with preferential conditions of cost in the long term (P2), with other suppliers without long-term contract and greater flexibility (P3), with manufacturers and/or distributors contacted only punctually to mitigate risks of shortages in the chain (P4), with manufacturers, as for the generic pharmacy products, that have a standard quality and price (P5).

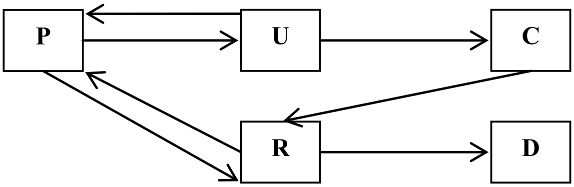

Fig. 1 M-graph for the retail sale in the pharmaceutical sector

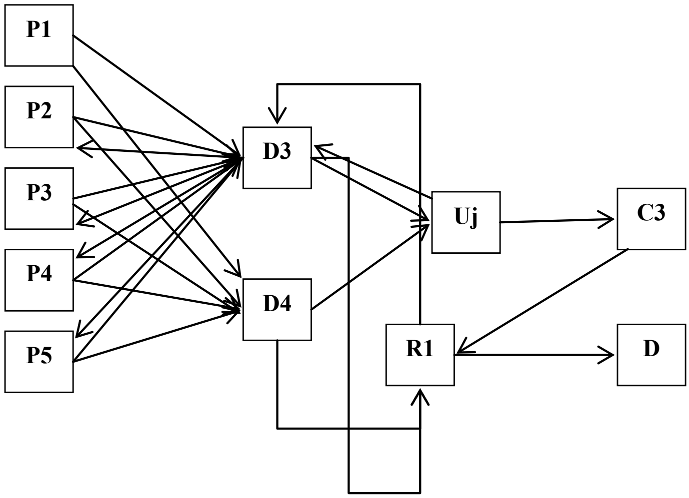

Fig. 2 Graph for the retail sale in the pharmaceutical sector

Imported products are stored and distributed by a logistic operator (D3) or with last-mile delivery (D4). All the output to any client Uj may be done from D3 or D4 (therefore, j can take values up to more than 1100). Finally, the collection of products in return (C3) and the preparation for the recycling R1 of them, before going to a depot for pharmaceutical products (D), complete the m-graph in Fig. 2. For instance, vertices P1–P5 are of type $T\alpha$ (beginning of the flow), while D3 and D4 are *Mm* (many inputs provide many outputs).

The SC microstructure reflects the facilities where operations are developed, the incoming flows between the facilities and the respective means of transport. In this supply chain, the distribution D3 and D4 is currently done through two centers, which are not in the same place (as they have 70 km between them). The number of delivery points Uj is more than 1100 throughout Chile, which has more than 4000 km from north to south. In fact, these delivery points are classified into 15 regions (most of them have the three kinds of order points and close to the local distributions centers). Currently, the distribution is outsourced to four different logistic operators, each one responsible for one or several regions. Considering this, the number of vertices in the μ-graph is very high. For this reason, the μ-graph is not provided.

4.3 Reality Versus Objectives: Strategic Coherence of the SC

Some economic indicators have been computed in the current supply chain. For any business, orders spend 2 days in preparation in the distribution centers and between 1 and 6 for transport, this depending on the delivery point location. Moreover, currently the logistic costs are near 10% of the incomes from sales; finally, the fill rate, i.e. the inventory's availability to meet demand, is around 80%.

A strengths, weakness, opportunities, and threats (SWOT) analysis to know in which aspects the company is strong and in which ones it is weak may be.

- Strengths: good margin for some clients and products, own products, more variety of products than a single manufacturer and flexibility in the deliveries.
- Weakness: some logistic operations are inefficient, chain not designed for each specific type of client, no planning for purchases.
- Opportunities: increase the use of technology for traceability, treat each supplier and client according to its particular needs.
- Threats: high variability in the demand from public institutions, suppliers usually establish prices, competence with own suppliers.

Considering the SWOT conclusions, the distributor has some incoherence between the objectives and the design decisions for the different channels, since its design is homogenized. Therefore, as its main focus is currently the reduction of costs as much as possible, the response times may be deficient. At the same time, the chain has sometimes inability to cope with the disruptions caused by the risks at different points of it.

4.4 Study of the Customers and Scenarios of Demand

The incomes from sales to the public health system represent the 77% of the total amount, followed by the 20% to retail sale (pharmacies) and only a 3% is sold to private health institutions. If the analysis is done geographically, most of the sales (60%) are concentrated in three regions.

An ABC classification for clients and products has been done in order to focus the study of risks in the more critical binomial client-products.

The 1107 clients are divided into 230 A clients, 306 B clients, and 571 C clients. A deeper analysis only on A clients indicates that 162 are delivery points of the public system and 68 are private businesses, 62 of which are pharmacies.

On the other hand, the 1499 products classified according to the sales are divided into 346 A references, 410 B references, and 743 C references. A deeper analysis on A products shows the relevance of the first eight ones compared to the rest; they are delivered to the public health system, thanks to long-term contracts.

If both analyses are done together, the 346 A references are demanded by the 230 A clients (i.e. 100% of the A clients), which supposes more than 4 million product units and a 67% of the incomes from sales. 407 B references, nearly all of them, are also requested by A clients (639,000 product units and a 11% of the incomes from sales). This gives an idea of quite homogeneity in the consumption of products considering the different clients.

Table 2 Risks in the M-graph of the SC in the case study

Risks	Vertex P	Vertex U
Strategic	SR1, SR2, SR3	SR4
Tactical	TR1, TR2	*
Operational	OR1, OR2	OR3

4.5 *Identification and Evaluation of Risks in the Supply Chain*

The supply chain of the three business channels is subject to similar risk events, which will be classified into strategic, tactic, and operative. These events are mainly determined by the reliability of the different actors in the chain, the quality of the product or global facts. The effects of disruption of these events are localized through the different vertices and arcs of the previous M-graph (Table 2). A selection of risks (initially, the most relevant ones) is as follows:

- Strategic: price fluctuations (SR1), reliability of national suppliers (SR2), reliability of logistic providers (SR3), variable demands (SR4).
- Tactic: inaccurate procurement planning (TR1), liquidity problems (TR2).
- Operative: strikes (OR1), product out of conditions (OR2), payments from public health institutions (OR3).

Some summarized results on the above risks are the following.

Although in the world the prices at this moment are stable, Chile is an emerging market in pharmaceutical products and it may suffer fluctuations (SR1). A price may vary up to 20% with respect to its main value. Besides, the probability that a price varies between two consecutive acquisitions of a product is 56%.

The mean delivery time of 12 suppliers (SR2) is 6 days or higher, followed by an important group which has values between 5 and 6 days. Only one of the suppliers P2 (Fig. 2) has a mean delivery time of 6 days, but 60% of them are in the second group. The suppliers do not accomplish delivery times or the requested quantity in 31% of the times, and in this subset only a 3% of the orders are partially delivered to the distribution center.

The reliability of logistic agents (SR3) is deficient, although the delays are not long times. To deliver an important number of orders, the times are 4 days or higher. These values can reach up to 15 days for the farthest regions.

Finally, the demand evolution in this market (SR4) is increasingly reflected in the average sales growth of 15% per year.

After considering the quantitative results given in Sects. 4.4 and 4.5, we can observe that the main decisions to prevent and mitigate risks must be taken on vertices P2, D3, and D4, and therefore in the arcs connecting these vertices in Fig. 2. This may be extended to the subset of Uj vertices associated with A clients.

5 Conclusions

Most of the papers devoted to SC design concentrates on a single kind of product or client [4]. Here, three kinds of customers are studied together, and although initially they are studied separately, this can lead to the improvement of the SC design by synergies. A methodology to deal with risks is presented and later applied to a case in the pharmaceutical sector. The first five steps of the methodology, basically the diagnostic of the current supply chain and the way to improve its initial functioning, are presented.

To achieve a good redesign, thanks to the figures obtained in step 5, a decision tree can be a good tool to visualize the possible alternatives for each business channel. This will allow to observe common decisions among businesses and evaluate a coordinated multi-business supply chain in search of good efficiency results and lower risks. Complementarily, a multi-objective model can be very useful to develop step 6 of the methodology, in the same way as, for instance, Nooraie et al. [16] propose.

Acknowledgements This work was supported by the *Ministerio de Economía y Competitividad* through the project DPI2015–67740-P (MINECO/FEDER).

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Quantitative and Qualitative Models for Managing Risk Interdependencies in Supply Chain

A. Díaz-Curbelo and A. M. Gento Municio

Abstract The interdependent nature of supply chain elements and events requires risk systems must be assessed as an interrelated framework to optimize their management and integrate effectively with other decision-making tools in uncertain environments. This research shows a synthesis and analysis of the main qualitative/quantitative methods that have been used in the literature considering the treatment of event dependencies in supply chain risk management in the period 2003–2018. The results revealed that the integration with disruption analysis tools and artificial intelligence methods are the most common types adopted, with increasing trend and effectiveness of Bayesian and fuzzy theory approaches.

Keywords Supply chain · Risk assessment · Dependency · Quantitative methods

1 Introduction

Integrated Supply Chain Management (SCM) is a major concern in today's competitive market environment. The last few decades have been characterized by significant changes in the SCM due to increased globalization and innovation rate. This global increase in Supply Chain (SC) relationships is associated with greater interconnection between suppliers and manufacturers, leading to greater dependence on SC companies and a higher level of complexity [1, 2]. In this sense, despite their large benefits, extended SCs are more vulnerable, exposing organizations to higher levels of risk. In this regard, risk management has emerged as a major research topic in the literature of Operations Management and SCM [3].

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A risk event can be caused by a set of risk factors and can lead to different impacts throughout the supply network [4]. It is necessary capturing the interdependencies between risk events under uncertainty. Therefore, effective supply chain risk management (SCRM) should take into account the systemic nature of risks in the form of events so that they can be modeled, assessed, treated and controlled.

Although several studies have reviewed the literature on SCRM methods [3, 5–8], in the knowledge of the authors, no precedent was found for a literature review specifically analyzing qualitative and quantitative methods for dependency management as a key factor in SCRM. Therefore, we have addressed the following research question: How can the relationships between risk events be treated to quantify the risk level to manage mitigation strategies effectively in uncertain SC environment?

For this purpose, we analyze documents that explicitly consider, model, and evaluate interdependencies risk events in the management of the SC. We focus on those published in academic and professional journals of high impact and we limited the research to the English language and a temporary space from 2003 to 2018. At the end of the methodological process followed, 107 articles were obtained to perform the analysis.

We organize this paper as follows: first, we summarize the methodology used to carry out the literature review and analysis; next, we show the analysis and discussion of the main qualitative and quantitative, individual and integrated SCRM methods; finally, concluding remarks on strengths and trends motivating future research.

2 Methodology

The general methodology used for the development of this research is shown in Fig. 1. For this purpose, the research methodology proposed by [9] was adapted, which allowed the identification and review of the relevant literature in the period

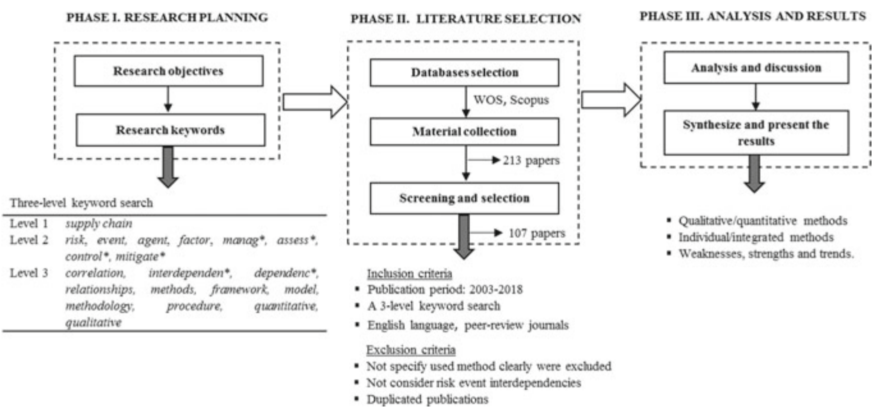

Fig. 1 Research methodology

2003–2018. According to [6], from 2003 onwards there has been a growth in the number of publications related to SCRM.

The analysis focused on documents that explicitly model, assess or manage risk in SCM considering interdependencies analysis. Research that did not consider event dependencies was excluded. We focused on those published in high impact academic and professional journals (SCOPUS and WOS), mostly in the areas of Operations Research and SCM. At the end of this process, 107 articles were obtained as a basis for the analysis.

3 Results and Discussion

The literature review made it possible to identify the main qualitative/quantitative, simple/integrated methods (Tables 1 and 2) that have been used in the literature with the perspective of dependency between SC risk events.

In the consulted literature, several models have been proposed to capture the interdependence between SC risks. As for the family of causal disruptive techniques, many methods have been designed for the identification and modeling of risks in manufacturing and service industries. Some of these methods have proven useful for assessing all types of risks. Examples of the most common methods are Event Tree (ET), Fault Tree Analysis (FTA) and Bow-Tie (BT).

In ET, qualitative analysis identifies possible outcome events from a source event, while quantitative analysis estimates the probability or frequency of the outcome event (probability) for the tree. Similar to ET, an FTA is a logical and graphical

Table 1 Summary of individual methods

Methods	References
ANP	[11, 12]
BN	[13–19]
BT	[10, 20–26]
Decision tree analysis	[27–30]
Disruption analysis network	[31]
FMEA	[32–43]
FTA	[15, 44–51]
Games theory	[52–54]
Hybrid PNs	[55]
Interpretive structural modeling	[56–58]
Multiple regression model	[59–61]
PN	[62, 63]
Simulation	[64, 65]
Supply network opportunity assessment package	[66]

representation that explores the interrelationships between a potentially disruptive event in a system and its causes. According to [10], a typical FTA consists of the main event, basic events and logic gates. The technique follows a top-down approach that is useful for brainstorming about causes and consequences.

An FTA can also be analyzed qualitatively and quantitatively. A quantitative analysis mathematically calculates the probability of occurrence of the main event, as well as other relevant numerical indices, e.g. the severity of the consequence. These estimates depend to a large extent on the availability of fault data. However, according to [95, 108], for most large and complex systems, it is often difficult to obtain accurate failure data due to lack of knowledge, scarce statistical data, and ambiguous system behavior.

In the same line of capturing the interdependence between risks in SC, fault and event trees can be integrated into the form of a BT diagram where the central event represents the release of a hazardous agent. For example, in [10] they used the BT model for risk management of seaports and offshore terminals, in [20] for accident analysis in a pharmaceutical production plant, and in [24] for risk analysis in the oil and gas industry. An interesting proposal is also of [79] who propose a model based on the BT method to see the interdependence of risks and a set of associated mitigation strategies in the high-end server manufacturing SC.

At the same time, Interpretive Structural Modeling (ISM) is a hierarchical technique that establishes the order and direction of complex relationships between the elements of a system. For example, in [56], it has been used to determine causal relationships between risk mitigation strategies. However, according to [72], these models do not explicitly capture the interdependence between risks.

Despite their extensive use, these traditional models have several limitations. The first is the assumption of statistical and stochastic independence between events, a limited focus on capturing data from common causes of failure. Another unrealistic assumption is to consider only binary states in the behavior of systems. It is also not considered a temporary behavior. However, in real-life systems, events present a more conditioned and complex dynamic. These assumptions can lead to an inadequate estimation of the reliability of the SC. In this sense, alternative approaches have been developed to mitigate these limitations.

In this sense, Bayesian networks and Petri nets are highlighted. These two different approaches are used as individual approaches or in association with other methods to address many of the limitations of classical approaches. The two approaches share capabilities such as enabling predictive analysis of system failure behavior taking into account statistical, stochastic, and temporal dependencies of events.

We can see the proposal of [87] with a timed PN-based approach for risk assessment and real-time control of SC networks. In this approach, the FMEA is used to identify disturbance factors in the SC, the dynamic and stochastic behavior of the SC is modeled using timed PNs. In [62], they use PNs for enterprise resource planning risk assessment taking into account the dependencies between different risk factors. Lee et al. [101] has proposed a PN framework for modeling and analyzing distributed manufacturing networks. In this case, a Monte Carlo simulation was used to validate the mitigation process. Guo et al. [103] propose a comprehensive risk assessment

Table 2 Summary of integrated methods

Methods	References
ANP; goal programming; fuzzy theory; analysis of five forces; value at risk	[67]
ANP; rough set theory	[68]
BN; ant colony optimization	[69]
BN; Bow-Tie analysis	[70, 71]
BN; FMEA	[17]
BN; FTA	[72]
BN; fuzzy theory; AHP	[73]
BN; fuzzy theory; FMEA	[74]
BN; interpretive structural modeling	[75]
BN; simulation	[76, 77]
BT; FMEA; fuzzy theory; Lean Manufacturing	[4]
BT; fuzzy theory	[24, 78, 79]
Capital asset pricing model; net present value; variational inequality model	[80]
Cluster analysis; factorial analysis	[81]
Decision tree; mathematical programming	[82]
Decision tree; simulation	[64, 65]
Economic value added; stochastic programming	[83]
ET; fuzzy theory	[84, 85]
FMEA; AHP	[38]
FMEA; AHP; experiment designs; discrete event simulation	[86]
FMEA; PN	[87]
FMEA; Quality Function Deployment (QFD)	[88]
FMEA; fuzzy theory	[89–94]
FTA; fuzzy theory	[95]
Genetic algorithms; statistical methods	[96]
Global production network; fuzzy theory; inoperability input–output model	[97]
Graph theory; life cycle inventory	[98]
Graph theory; supply chain vulnerability index	[99]
Lagrangian relaxation; integer non-linear programming model	[100]
PN; Monte Carlo simulation	[101]
PN; triangularization clustering algorithm	[102]
PN; fuzzy theory; AHP; Entropy method, cloud model	[103]
QFD; AHP	[104]
Radial basis function neural network; fuzzy theory	[105]
Regression models; exploratory factor analysis; reliability tests	[106]
SCOR model; AHP; fuzzy theory	[107]

framework based on diffuse PNs in combination with AHP, entropy and cloud model methods for long-distance transport pipelines.

At the same time, the use of BNs has increased rapidly due to their flexible structure and their reasoning capacity under uncertainty. The main advantage of BNs over other existing methods is their versatility and adaptability. BNs can have different functionalities such as predictive analysis and diagnosis, updating and optimization of models, etc. Some recent studies have proposed BN-based frameworks for modeling and assessing the risks of SC [17, 18, 72, 73, 75–77]. Different dependability techniques such as ET, FTA, Hazard and Operability Analysis (HAZOP) and BT diagrams are translated into BNs for risk assessment. In [73] in addition to using FTA in qualitative analysis to identify the causes of risks, they use the fuzzy set theory combined with expert judgement to obtain unknown failure data from basic FTA events. The probability of hazardous events and other related reliability indices occurring is calculated by translating the FTA into a BN model. In [71], they also use a Bayesian approach to make a BT diagram. The proposed approach improves BT diagrams by allowing dynamic analyses. [76] introduced an algorithm also based on BN to map the risks and mitigation measures proposed in SC.

PNs and BNs can consider the multiple states of failure and reparability of components during system behavior modeling, a limitation solved with respect to traditional approaches. However, they have different strengths according to the context. For example, in diagnostic analysis, BN-based approaches make it possible to identify new evidence across the network and update previous beliefs about the probability of failure. When accurate failure data are scarce, expert judgments are often used to obtain the prior probability of BN nodes. There are criticisms of the subjectivity of expert judgement. However, several studies (e.g. [73, 74]) serve to illustrate the effectiveness of BNs in SC modeling and management. BN combines both statistical data and subjective judgments, if data are not available. In this sense, they are considered more robust to other methods, as they can update previous assumptions and probabilities by learning from the new information.

However, the interdependent nature of the elements of the SC should be considered to the greatest extent possible. This is the key aspect of this analysis. In most studies, the proposal only optimizes a portfolio of specific strategies for a single performance measure rather than considering multiple (potentially conflicting) measures. In this regard, we highlight the contribution of [72] to overcoming these constraints through the introduction and implementation of an integrated SCRM approach, which considers the impact of SC risks on multiple objectives and optimizes mitigation strategies. In this way, research remains necessary, not only to capture the interdependencies between risks, but also as a holistic approach to the entire risk management process within an environment of interaction between risks and strategies.

As a summary, a wide and varied range of methods were identified and grouped as shown in Fig. 2. Considering the 107 reviewed papers, there is an increasing trend in the use of integrated approaches. Approximately 40% of the reviewed studies adopt the integration of two or more methods. In general, disruption analysis techniques (85.1%) is the most common type adopted. Among this group, FMEA has been the

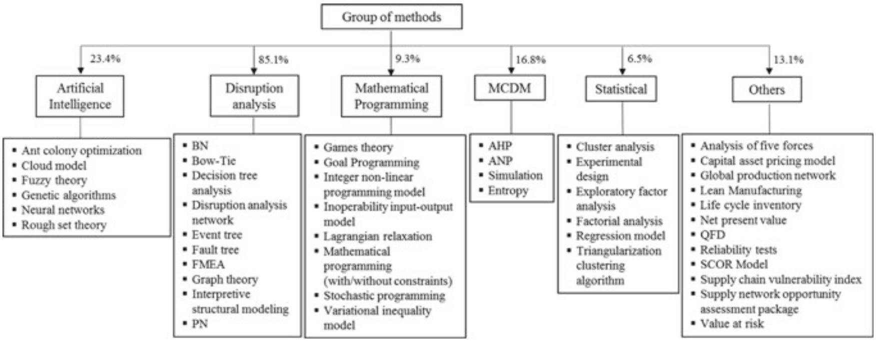

Fig. 2 Groups of identified methods

most used (29%), followed by FTA and BN (11% each one). In the sense of overcoming the limitation of common cause factor modeling within the risk network, the trend toward BNs and PNs approaches is appreciated. These methods are highlighted by their robustness in mitigating many of the limitations of the classical methods.

Due to the highly subjective nature and the lack of information, it is often difficult to quantify risk parameters. In this sense, Artificial Intelligence tools group (23%) show interesting trends. In this group, fuzzy theory (80%) plays a significant role in obtaining more reliable risk assessments in environments under random and epistemic uncertainty.

Integration with MCDM methods is another remarkable combination (13%). Of this group, in particular, the AHP method is highlighted (35.7%). Considering all the 46 different tools identified in the reviewed studies, many of them are used only once (14 out of 46). This is the case of the techniques grouped under the label "Others", which includes common techniques in SC and business management.

4 Conclusions

This paper presented a literature review of 107 studies that propose qualitative/quantitative, individual/integrated models to support SCRM based on dependency as a key dimension. The results show approximately 40% of the studies presented integrated methods of two or more methods with the aim of obtaining more reliable and effective risk assessments. Disruption analysis tools and Artificial intelligence are the most explored types of methods. FMEA and fuzzy sets are the most common ones combined with others but growing trends toward Bayesian approaches are appreciated.

From the standpoint of effectiveness, BNs, PNs and fuzzy approaches are considered robust approaches to manage dependency combined with ambiguous reasoning in environments under uncertainty. The analysis of common cause disruptive events and the joint impact can lead to better management of SCs rather than treating each risk type in isolation. This can contribute to the optimization of risk strategies due to a holistic management of the process.

Once again, elements of integrative thinking can be appreciated, using the combination of different perspectives to represent and express the risk level more reliably. Interdependencies and uncertainties are relevant issues to effective risk management, therefore integrated methods will continue to play a vital role to SCRM. In many cases, a combination of quantitative and qualitative methods constitute the adequate way to support decision-making.

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The Behavior of Lean and the Theory of Constraints in the Wider Supply Chain: A Simulation-Based Comparative Study Delving Deeper into the Impact of Noise

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Abstract The design and implementation of *systems thinking* strategies for supply chains, based on collaboration among partners, is gaining ground as a key source of competitive advantages. Therefore, a growing number of companies is moving the scope of their lean management (LM) and theory of constraints (TOC) solutions from the production system to the wider supply chain. Building on prior research studies, we explore their robustness against noise in a supply chain setting. To this end, we consider the Kanban and drum-buffer-rope (DBR) control systems, respectively, from the LM and TOC paradigms; we model a four-echelon supply chain by means of an agent-based approach; and we measure the net profit of the supply chain under six scenarios with increasing level of noise. As can be expected, we observe that the net profit decreases significantly as the severity of the noise grows. This happens both for the LM- and TOC-based supply chains. However, it is relevant to note that the gradient of the curve is stronger for the Kanban system. This means that DBR makes the supply chain more robust against noise. As a result, we conclude that the benefits derived from implementing DBR, in comparison with Kanban, increase significantly as the noise becomes more demanding.

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1 Introduction

Lean management (LM) and the theory of constraints (TOC) define two different strategic approaches to management that are built on the same pillars: those of *systems thinking*.[1] The former emerged from the principles of the Toyota Production System, designed and developed by Taiichi Ohno [30] from the late 1940s to the early 1970s—although it did not become popular worldwide until the 1990s—[14, 44], while the latter became prominent after the publication of Eliyahu M. Goldratt's books in the 1990s [17, 41].

Given that they share the same pillars, there are strategic similarities between LM and TOC. Moore and Schinkopf [28] underscore four main similarities between them: (i) the *value* principle, according to which customer's perception of value is central to them; (ii) the key role of the *flow* in the management of the system; (iii) the endless *pursuit of perception* based on continuous improvement cycles; and (iv) the adoption of *pull* methods for controlling the flow of materials. In this regard, LM proposes the Kanban control system [21] for just-in-time production,[2] while TOC suggests the drum-buffer-rope (DBR) methodology [6].

At the same time, there are relevant divergences between LM and TOC, which mainly stem from their different operational goals. On the one hand, LM aims at increasing profits by minimizing waste. On the other hand, TOC places the focus on the maximization of the throughput [28]. Accordingly, Kanban focuses on eliminating unevenness and overburden regardless of where they are in the system, while DBR directly concentrates on the bottleneck of the system.

Both LM and TOC have widely proven to be efficient means for managing production systems; see Liker [23] and Hines et al. [14] for LM, and Mabin and Balderstone [24] and Gupta and Boyd [13] for TOC. But which one is best and what does their performance depend on? Several authors have addressed these questions, which would help managers direct redesign and investment efforts to maximize the performance of their systems. In this regard, we may claim that there are two main lines of conclusions in the literature. Some studies have concluded that TOC-based scheduling systems systematically offer higher performance than LM-based mechanisms, including Koh and Bulfin [22] and Watson and Patti [42]. At the same time, other researchers have observed that each one has its own region of superiority, such as Takahashi et al. [39] and Jodlbauer and Huber [20]. We highlight that this

[1] This perspective highlights the need to understand systems as a whole rather than a collection of parts, plunging actors into a global optimisation environment, where they care about interrelationships among processes, interdependencies among decisions, patterns instead of snapshots, and root causes of the inefficiencies rather than their symptoms [36].

[2] Although less common, LM also employs CONWIP (the acronym of 'CONstant Work-In-Progress) as an alternative to Kanban. Interested readers are referred to Takahashi and Nakamura [40] for a comparison between them.

observation buttresses the findings by Grünwald et al. [11], one of the first comparisons between LM and TOC, claiming that Kanban works better in highly static or predictable scenarios, and DBR makes a difference in complex settings.

Nonetheless, it is important to highlight that all these analyses have been carried out for production systems. However, as the management of supply chains through *systems thinking* approaches becomes a crucial source of competitive advantages in the current business scene (see [31, 37]), both LM and TOC principles have started to be implemented in the wider supply chain setting. By way of example, we refer interested readers to Naylor et al. [29] and Martínez-Jurado and Moyano-Fuentes [27] for LM, and Simatupang et al. [38] and Puche et al. [34] for TOC.

In light of this, Puche et al. [33] broaden the LM versus TOC comparison to the area of supply chain management. They analyze the performance of the Kanban and DBR production schedules in two different supply chain scenarios. The first one, labeled as "*mild*", is characterized by favorable conditions—short and stable lead times, low unit costs, small amount of defective products, etc. The second one, labeled as "*acid*", has opposite features. They reveal that, in general terms, DBR outperforms Kanban in the wide parameter space. In addition, they point out an interesting observation: in the presence of acid noise, DBR achieves a net profit that is significantly higher than that obtained by Kanban (average net profit increase: 8.47%); however, relevant differences in the net profit do not emerge in the mild scenario. Importantly, the authors underline that Kanban can generally be implemented at a lower cost in supply chain settings, primarily as it requires less collaborative efforts; thus, it may be preferable in easy-to-manage supply chain scenarios.

Motivated by the previous considerations, in this work we delve deeper into the noise effects in LM- and TOC-based supply chains. In this way, we aim to obtain further insights on the relationship between the LM versus TOC decision and the noise affecting the supply chain by considering six different levels of noise. We aim to explore the robustness of both systems against noise—that is, how they lose profit as the noise becomes more demanding. Overall, our analysis is expected to provide managers with a richer understanding on the interplays between supply chain noise and performance in LM and TOC environments; which would help them make well-informed decisions in the context of their own supply chains.

2 Research Design and Model Implementation

Our methodological approach is based on modeling and simulation techniques, in line with many prior studies in the discipline of supply chain management that explore collaborative strategies; see, e.g. Holweg and Bicheno [16], Cannella and Ciancimino [1], and Costas et al. [3]. We investigate a single-product, serial supply chain with four nodes—named as factory, distributor, wholesaler, and retailer—like the one considered in the popular Beer Game[3] [18]. Traditionally, the Beer Game scenario assumes only one source of uncertainty, in particular, customer demand. To bring it closer to the real-world operation of supply chains, we also model other operational obstacles faced by these systems, specifically, defective products, capacity constraints, and lead time variabilities.

Likewise, we do not only consider the materials and information flows among the nodes but we also consider the financial flow in order to measure the economic performance of the supply chain. In this sense, we capture four sources of cost: buying raw materials (*provisioning* cost), elaborating new products (*production* cost), transporting products between nodes (*shipping* cost), and stocking up products (*storage* costs). In contrast, money is only made in the supply chain by selling the finished goods to the end customer.

Taking the above into account, we model ten noise factors. These include both operational and economic uncontrollable parameters that impact on the net profit of the supply chain. To investigate in depth the effects of noise, we define different levels for each of these factors. To explore the differences in performance between the Kanban and DBR systems under different noise scenarios, we group the factors into six *noise grades*: $Z \in [1, 6]$. Table 1 describes each grade by providing information on the level associated with each factor.

The rationale we used for defining the levels of the different factors is similar to the one described and followed in Puche et al. [33]. It should be noted that the definition of the extreme noise grades here, i.e. mild and acid, match those in that article for benchmarking purposes. In addition, it is important to highlight that the rest of the factors in the supply chain have been interpreted as fixed factors in the different simulations performed. These are (i) raw material cost: 0.4 $/u, (ii) selling price: 1.5 $/u; (iii) minimum order lead time: 0 days; (iv) minimum shipping lead time: 7 days; and (v) minimum production lead time: 3 days.

We quantify the financial performance of the supply chain via the net profit (NP). According to the Throughput Accounting (see [25, 15]), this metric is obtained as the difference between: (i) the *throughput* (T), measuring the money captured by the system, i.e. sales revenue minus provisioning costs, and (ii) the *operating expense* (OE), measuring the money spent to turn raw materials into finished products, i.e. the sum of production, shipping, and storage costs.

To better understand the results that we will obtain via simulation, we also use three additional, first-line metrics: (i) *total sales* (TS), providing indirect information of the customer service level in the supply chain; (ii) *average time* (AT) of products in the supply chain, in days, which informs about the supply chain agility; and (iii) *rolled throughput yield* (RTY), i.e. the ratio of sales to raw materials purchased, which decreases as the amount of defective products grows.

We have implemented the supply chain model in the form of a multi-agent system (MAS). The agent-based approach provides autonomy, robustness, and flexibility to models exploring dynamic large-scale problems, like the one considered here [35].

[3]A role-playing exercise, developed by the MIT more than half a century ago, that continuous to be a powerful tool to explore dynamics of supply chains, as discussed by Macdonald et al. [26].

Table 1 (a) Definition of the noise levels—Levels 1–3, (b) Definition of the noise levels—Levels 4–6

Noise factor	Noise grade		
	1 (Mild)	2 (Low)	3 (Moderate)
A.Defective products rate	250 ppm	500 ppm	1,000 ppm
B.Transport capacity constraint	120 u	140 u	170 u
C.Factory capacity constraint	120 u	140 u	170 u
D.Demand: standard deviation	5 u	10 u	15 u
E.Production cost	0.001 $/u/day	0.002 $/u/day	0.004 $/u/day
F.Shipping cost	0.001 $/u/day	0.002 $/u/day	0.004 $/u/day
G.Storage cost	0.001 $/u/day	0.002 $/u/day	0.004 $/u/day
H.Order lead time: Range	0 days	0 days	0 days
I.Production lead time: Range	1 day	1 day	2 days
J.Shipping lead time: Range	1 day	1 day	2 days
Noise factor	*Noise grade*		
	4 (High)	*5 (Very high)*	*6 (Acid)*
A.Defective products rate	3,000 ppm	6,000 ppm	12,000 ppm
B.Transport capacity constraint	300 u	9876 u	9876 u
C.Factory capacity constraint	300 u	9876 u	9876 u
D.Demand variability	25 u	30 u	45 u
E.Production cost	0.007 $/u/day	0.01 $/u/day	0.02 $/u/day
F.Shipping cost	0.007 $/u/day	0.01 $/u/day	0.02 $/u/day

(continued)

Table 1 (continued)

Noise factor	Noise grade		
	1 (Mild)	2 (Low)	3 (Moderate)
G.Storage cost	0.007 $/u/day	0.01 $/u/day	0.02 $/u/day
H.Order lead time: Range	1 day	1 day	2 days
I.Production lead time: Range	3 days	4 days	6 days
J.Shipping lead time: Range	3 days	4 days	6 days

For this reason, this approach has been widely used in supply chain studies over the last decade, see e.g. Chatfield and Pritchard [2], Dominguez et al. [5], Costas et al. [4], and Ghadimi et al. [7]. To model the dynamics of the supply chain, we have used unbounded and stochastic Colored Petri Nets [19]. To implement the agent-based model, we have used the NetLogo environment [43].[4] Ponte et al. [32] provide a detailed description of the agent-based model that we have employed in this article. Specifically, we refer interested readers to Sect. 2.4 (*Agent-based implementation of the model*), which describes the static architecture of the system, its dynamic behavior via Petri nets, and how it has been validated and verified.

3 Results, Analysis, and Discussion

In this work, we explore the six noise scenarios defined above both when the supply chain operates according to Kanban and when it operates with the DBR mechanism. A time window of 230 days has been simulated for each of the 12 resulting runs, from run I to run XII, with the first 30 days being a warm-up period that is aimed at minimizing the impact of the initial state of the supply chain. Thus, the results we report are based on 200 days.[5] These are shown in Table 2.

We now conduct an exploratory study based on a dot graph, which is displayed in Fig. 1, followed by an ANOVA in order to understand the interaction between the compound noise grades (i.e. the disturbance of the system) and the inventory policy (i.e. the controllable factor). The results of the ANOVA study are provided in Table 3. It should be noted that both variables, i.e. the noise grade and the inventory policy, are significant (at a significance level of 10%). We note that the adjusted R^2 obtained

[4]NetLogo is a programmable modeling environment for agent-based modelling and simulation developed at Northwestern's Center for Connected Learning and Computer-Based Modeling. Please visit https://ccl.northwestern.edu/netlogo/ for more information.

[5]We checked the stability of the response of the agent-based supply chain and the repetitiveness of the results for our (30 +)200-day approach according to common practices.

Table 2 Results of the 12 simulation runs

Run	Noise grade	Policy	NP [$]	TS [u]	AT [p]	RTY [%]
I	1 *(Mild)*	Kanban	20,245.83	19,377	24.11	99.46
II	1 *(Mild)*	DBR	20,357.65	19,174	18.97	99.48
III	2 *(Low)*	Kanban	19,438.00	19,129	24.42	98.62
IV	2 *(Low)*	DBR	19,993.10	19,177	19.81	99.13
V	3 *(Moderate)*	Kanban	18,325.70	19,250	28.02	97.28
VI	3 *(Moderate)*	DBR	18,921.57	19,300	22.11	97.7
VII	4 *(High)*	Kanban	16,173.50	19,815	30.55	90.98
VIII	4 *(High)*	DBR	17,296.70	19,860	26.85	92.19
IX	5 *(Very High)*	Kanban	12,387.30	19,599	34.21	82.02
X	5 *(Very High)*	DBR	14,671.00	20,304	26.55	84.56
XI	6 *(Acid)*	Kanban	-1,511.81	19,220	38.76	63.57
XII	6 *(Acid)*	DBR	3,144.98	19,677	32.25	68.59

for the model is 97.15%, confirming that it represents accurately the results obtained via simulation.

Figure 1, which displays the net profit obtained by the LM- and TOC-based supply chains in the six noise scenarios, shows that Kanban and DBR offer similar performance when the intensity of the noise is very low. In both cases, the net profit is close to the ideal net profit that can be achieved under such conditions. However, as the intensity of the noise grows, both supply chains suffer from a noticeable decrease in the net profit. Nonetheless, it can be seen that this decrease is more accentuated in the Kanban system. Thus, DBR begins to make a difference as the noise becomes

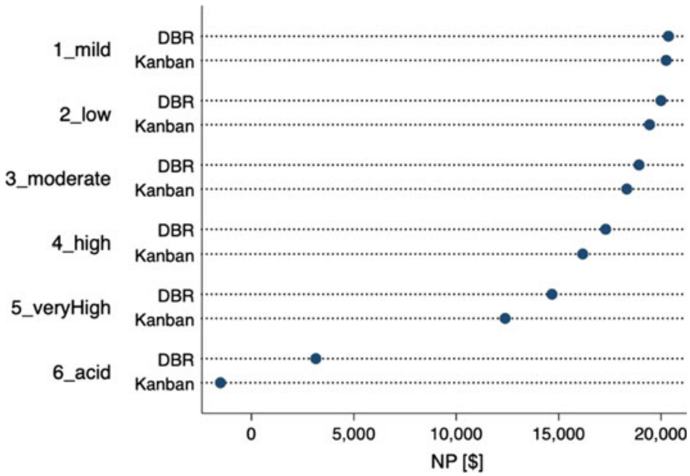

Fig. 1 Relationship between the net profit and the noise level for both supply chains

Table 3 Results of the ANOVA study

Source	Sum of Squares [Partial]	Degrees of Freedom	Mean Squares [Partial]	F ratio	P-value [Prob > F]
Model	5.469e + 08	6	91143407	63.55	0.0001
X_Policy	7248603.2	1	7248603.2	5.05	0.0744
Z_Noise grade	5.396e + 08	5	1.079e + 08	75.25	0.0001
Residual	7170526	5	1434105.2		
Total	5.540e + 08	11	50366451		

more intense. The more severe the noise conditions, the greater the difference in the net profit. That is, the sensitivity of the LM-based supply chain to the noise is higher, making it less robust to noise increases.

Looking at the last two rows (runs XI and XII) of Table 2, we observe that the net profit increase induced by the DBR methodology stems from a win–win solution. Through its bottleneck orientation, the inventory is appropriately allocated across the TOC-based supply chain, and hence this supply chain is able to achieve a higher service level (*TS* is higher) with greater agility (*AT* is lower) and less defective products (*RTY* is higher). From this perspective, we can conclude that the TOC-based supply chain becomes both more efficient and flexible.

It is important to note that our results are aligned with the second line of conclusions discussed in Sect. 1 (*Introduction*) for those papers comparing LM and TOC in the context of production systems. Also, the results in this work allow us to better understand some findings revealed in Puche et al. [33], through the consideration here of six scenarios of noise. We have seen the gradual increase of the difference between Kanban and DBR as the noise becomes more severe, which leads us to conclude that (i) the excess of complexity that the DBR methodology entails over the Kanban system may not be justified in easy-to-manage environments, but (2) adopting TOC-based solutions may be very rewarding when the supply chain operates in dynamic and uncertain contexts.

4 Conclusions

Supply chain managers now need to create, sustain, and maximize value in a complex business scene. Collaborative strategies for the supply chain, built on the pillars of *systems thinking*, are able to make a difference. In light of this, this work has compared the lean manufacturing (LM) and theory of constraints (TOC) holistic approaches to manage supply chains. Using agent-based modeling and simulation techniques, we have explored the performance of their pull rules to control the inventory, Kanban and drum-buffer-rope (DBR), in a four-echelon, single-product supply chain that faces a wide variety of noise sources.

We have observed that both systems lose significant net profit as the noise becomes more severe. However, the DBR methodology has proven to make the supply chain more robust against such noise. Interestingly, we have found that the difference in performance between DBR and Kanban, favorable to the former, grows noticeably as the noise becomes more demanding. Therefore, as regards the managerial implications of our work, we highlight that DBR proves to be a more appropriate alternative in uncertain and/or dynamic scenarios, while Kanban provides similar results at a lower implementation cost in foreseeable and/or static scenarios. In this sense, our findings have buttressed and extended prior research works in this area, from Grünwald et al. [11] and Takahashi et al. [39], in the context of production systems, to Puche et al. [33], in a supply chain scenario.

Having said that, it is important to emphasize again the exploratory nature of this work. Further studies are necessary to investigate in detail the link between net profit and supply chain noise. Ungrouping the noise grades (or compounds) into their individual components would allow for a more comprehensive understanding of the problem. Factor analyses may be of use in this regard. This is an important avenue for research taking into consideration that this study has provided clear evidence that the LM versus TOC dilemma in supply chain settings enormously depends on the severity of the environmental noise.

Another research avenue worth pursuing would be based on extending the application of LM and TOC principles from traditional, open-loop supply chains to the emerging closed-loop systems, which integrate forward and reverse flow of materials. Such closed-loop systems are gaining practical relevance in the current business environment due to current societies adopting more circular economic models in a bid to minimize environmental impacts and leverage economic opportunities [9, 10, 12]. From this perspective, investigating the LM versus TOC comparison in closed-loop settings with the aim of understanding how such closed-loop system can be optimized in practice would arguably help to accelerate the transition toward the desired circular economic models.

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Education and Training

Influence of Gamification on Student Motivation in Business Organization Subjects

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Abstract The Information and Communication Technology (ICT) offers new possibilities of improvement of the educational process in higher education. Nowadays, it is very important to motivate students to actively participate in classes and the use of games generates positive emotions such as feeling committed and fulfilled. The objective of this research is to analyze the impact of Kahoot! tool in the teaching of two subjects of business organization domain. Both subjects have identical contents but with the peculiarity that one of them is taught in the English language. From the perspective of students, the research shows that they are very pleased with the introduction of gamification as part of the educational process, showing a positive feedback of the tool. They consider that this tool increases the motivation and learning in a funny way. From the teaching perspective, the Kahoot! introduced in the class a series of intangibles that are difficult to measure quantitatively but that undoubtedly help to improve the dynamics of the group.

Keywords Gamification · Kahoot · Business organization · Motivation · Learning

1 Introduction

The rapid development of Information and Communication Technology (ICT) provides an improvement and dynamism in the teachings of the field of Business Organization. This development has influenced the traditional educational process and also changed the role of students and professors. In this new context, the gamification tools promote the greater participation of the student in the development of the subject, improving the results of the teaching-learning and evaluation process. The use of games generates positive emotions such as feeling committed and fulfilled [5]. These positive effects are due to the fact that games function as potentially motivating tools [11]. In order to create a concept where to study the effects of games in learning

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contexts, the definition of gamification emerges as the use of game design elements in non-game or pure game environments [4]. Gamification is currently applied in different domains such as marketing [7] or education [6] which is the field in which the present investigation is going to focus on. There are previous works about gamification in the literature [12] which are usually grouped depending on the educational stage in which the field study was conducted (primary, secondary, university).

At the university level, there are several notable studies such as the one carried out by De-Marcos et al. [2], which showed how gamification improves individual work and competitiveness among students, or that carried out by Barrio et al. [1], where it was found that the use of answer games increased the motivation, confidence, and attention of the students. More specifically in engineering studies, highlights the study conducted by Markopoulos et al. [9] where he recognized the positive effects of gamification in engineering education such as increased motivation, interest, and knowledge acquisition. The mentioned studies usually consist of applying some gamification tool in groups of students and evaluating their effects. In this sense, there are multiple tools to carry out the gamification in the classrooms. Game-based learning systems can be implemented through simulators, or mobile applications [12]. Among the mobile applications highlights the tool called Kahoot! [8], very useful for creating quiz games, debates, and surveys [10].

Based on this background, it is of interest to continue analyzing the effects of gamification in university subjects, more specifically in the area of business organization, applying a widely extended tool such as the Kahoot!. Consequently, the objective of this research was to analyze the impact of the Kahoot! in the teaching of two subjects of business organization with identical contents but with the peculiarity that one of them is taught in the English language.

After this introduction, the remainder of the paper is structured as follows. Section 2 is devoted to explain the proposed methodology. Then, Sect. 3 analyzes the results while Sect. 4 presents the conclusions.

2 Methodology

In this section, firstly, we present the selected subjects and we provide overall information of them. Secondly, the Kahoot tool is introduced and then, we explain how it works. Finally, the design of the methodology is detailed.

2.1 Description of the Selected Subjects

In this study, we have selected a subject that is taught in Spanish and English language in two different groups. The content of this subject in each group is identical, being the language the only difference. The title of the subject is "Occupational Health and Safety Management", which belongs to the Business Organization area and it is taught in "Labour Relations and Human Resources degree", which is offered by the University of Malaga.

The number of students varies in the two groups since the one offered in Spanish is compulsory in the mentioned degree, while the one offered in English is eligible by the student. As a consequence, the Spanish group has around 74 students each year, while the one offered in English has around 40 students every year. It should be noted that a high percentage of students of the subject in English are foreign exchange students, from various degrees from their country of origin, most of them in the field of economics and engineering. The usual profile of the student who studies this subject is usually an average age of 21 years. Although every year there is usually a percentage of around 25% of students who are older than that age, which makes their work compatible with their university studies. Regarding gender, 43% of the total of those enrolled in both subjects were men, while 57% were women.

2.2 Kahoot!

Kahoot! is a student response system that engages students through game-like pre-made or improvised quizzes, discussions, and surveys [3]. Students do not need a Kahoot! Profile to access the quiz and can access the quiz through any device with a web browser. The teacher can access previously published games with their respective questions and answers, adapt them, or create new questions and answers.

Once the questions have been designed and the answers included in the platform, the teacher saves the Quiz. Once in class, the teacher activates the Kahoot to start playing. When activated, a Game Pin is generated, which each student should enter through the platform https://kahoot.it. After that, the student chooses an alias to play (usually surname and first name). Once all the participants have registered, the teacher starts the game by pressing "Start" and the first question appears, with 4 possible answers and that can be answered in the predetermined time by the teacher, which is usually 20 s per question.

The student answers as if he/she had a button on the screen of the device with which he/she is participating, since the screen is divided into four possible response options. After each question, a bar graph appears indicating the number of students that have chosen each of the four options, and the following screen shows a podium with the three best students based on their successes and the speed with which they have answered. Next, the following question appears, and the sequence is repeated until the questions are finished and a final podium with the three best students appears, as well as a list with the total classification of the students. All the results can be downloaded in an excel sheet and downloaded so that the teacher has a control and follow-up of the students at a particular level, as well as the evolution of the group.

2.3 Questionnaire Design

For the present research investigation, a total of five questionnaires were designed with a total of four questions per one. Three of them were designed in English and two in Spanish language. At the time of being answered by the students, one of the questionnaires in English language was answered by both, Spanish and English groups. This was possible thanks to the fact that the contents of both subjects are the same, with the only difference of the language. In short, the two groups completed a total of three Kahoot!. Next section details the results for both, the Spanish and English groups.

3 Results and Discussion

3.1 Spanish Group

Table 1 shows the results of the questionnaire carried out in the Spanish group. The Kahoot! questionnaires were developed spaced in time, the first at the beginning of the course in the first month of the semester, the second in the middle, and the third during the last month of class. It can be seen a considerable increase concerning the percentage of correct answers ranging from 49% in the first questionnaire to 80% in the last one. These results seem to indicate that the impact on the acquisition of knowledge is not only positive, but that impact increases as the dynamics consolidate throughout the course. It should also be mentioned that questionnaire 2 was carried out in the English language, on a subject taught in Spanish, which meant an added degree of difficulty. Despite this fact, the students improved the results of the preceding questionnaire.

Due to the increase in the correct rate, the average score increased, but this increase was also influenced by the speed of response, since higher speed higher score. In view of the data obtained, the answers improved in both rates and speed.

Table 1 Result of Spanish group

	Questionnaire 1	Questionnaire 2	Questionnaire 3
No. of participants	61	52	38
Percentage of correct answers	49.36%	58.65%	79.79%
Failure rate	50.64%	41.35%	23.03%
Average score	1630	2046	2839

Table 2 Opinion of the students of the Spanish subject

	Average	Deviation
Kahoot motivates me to learn more	3.2	0.63
Kahoot facilitates the learning of the subjects	3.04	0.6
Kahoot is an effective tool to correct my misconceptions about the subject	3.32	0.47
Kahoot is fun	3.28	0.52

At the end of the course, the students were asked to respond to a brief questionnaire about their experience with the Kahoot! Tool. This questionnaire is based on a Likert scale where value 1 was “totally disagree” and value 4 was “totally in agreement”. Results are shown in Table 2 and as can be seen, most students agreed that the use of Kahoot! increased their motivation, facilitated their learning, helped them to correct errors in concepts, all while having fun.

3.2 *English Group*

Regarding the results of the subject in English language shown in Table 3, several aspects stand out. As can be observed, results varied significantly in comparison with the Spanish group in spite of the questionnaires were carried out in the same weeks of the course and similar contents were evaluated. On the one hand, the positive tendency in the improvement of the percentage of correct answers is barely appreciated between the first and last questionnaire, being very similar between them and decreasing noticeably in the mid-course questionnaire. Although we can see a more significant improvement in the average score between the first and last questionnaire, from which it follows that the hits were similar, the speed of response increased in the last one.

On the other hand, the questionnaire conducted in the middle of the course presented the worst results of all those made in all the groups. That same questionnaire in English was made in the Spanish group and obtained almost 10% more hits, a fact that although at first may seem contradictory may be due to various factors.

Table 3 Result of English group

	Questionnaire 1	Questionnaire 2	Questionnaire 3
No. of participants	32	19	25
Percentage of correct answers	66.30%	49.28%	67.71%
Failure rate	33.70%	50.72%	32.29%
Average score	1716	1501	2431

Table 4 Opinion of the students of the English subject

	Average	Deviation
Kahoot motivates me to learn more	3.1	0.61
Kahoot facilitates the learning of the subjects	3.2	0.59
Kahoot is an effective tool to correct my misconceptions about the subject	3.4	0.55
Kahoot is fun	3.3	0.49

Among these conditioning factors, it is worth noting that the native language of the students of the English group in the majority of cases is different since the students came from countries as diverse as Germany, Greece, France, Turkey, or South Korea. The heterogeneity of this group was not only country and language, but also of degree of origin which evidently conditions the development of the class. The discrete result of this questionnaire was of great help to the teacher to put the focus on that session and redesign the delivery of these contents, and future contents, both for this year and for upcoming courses.

As well as the students of the Spanish group, in the last session of the course a questionnaire was distributed to them to gather their opinion about a series of aspects of the Kahoot!. Table 4 shows the results that were similar between both subjects. In general, their impressions were that the Kahoot motivated them, facilitated learning while having fun and helping in correcting errors.

4 Conclusions

The experience of the design, development, and implementation of questionnaires based on the Kahoot tool! in subjects of the Business Organization area has been very positive both from the point of view of the teacher and from the point of view of the students.

The students of the two subjects presented a series of similarities and differences. Among the similarities highlights the fact that despite being taught in different languages have issued a feedback on the very similar and positive tool. The students emphasize a greater motivation to learn, at the same time as the fun in the classroom and the assimilation of concepts. Regarding the differences, the most significant was that the overall improvement of the results throughout the course was greater in the Spanish group.

From the teaching point of view, the Kahoot! introduced in the class a series of intangibles that are difficult to measure quantitatively but that undoubtedly helped to improve the dynamics of the group. The degree of attention was greater throughout the sessions since what was being explained was likely to be included in some issue of the Kahoot!. Another positive aspect was that the failure in any particular issue fostered a second more specific and concrete explanation in which the students were more likely to raise their doubts. It was also a great help, thanks to the real-time feedback of the students, to focus on those contents that were not entirely clear to improve their design and delivery.

In addition to these mentioned intangible aspects, more easily quantifiable evidences were found as were the academic results. Comparing with historical records of the subjects, the fact that in 2 previous years the average of non-approved was around 23%, whereas in the year that the Kahoot! was implemented that percentage decreased to 13% as an average of both. In view of the improvement of the results, it can be interpreted that the Kahoot! acted as a factor of improvement of academic performance.

Statement on Compliance with Ethical Standards The Research Ethics Committee of the University of Málaga approved the protocol and procedure followed by the authors in this research work. (ref. 049). All participants of our study gave their informed consent. The relevant data has been anonymized and authors also declare that they have no conflict of interest.

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Perceptions About Availability of Technological Resources and Training Needs: A Gender Perspective Based on Supercomputing-Related Courses

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Abstract The use of technology is key in the performance in a lot of fields, helping in the improvement of results in a wide variety of organizations. Currently, Supercomputers are considered as one of the most relevant and powerful technological infrastructures, because of this, the analysis of the availability and the training needs, in relation to technology based on supercomputing services, are very important to understand the development of Research and Development (R & D) activities in all type of organizations. It is also important to know the perception of this variable in relation to gender, in order to ensure equality of opportunities to guarantee equal education for any person. During the literature review, one of the main limitations found, in the training of qualified personnel, is the lack of availability of technological infrastructures. In relation to gender, some studies were found, about relations of gender, technology, and education. The present work analyzes the influence of the perception of availability of technological resources in the perception of adequate training of students, related to supercomputing, with a special view in the gender perspective.

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Keywords Learning · Supercomputer · Ph.D. · Researcher · Course · Technology · Gender

1 Introduction

The need of availability of technological infrastructures is a key issue when studying training aspects, mainly in those situations in which high computer technology is an important part of the work.

One of the most important infrastructures for the training of qualified personnel are supercomputers, which are infrastructures that provide advanced computational services to support mainly R & D activities in the numerical simulation of complex problems, characterized by the great reduction of processing time for obtaining results and reducing costs in the design of final products, by reducing the need to manufacture a large number of prototypes [29]. Through the review of the literature, it has been observed that one of the main limitations in the training of qualified personnel is the lack of availability of technological infrastructures.

This paper analyzes how the perception of availability of technological resources by users of supercomputing centers influences in the perception of the quality of training received, with a special analysis in the gender perspective.

The objectives set out in this work can be summarized as follows:

1. Analyze the existing limitations in relation to the availability of technological resources.
2. Analyze the type of students and their opinion in relation to the availability of technological infrastructures and training in technology.
3. Elaborate a logistic regression model with the previous variables.
4. Comparative analysis of the model, in relation to gender.

Technology and training are considered two of the main criteria in international competitiveness rankings, according to the World Competitiveness [18] and the World Economic Forum 2017–2018 [30], helping countries to achieve prosperity and higher quality of life. These Competitiveness Reports have been used as a tool that contributes to improve economy's productivity and its ability to achieve sustained levels of prosperity and growth. The main ones involved in the development of the conclusions of these studies are policy-makers, business executives, and academics.

In many advanced countries the value of economic growth, for the society, has been based on the way in which challenges of technological change were faced. In relation to this, some authors [9] allude to the availability of resources as a factor of interest to favor the innovative use of ICT in the classroom, while others emphasize that technological availability is a crucial element in the exploitation of ICTs for training activities [6]. Supercomputing is one of the most cutting-edge technologies incorporated into education, with which the student explores real scientific problems from very diverse fields of knowledge [29], through practical experience [3], which improves their training.

Technology education has a strong gender-related dependence, in fact, the gender-technology relation challenges were studied widely since decades [15, 1]. In the same line, some authors [19, 31, 33, 10, 11] show gender and technology relations in education.

Currently, in many countries, the adult education systems tend to reinforce existing gender and economic disparities, with greater frequency of reskilling and upskilling by more educated, high-income workers with digital literacy skills [5]. According to different international reports around 25% is the percentage of women studying or working in the technology sector [4]. Gender equality and empowerment is currently an imperative across countries in modern societies. Ensuring gender equality, through active labor market policies, is essential for a real equal opportunities stage.

In order to motivate the equality of genders, and the development of the potential in technology, gender sensitive approaches should be developed in technology education [37].

The methodology used in the work has been (i) review of the literature in databases specialized in the subject; (ii) survey on training and technology, in which 97 students enrolled in courses related to supercomputing participated.

The results obtained are summarized in the following sections.

2 Objectives

The main objective of the study is the joint analysis on the perception of availability of technological resources and training needs, based on the specific case of supercomputing.

The specific objectives of the study are the following:

Objective 1. Limitations regarding the availability of technology and solutions to them.

Objective 2. Analysis of the Answers on Opinion of Technological Availability and Training.

Objective 3. Development of the model.

Objective 4. Comparative analysis, in relation to gender.

3 Methodology

The methodology used in this paper has been, firstly, the revision of the literature through the analysis of specialized databases in the subject, in order to know the scope of the phenomenon under study. The search process was based on manual search, mainly of journal papers and specific conference proceedings during the last decade. The journals selected include either empirical studies or literature surveys.

Subsequently, a quantitative method based on a survey was carried out, for which a group of items was prepared with the help of an Expert Committee, which were later validated in a pilot test. The final questionnaire obtained was sent to the students that appear in the database of the Supercomputing Center of Castilla y León (SCAYLE) after having participated in training activities organized by the Center.

The questionnaire used in the present study has been developed in the framework of a larger study, in which we want to deepen the influence that technologies have on the development of pedagogical, knowledge, and content aspects, taking as base the records mentioned in the previous paragraph. The survey comprises 18 questions divided into 2 sections, on a scale of 1 (the worst possible situation) to 7 (the best).

To carry out the empirical study, logistic regressions (multinomial and binomial), as the most commonly used to analyze models whose dependent variable is a nominal type with more than two categories, that is, it is a polytomic variable [8]. Logistic regression has been widely used for its ability to treat both numerical and categorical independent variables, and for the usefulness of the information derived from the analysis of the so-called "odds ratio" [2, 17].

4 Results

Results for each of the objectives proposed are the following:

Objective 1. Limitations regarding the availability of technology and solutions to them

Once the review of the literature has been carried out, a series of limitations have been found, mainly derived from the scarce availability of supercomputing facilities [3, 12, 32] due to (i) high costs [34, 36] or (ii) problems with the use of the operating system interface [21].

Some of the solutions have been (i) sharing infrastructures [27, 34], (ii) implementing new software [38], (iii) use open source software and operating systems to reduce cost and for easy use [3, 16, 35], or (iv) carry out the work through the computer system based on clusters looking for flexibility [3].

Objective 2. Analysis of the answers on opinion of technological availability and training

The survey was prepared with the collaboration of an Expert Committee, which was subsequently validated in a pilot test. The final questionnaire obtained was sent to the students that appear in the database of the Supercomputing Center of Castilla y León (SCAYLE) after having participated in training activities in various fields (mainly in the Biomedical areas) organized by the Center. The total number of students that participated in the last 8 years in training actions, which were included in the Center's records, was 333, with the number of questionnaires answered 97, which represents 29%, and may be within acceptable limits of representativeness of the population under study.

The general results of the survey related to the characteristics of the participants can be seen in Table 1.

Table 1 Results of the test

Gender	
Male	43
Female	54
Age	
25 to 35 years old	51
36 to 50 years old	36
More than 50 years old	10
Field	
Sanitary and biomed. Areas	66
Engineering	16
Others	15
Entity of belonging	
Universities	63
Research Centers	27
Firms	7

The variables analyzed through the development of the model of the present study are categorical and are the following:

- The question of whether you have easy access to the technological resources you need to carry out your activity, the answers were Yes, 74 students; No, 7; and Maybe, 16.
- Regarding the question of whether your entity offers adequate training in the use of technologies, the answers were Yes, 44 students; No, 27; and Maybe, 25.

Objective 3. Elaboration of the Model

For the development of the model, similar studies have been followed [7, 13, 14, 22–26, 28], that related both variables: (i) technological availability, as an independent variable and (ii) availability of training, dependent variable.

For the contrast, a multinomial logistic regression has been used, which is used to analyze models whose dependent variable is a nominal type with more than two categories, that is a polytomic variable [8].

With the data obtained in the regression, we observe that it presents good indicators of validity, since (i) the percentage of valid cases is 100%; (ii) the Chi test of likelihood ratio indicates that it is significant.

The analysis of the Pseudo-R2 that quantifies the proportion of the variance explained by the logistic regression model obtained presents acceptable values. The most important parameter to analyze the adjustment is the Nagelkerke R2 that verifies the predictive effectiveness of the probability of occurrence of the categories of the dependent variable. In this case, the value is 25.7%, which can be considered acceptable [20]. This data indicates that the remaining 74.3% of the model could be explained by other variables not included in the study.

In the final estimation of the parameters obtained (Table 2) we can see that the explanation of the dependent variable DISFOR is significant with respect to the independent variable DISTEC in the case that both had the answer "Yes".

A phenomenon of interest is to compare the level of influence or strength of the independent variable on the dependent variable. In this sense, we look at the Odd ratio (column Exp. (B)), whose result tells us that affirmative opinions on technology availability (DISTEC), mean that there is 7 times more likely that the response on availability of technology training (DISFOR) is affirmative, that in the case of those who consider that they do not have adequate technological availability. These results are significant, according to the criteria of Jovell [20] that a significance of the Wald statistic less than 0.25 is adequate. At the same time, the fact of having a lower limit and an upper limit of the confidence interval, higher that 1, shows, in the case of response Yes for both variables, a strong significance.

Table 2 Parameter estimated

								95% Confidence interval for Exp (B)	
DISFOR[a]		B	Standard error	Wald	gl	Sig	Exp(B)	Lower limit	Upper limit
No	Intersection	0,288	0,540	0,284	1				47,988
	[DISTEC = No]	1,504	1,208	1,551	1	0,594	4500	0,422	
	[DISTEC = Yes]	−0,539	0,647	0,694	1	0,213	0.583	0,164	2,073
	[DISTEC = Maybe]	0[b]	0,816		0	0,405			
Yes	Intersection	−1,099	0,000	1,810	1				
	[DISTEC = No]	−17,724			1	0,178	2,007E–8		2,007E–8
	[DISTEC = Yes]	**1,946**	**0,864**	**5,076**	**1**			2,007E–8	38,046
	[DISTEC = Maybe]	0[b]			0	**0,024**	7000	1,288	

[a]The reference category is Maybe
[b]This parameter is set to zero because it is ‹redundant

Objective 4. Comparative analysis, in relation to gender.

Through the base of the multinomial logistic regression model described in O3, variables shown are as follows: (i) technological availability (DISTEC), as an independent variable, and, (ii) availability of training (DISFOR), dependent variable, were used to analyze the results according to gender.

For a better understanding of the phenomenon in relation to gender, responses were grouped in Affirmative (value = 0) and Not Affirmative (value = 1), in order to use a binary logistic regression, for comparing the results both in female and male genders to see which group consider more deeply that availability of technology (DISTEC) influence in the consideration of adequate training (DISFOR).

Table 3 shows the responses shown in Table 1, depending on the gender:

In both cases, as in the general O3 model, with the data obtained in both regressions, we observe that it presents good indicators of validity: (i) the percentage of valid cases is 100%; (ii) the Chi test of likelihood ratio indicates that it is significant, as seen in Table 4.

In relation to the analysis of the proportion of the variance explained by the model obtained (Pseudo-R2), Nagelkerke R2, that verifies the predictive effectiveness of the probability of occurrence of the categories of the dependent variable, can be considered acceptable according to [20], in spite that are not high values, as seen in Table 5.

Looking at models, the –2 log. Likelihood ratio, in both models, is significant, meaning that at least, a subset of the predictors have non-zero effects.

Although the goodness of fit coefficients is not entirely reliable, the classification table is normally the criteria that we must follow to indicate the goodness of fit of the models. This table shows the cases well classified in the main diagonal, and the cases poorly classified in the second diagonal. Table 6 shows that the percentage of subjects correctly classified by the model is 64,8%. From these data in Step 1, not

Table 3 Responses to DISFOR and DISTEC depending on gender

Gender	Response	DISFOR	DISTEC
Female	Yes	67	84
	No	14	4
	Maybe	16	9
Male	Yes	74	87
	No	14	3
	Maybe	9	7

Table 4 Omnibus test of the models

Model	Chi-square	gl	Sig
Female	10,914	1	0,001
Male	7,912	1	0,005

Table 5 Resume of the models

Model	Step	−2 log. Likelihood ratio	Cox and Snell R2	Nagelkerke R2
Female	1	63,278a	0,183	0,245
Male	1	51,489a	0,168	0,224

[a]The estimate has ended in iteration number 5 because the parameter estimates have changed by less than, 001

Table 6 Table of classification of female gender[a, b]

Steps	Observed		Forecasted		
			DISFOR		
			Affirmative	Not affirmative	Correct %
Step 0	DISFOR	Affirmative	0	24	0
		Not Affirmative	0	30	100
	Overall %				55,6
Step 1	DISFOR	Affirmative	23	1	95,8
		Not Affirmative	18	12	40
	Overall %				64,8

[a]The constant is included in the model
[b]The cutoff value is, 500

affirmative availability of training (40%) shows low values and an affirmative availability of training (95,80%) shows high values so that the model adequately shows the phenomenon in study. Table 7 shows that the percentage of subjects correctly classified by the model is 65,1%. From these data in Step 1, not affirmative availability of training (39,1%) shows low values and an affirmative availability of training

Table 7 Table of classification of male gender[a, b]

Steps	Observed		Forecasted		
			DISFOR		
			Affirmative	Not affirmative	Correct %
Step 0	DISFOR	Affirmative	0	20	0
		Not Affirmative	0	23	100
	Overall %				53,5
Step 1	DISFOR	Affirmative	19	1	95,0
		Not Affirmative	14	9	39,1
	Overall %				65,1

[a]The constant is included in the model
[b]The cutoff value is, 500

Table 8 Variables in the equation (female)[a]

								95% Confidence interval for Exp (B)	
B			Standard error	Wald	gl	Sig	Exp(B)	Lower limit	Upper limit
Step 0	Constant	0,223	0,274	0,664	1	0,415	1,25		
Step 1	DISTEC(1)	−2,73	1,087	6,304	1	0,012	0,065	0,008	0,549
	Constant	2,485	1,041	5,7	1	0,017	12		

[a]Variables specified in step 1: DISTEC

Table 9 Variables in the equation (male)[a]

								95% Confidence interval for Exp (B)	
		B	Standard error	Wald	gl	Sig	Exp(B)	Lower limit	Upper limit
Step 0	Constant	0,140	0,306	0,209	1	0,648	1,150		
Step 1	DISTEC(1)	−2,503	1,111	5,071	1	0,024	0,082	0,009	0,723
	Constant	2,197	1,054	4,345	1	0,037	9,000		

[a]Variables specified in step 1: DISTEC

(95,0%) shows high values so that the model adequately shows the phenomenon in study.

The adjustment of the model through the Hosmer–Lemeshow test has not been applied due to the small number of variables applied in the study, where the values observed and expected are coincident.

Once seen the significance of the data, the results of the final models are shown in Tables 8 and 9.

In order to compare the difference of the results between genders, next step will be the analysis of odd ratio (OR) of the column Exp. (B) of Tables 8 and 9 of both cases. As seen, values in the case of male gender (0,082) and in the case of female gender (0,065), shows that the OR of DISTEC variable is significantly less than one, which is considered a protection factor, so higher values of this variable are associated with higher values of the DISFOR variable.

For the analysis of the results of Tables 8 and 9, we proceed to analyze the inverse of the Odd ratios, so that the results are as follows:

– Odd ratio reversal Table 8 (female): 1/0.065 = 15.38.
– Reverse of the Odd ratio Table 9 (male): 1/0.082 = 12.19.

In this case, we observe that, in the female gender, the value of positive consideration of the availability of technological tools (DISTEC) has a greater influence on the consideration of having adequate training (DISFOR) than in the case of the male gender.

Finally, we highlight that these results are significant, according to the criteria of Jovell [20] that a significance of the Wald statistic lower than 0.25 is adequate. At the same time, the fact of having a lower limit and an upper limit of the confidence interval, lower that 1, shows, in the case of response Yes for both variables, a strong significance.

5 Conclusions

In relation to the proposed objectives, the following conclusions have been reached:

1. It is appreciated that, through the review of the literature, there are a lot of studies that analyze the phenomenon. Both the problem of availability of technological resources and the solution to it are aspects of interest and relevance in the field of studies related to training.
   The incorporation of gender studies in the curricula is very important to close the gender gap in education. In this line, a wide number of studies about the relation of gender and technologies were found, which determine the importance of this aspect in future researches in this issue.
2. It is observed, firstly, that students who participate in the courses are highly qualified, belonging mainly to Universities (65%) and Centers related to research (28%), working most of them in the Sanitary and bioareas (68%). In relation to gender, 44% are male and 56% are female.
   Secondly, in relation to the questions that analyze the variables under study, it is observed that a large number of respondents estimate that they do have adequate technological resources, and, at the same time, they consider that they have adequate training in the use of technology.
3. The results of the empirical study allow us to conclude that the parameter that best explains the affirmative result of the variable on perception of the availability of training (DISFOR) is the affirmative response on the availability of technology (DISTEC), so that, it can be concluded that students who consider that they have available an adequate technology tool, also consider that they have good training associated with it.
4. The results based on the empirical study by gender shows that females have more possibilities to consider that an adequate training (DISFOR), is influence by the availability of technology (DISTEC). It can be concluded that the positive consideration of availability of adequate technological resources of the students of both genders is linked with the consideration of having a good training associated with it.
   As a resume, we can conclude that the study of availability of technological resources is important because it is considered a critical driver of productivity

growth and value creation that help in the new reality for organizations, influenced by the advent of the Fourth Industrial Revolution (4IR), new empirical evidence, and new data.

The quality and quantity of R&D investment, technology and financing, play critical roles in the innovation for creating successful products, so, the skills in the use of technologies, that enhance the capacity to innovate, should be studied deeply.

In the future, technologies are likely to be disruptive both for the outcomes of research and labor market, due to the fact that workflow is clearly at high risk of being automated. Policies are needed to ensure that technology impact on the economy, avoiding the prevailing gender gaps, based in a parity in education, training and access to technology. This suggests a need to reform and adapt the whole education systems and workforce training to reduce skill-mismatches and remove barriers to lifelong learning. In this line, education programs should approach conceptual mismatches between gender or sex and change its foundations to guarantee equal education for any person by limiting the influence of social stereotypes and dominant culture.

Finally, we have to highlight that the present work is transversal, so that the interpretation of the results is limited to describing associations and as recommended by Jovell [20], considering that the results of logistic regression in cross-sectional studies should be used as descriptive and not to perform future inferences.

Through the data obtained in the study, we have reached conclusions that may be of interest for the preparation of training actions in the future for courses related to technology. However, as limitations, we emphasize that the model could provide more interesting data considering a greater number of explanatory variables.

Statement on Compliance with Ethical Standards For the realization of this study, the data used have been collected from students of the database of the Center of Supercomputing Center of Castilla y León (SCAYLE) who previously admitted, in the online forms for collecting their personal data, any referral of information and/or participation in studies carried out by the Center. SCAYLE does not have an Ethics Committee, so favorable information has been collected from the Center's Management for the development of work, taking into account that the use of the information is anonymized and the data is only used in aggregate form.

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Design Thinking (DT) in Engineering Education (EE): A Systematic Literature Review (SLR)

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Abstract Design Thinking not only is a well-known technique for user-oriented product design, but also is an education technique in Higher Education. Design thinking is increasingly used as an innovative educational tool to promote in engineering student transversal skills as critical thinking, creativity, and teamwork. However, despite its popularity, the teaching community has implemented it in many different ways focusing on specific aspects without taking in notice of previous experiences. The aim of this work is to analyze the literature published about Design Thinking experience in Engineering Education through a systematic literature review. Our conclusions will contribute to this educational area pointing the state of the art and the future lines of this educational methodology.

Keywords Engineering · Education · Design thinking · Systematic literature review

1 Introduction

Nowadays, modern society is facing huge techno-economic and social changes leading to new forms of organization. Due to this challenge, Higher Education is required to implement new teaching methodologies, directed toward developing in students a set of skills necessary for performing properly in this new paradigm. These new skills which have to be promoted include creativity, teamwork, critical thinking, and the ability to face complex problems. These skills will be, even more

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so than theoretical knowledge, what will define the position of students in the future labor market. The educational community has introduced different methodologies attempting to empower these skills. One stands out for its resounding success among all, known as Design Thinking.

The design thinking (DT) method has become popular among teachers based on its results at Stanford University [3]. However, despite its popularity, there is a weak point that prevents its utilization as the main method: it does not have a stable application framework. Every teacher tries to change some essential aspects to differentiate it from previous ones. This is very frequent in young techniques, but after ten years of popularization it is time to establish a framework for it in order to create a solid base with which to move forward.

Therefore, this paper aims to address this problem by analyzing the most important applications of Design Thinking in Education, continuing the work carried out by Serrano et al. [12], and developing Engineering Education through a Systematic Literature Review that will answer the following main questions:

- What are the leading educational areas in which DT has been applied?
- Why has DT gained relevance in engineering education?
- What results have been obtained from its application in engineering education?
- What are the recommendations and main future lines of research obtained from experiences already carried out?

2 Methodology

A systematic literature review (SLR) is originally from the field of Health Sciences [9, 15] and is based on the application of a set of reproducible protocols in a database. This method allows researchers to obtain greater objectivity and transparency, as well as achieving iterability in the revision of any topic. It differs from the narrative literature review, which is guided by the investigator's interests. SLR consists of combining a comprehensive database with criteria of inclusion, exclusion, and specific classification. To define the scope of the review, there should be enough flexibility to allow originality but enough structure to avoid any bias in the research results. According to Tranfield et al. [15], a systematic literature review is composed of three phases: Planning of the review, Conduct of the review, and Analysis of the results.

In the planning phase, we defined the database used as a source of information and fundamental questions of the research. The database used was the ISI Web of Science, which is one of the most complete databases for all areas of knowledge.

First, an initial search was made with all the documents that could be related to the concept of Design Thinking during the period 1987–2018. The range of more than 30 years analyzes the evolution of this method and its teaching applications. Establishing the beginning of the period in 1987 was not random. In this year Peter Rowe [11] published his book, entitled "Design Thinking", which named the concept as it is nowadays known.

So, after analyzing the most relevant published papers, a search protocol was implemented. First, we established all the journal articles containing the concept of "Design Thinking" in "Title" and/or "Abstract" as inclusion criteria. Second, we established our exclusion criteria, selecting only scientific journal articles whose core was related to education. The science indexes used in this research were Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), and the recently created Emerging Sources Citation Index (ESCI). The first search (inclusion criteria) yielded 221 scientific articles about Design Thinking, which were reduced to 83 articles after applying the exclusion criteria. This reduced group of papers was analyzed in-depth in the next phase.

3 Results

To analyze the papers filtered by the inclusion and exclusion criteria, we studied their formal aspects (date of publication, journal, and educational area), as well as the content of the papers (nature of the experiment, analysis of the results, and recommendations). In this part, the analysis focused on those related to Engineering Education.

The analysis of publication dates revealed the almost foundational importance of the work of Brown [3] as pointed out by Johansson-Skoldberg et al. [5]. This document settled the beginning of DT's popularity worldwide. In addition, it can be pointed out that although the number of papers on DT has decreased in the last two years, their application in education has remained stable (Fig. 1).

Table 1 shows the journals in which studies on DT methodology were published. Some of the most-used journals for researchers in Engineering were *Design Studies* (position 25th of 86 in the Web of Knowledge category *Engineering Multidisciplinary*), *Journal of Engineering Design* (position 29th of 86 in *Engineering Multidisciplinary*), and *International Journal of Technology and Design Education* (position 41th of 86 in *Engineering Multidisciplinary*).

Table 1 also shows that this subject matter has been published in high-impact journals in other fields, such as *Harvard Business Review* (25 out of 210 in the Management category) and *Academy of Management Learning & Education* (18 out of 239 in the Education and Educational Research category). The importance of those journals focused on Education had an obvious significant weight in the articles selected since Design Thinking in Education was analyzed, but its weight would have been reduced if all articles about DT had been considered.

Continuing with the analysis of the disciplines interested in this methodology, we classified the literature according to the participants' educational areas or their theoretical orientation. Table 2 shows the results of this analysis. This classification revealed a fundamental characteristic of DT, which is its tendency to set up multidisciplinary teams in which different profiles are combined. This category came first (16.87%), followed by Management (14.46%), Engineering (13.25%), and Design

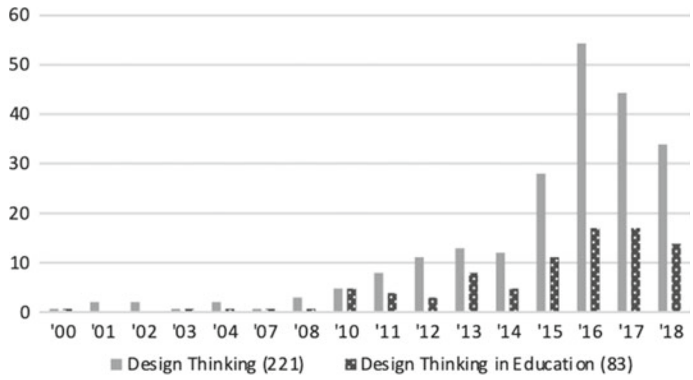

Fig. 1 Articles about design thinking (DT) and design thinking in education (DTE)

Table 1 Journals in which the articles about design thinking in education were published

Journal	Number of publications	Percentage of 83
Design Studies	6	6,70%
Thinking Skills and Creativity	4	4,40%
Education and Training	3	3,30%
Harvard Business Review	3	3,30%
International Journal of Art & Design Education	3	3,30%
Academy of Management Learning & Education	2	2,20%
Comunicar	2	2,20%
International Journal of Technology and Design Education	2	2,20%
Journal of Engineering Design	2	2,20%

Table 2 Educational areas of selected papers

Knowledge area	Number of papers	Percentage of 83
Multidisciplinary	14	16,87%
Management	12	14,46%
Engineering	11	13,25%
Design	10	12,05%
Education	9	10,84%
Architecture	3	3,61%
Medicine	3	3,61%
Journalism	2	2,41%
Primary Education	2	2,41%
Other	17	20,48%

(12.05%). It is a surprising result because Design was the last area in which DT was implemented. Also, it was observed that in recent years, DT has begun to be applied in disciplines such as Political Sciences and Medicine. The explanation for this phenomenon lies in the fact that DT provides a focus on people.

In order to carry out a content analysis of the articles focused on Engineering and Multidisciplinary areas (with the exception of two, the others mix Engineering students with other disciplines), the typology of the selected articles was analyzed by defining three categories:

- Theoretical: They delve into the framework of DT in Education making theoretical contributions or discussing its application (5 out of 24 articles).
- Educational Experiments: They analyze the application of DT in a controlled environment and have students as the subject of study (17 out of 24 articles).
- Real Experiences: They relate the experience of applying DT in a project that involves students and real social agents, for example, NGOs (2 out of 24 articles).

The analysis of the contents showed that the vast majority of papers focused on DT as a tool for developing creativity, critical thinking, and teamwork. The most applied methodology was Brown's [3], although they also applied their own techniques, (though always inspired by the work of Brown [3]. Analyzing the main orientations of this methodology, the reason for its popularity is easily understood; all adapt perfectly to the challenges posed in the teaching of Engineering:

- Integrative Orientation: It presents students with a challenge and encourages them to make use of available technology in order to produce the correct solution. This perspective is the one that most prevails in the multidisciplinary articles which combine Engineering and Management.
- Prototype Orientation: DT is highly experimental and is based on the empiricist process of "idea-prototype-test". This approach is used from the perspective of Design as a way to create, test, and improve products.
- Double Diamond Perspective: Its objective is to encourage creative ideas. It applies divergent thinking to explore many solutions and then uses convergent thinking to reduce their number until a final solution is reached.
- Human Orientation: People are the center of DT, both as end users and in the relationships that are generated during the development of the project (seeking the group's welfare). The need to transmit these values to future engineers is the main idea that underlies the teaching application of DT.

In relation to the objectives and results of the application of the methodology, conclusions from three areas were obtained: Application of the method, Comparison of methods, and Development in specific stages.

Regarding the first, there are experiences such as those focused on evaluating the results of the DT application in its entire dimension for developing soft skills and analyzing the final result of the activity [6, 7, 10, 8]. Studies show positive results from the application of DT. Regarding the second, the experiences focused on comparing DT with other methodologies found that DT was superior to other new teaching and traditional methodologies. For example, Tsai [16] compared the results of several innovative and classic techniques with DT. His results showed that DT methodology was far superior to other methodologies, especially when exam results were compared. Regarding the third, the last type of application of DT methodology occurs when teachers decided to delve into one of DT's phases (Ideation, Prototyping, or Implantation), as was the case of the studies by Taleyarkhan et al. [13] and Greenhalgh [4]. These papers focused on prototyping and used technologies such as CAD software and 3D printing, respectively. Both experiments showed that it was very useful to rely on these tools in this phase and that they also achieved significantly higher results than without using them. Taura et al. [14] studied the application of DT, and focused on the "ideation" phase in fostering creativity. In the experiment, they presented a problem to students, who were given a short time to define the solution. The results showed that those who knew DT could face the challenge more easily. The authors concluded that thought patterns influence the ideas generated and that DT methodology offered a "recipe" to generate more creative solutions. Behm et al. (2013) and Alhamdani [1] found similar results for this phase.

Finally, the main standard recommendation culled from all the articles was the need to carry out Design Thinking for a more extended period of time. Most of the experiences were short-time workshops. Also, many papers point out the need to introduce it in the curricular training of students as a technique for learning how to face complex problems. The most interesting direction proposed for future research was to go further in the collaboration between society and education by applying DT to help NGOs and disadvantaged groups. Other interesting lines were to delve into the educational technique itself, analyzing how personalities influence multidisciplinary teams' performances, how groups react to different environments (music, work areas, and so on) and address the need to develop an optimal method for evaluating results and the skills acquired.

4 Conclusions

The systematic review of the literature has revealed that Design Thinking is a proper teaching methodology for engineering areas and other disciplines. This technique achieves an increase in student's soft skills and is also a way to obtain innovative solutions. This is because the human orientation of Design Thinking provides at least two benefits. On the one hand, it provides solutions focused on the users' experiences. On the other hand, it provides a good working environment for finding creative solutions. Both aspects are the main goals of any modern profession. Higher Education must transmit this orientation to students at the outset of their learning.

In addition, this paper has demonstrated that the most applied technique of Design Thinking is the one created by Brown [3], because of its simplicity and its flexibility, it has become established as a standard in the field. Therefore, future applications of Design Thinking should follow its indications and introduce the fewest modifications to obtain comparable results.

In conclusion, the analysis of the practical experiences allows concluding that Design Thinking workshops in engineering education enhance creativity, teamwork, and critical thinking more than other innovative teaching methodologies do. Therefore, Design Thinking will grow in the educational sphere and in society, because it has been revealed to be the best technique for facing complex problems which focus on people's needs.

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Sustainability and Circular Economy

Ready for Industry 4.0—A Study of SMEs in Spain

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Abstract Industry 4.0 is one paradigm that is expected to change industrial SMEs performance. In this context, the work presented in this paper analyzes the paradigm of Industry 4.0 among 35 SMEs in Spain, participating in a project to share, discuss, understand, and plan their Industry 4.0 individual roadmap. Objectives, barriers, and interests regarding Industry 4.0 are discussed and compared with regard to company size, and other business key factors. The results presented in this exploratory research emphasize the differences among micro, small and medium SMEs when approaching Industry 4.0. Besides, the study identifies different Industry 4.0 technologies' importance for SMEs, as well as different balance for them depending on the company size and their value proposition. Barriers toward Industry 4.0 seem to be also very different with regard to the company size, what is consistent with other research results. Furthermore, the research also arises the spread of existing awareness about Industry 4.0 and the risk for smaller SMEs. This ongoing research gives an insight into the novel studies about Industry 4.0 in SMEs and deepens the knowledge for future research.

Keywords Industry 4.0 · Smes · Business model · Digitalization · Servitization · Value proposition

1 Introduction

Regardless of the consideration of what is or is not included under the "Industry 4.0" paradigm, the vast majority of definitions define as an element of their nature "the introduction of digital and other digitally supported technologies in business environments" fostering the Fourth Industrial Revolution [4, 12]. This Revolution 4.0

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aims at the technological and digital transformation of the business and organizational models [10], allowing a global business transformation to take place, marked by immediacy and by its constant evolution. Industry 4.0, encompasses large sectors, affects the present; and will define the employability of the future. Internet of Things, Augmented Reality, Artificial Vision, Collaborative Robotics, Big Data, Additive Manufacturing, Cybersecurity, or Cloud Computing are just some of the elements that make up this technological revolution [5].

This landing of the digital in the factory, actually affects all value chain links of the company and its networks, its suppliers, customers, services, and therefore the activities of the spaces and manufacturing ecosystems. The activities of technology development, design, purchasing, logistics, marketing, sales, after sales service and, of course, manufacturing itself in the midst of all of them, are to a greater or lesser extent affected by the effects of this current [8].

This high degree of connectivity of activities and processes aims to improve efficiency, allowing the physical and digital world to be interpenetrated and interwoven, creating an intelligent industry through the connection between physical and virtual processes. This translates into a considerable improvement in efficiency thanks to the implementation of multi-sensorial systems, eliminating the variability of the processes and optimizing each production process or service provision [15]. This transformation also brings innovation and improvement to value propositions and to current and future business models of companies, through the incorporation of new functionalities to products, the development of new products and services, or access to new forms of marketing and distribution, with the possibility of accessing new markets [3].

The capability of SMEs to fit this concept, and to use the associated technologies and skills to improve their value chain, value proposals, business models, activities and decisions systems will determine, to a large extent, their future competitiveness and sustainability [7].

2 Industry 4.0 in SMEs

Industry 4.0 represents a challenge for SMEs [6] due to its technological impact, and even more for its impact on the activities and business models of companies. Since many institutions consider that it is a key element of competitiveness for the industrial sectors, public administration as well as other active agents in the competitive development of companies, are promoting different programs and initiatives toward the development of Industry 4.0 [10].

In addition, SMEs are also aware of the impact of the introduction of Industry 4.0 technologies and the efficiency metrics that this can entail, in order to maintain or improve the competitiveness of the industry through greater digitization [13].

Despite this impulse, companies and especially SMEs consider that the incorporation of these technologies causes only technological implications, without being aware that this technological change causes deeper implications as intensification of servitization, and changes in business models [6].

Thus, in this context the objectives that companies pursue with Industry 4.0 should be clear, because it is not about implementing one or another technology, but about achieving lasting competitive advantages through those facilitating technologies. An example of this approach is the recent report of the World Economic Forum, which identifies “lighthouses’ related to the implementation of Industry 4.0 technologies in large companies [14].

In this same sense, SMEs must clearly identify their objectives and strategies in relation to Industry 4.0, and focus their transformation projects toward productivity, agility, and personalization of their proposals. For the development of this work, SMEs have different methods and maturity model approaches that could be applied [11].

Furthermore, in the academic field, different researches are being developed in the field of Industry 4.0 in SMEs, with different opinions regarding the impact that Industry 4.0 will have on SMEs in the future, especially in the case of small SMEs [9, 13]. Thus, this study analyzes the perception of a group of those small SMEs in relation to Industry 4.0, their objectives, approaches toward technology and confronting barriers.

The study focuses on the comparison of the existence of an Industry 4.0 strategy in companies, the strategic importance of Industry 4.0, the objectives pursued by companies when implementing Industry 4.0, the established importance of Industry 4.0 technologies, and the perception of barriers related to the implementation of Industry 4.0.

3 Method

Data was collected using a structured questionnaire administered during five sessions with the support of researchers. The different sessions carried out were directed to SMEs managers and the process was based on an explanation of Industry 4.0 concepts and technologies during each one of the sessions, continuing with a self-reflection exercise. Thus, each one of the SMEs’ managers and other companies’ personnel performed an individual and group awareness work, in order to put into their own context the explained concepts and technologies.

The field study was developed between October 1 and November 30, 2018. The data was collected using a structured questionnaire filled in after each one of the sessions, using previously defined scales [2, 12] on Likert (1—Not important, 2—Important, 3—Very Important) or categorical bases. The sessions planning and scheme, as well as the thorough discussions (putting into their own context Industry 4.0), assured the quality and calibration of the data.

Thirty-five companies participated in the study and all those companies completed the questionnaire. The questionnaire was mostly fulfilled by CEOs or other C-Level Executives (65,71%). The stratification of participating companies was defined by the number of employees: Micro—less than 10 employees (62,86%), Small—less than 50 employees (17,14%), and Medium—Less than 250 employees (20%).

4 Results

When analyzing the Industry 4.0 interests, as well as the objectives and barriers of participating SMEs different Industry 4.0 approaches appeared (Fig. 1), regarding awareness, readiness, and capabilities, in coherence with other research studies arise [13].

Furthermore, product-based organizations confirmed higher values compared to non-product-based companies in line with other research studies [12]. Product-based companies were more aware about the impact and importance of Industry 4.0, reported higher levels of definition in their Industry 4.0 strategy, had invested more in Industry 4.0 and were more confident about their readiness for Industry 4.0 (Table 1).

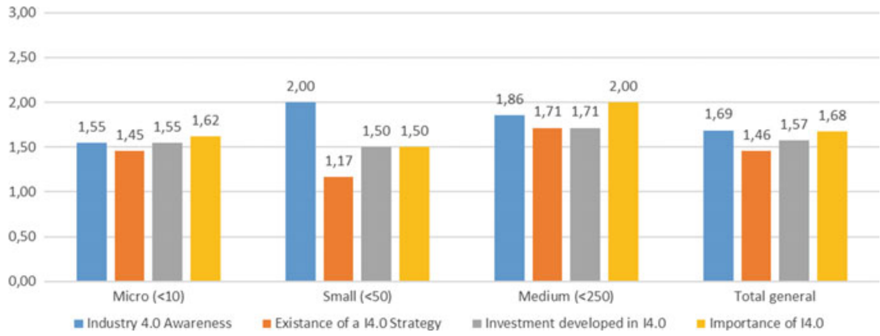

Fig. 1 Spanish SMEs and Industry 4.0

Table 1 Industry 4.0 approach and product-based companies

SMEs Industry 4.0 approach	Own product (NO)	Own product (YES)
Industry 4.0 Awareness	1,42	1,85
Existence of a I4.0 Strategy	1,25	1,55
Investment developed in I4.0	1,33	1,70
Importance of I4.0	1,50	1,79
Actual I4.0 situation (mean)	1,38	1,73

On the other hand, when comparing the objectives pursue by companies when implementing Industry 4.0, motivations among different size companies are distinct. MicroSMEs seem to have doubts about their objectives, while Small SMEs focus their objectives on the digitalization of their business. Bigger companies, on the other hand, consider that flexibility and efficiency are the main objectives when implementing Industry 4.0 (Fig. 2).

Additionally, product-based companies versus non-product-based SMEs highlight different objectives with higher overall values for the former ones (Fig. 3).

Another element studied in this research refers to the importance of Industry 4.0 technologies for participating SMEs. Different technologies may influence different elements of the business model of the company, from the value proposition (product or service) to the key activities or processes that the company develops, or the relationships and activities with suppliers and other key actors of its value chain [1]. Thus, the companies in the study, depending on their size (Fig. 4) and their business

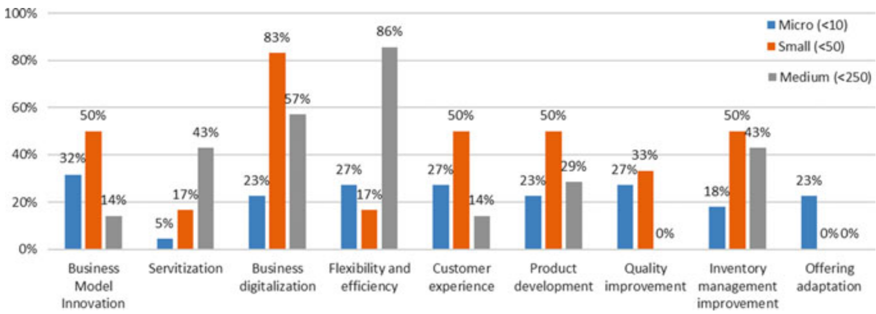

Fig. 2 Industry 4.0 implementation objectives

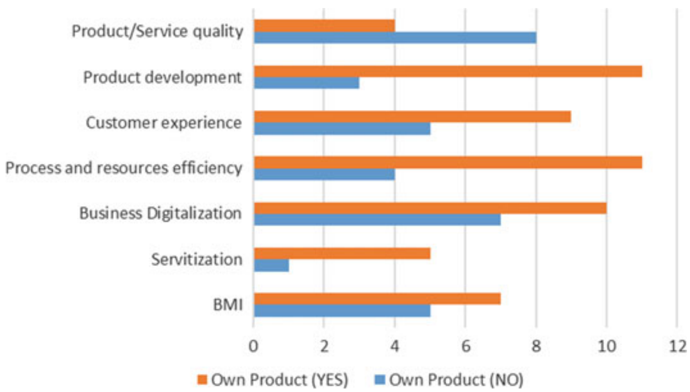

Fig. 3 Number of companies per Industry 4.0 implementation objective (product-based vs. non-product-based SMEs)

model (Fig. 5), indicate different levels of importance in relation to Industry 4.0 technologies.

MicroSMEs do not highlight any specific Industry 4.0 technology, in comparison to Small SMEs that consider Cloud Computing technologies key in the development of their strategy. Medium SMEs on the other hand are the ones with higher values in Big Data technologies and artificial vision and virtual reality, showing their capabilities to implement technologies that are more complex. Results suggest that technologies might have created higher expectations in MicroSMEs than those relied upon by an efficiency and effectiveness logic.

When considering technologies from the SMEs business model point of view (product-based vs non-product-based companies), Big data, Cloud computing, and Augmented reality are the technologies highlighted by product-based companies. Non-product-based SMEs identify collaborative robotics and additive manufacturing as the most important ones. However, Cybersecurity is a transversal one.

Finally, SMEs also refer to certain obstacles concerning Industry 4.0 (Fig. 6).

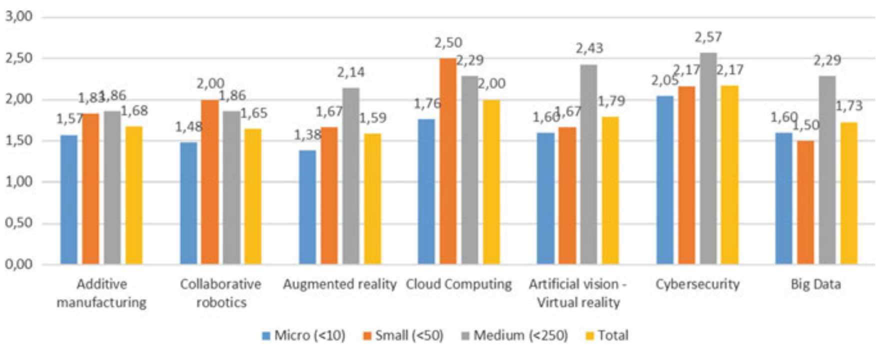

Fig. 4 Importance of Industry 4.0 technologies

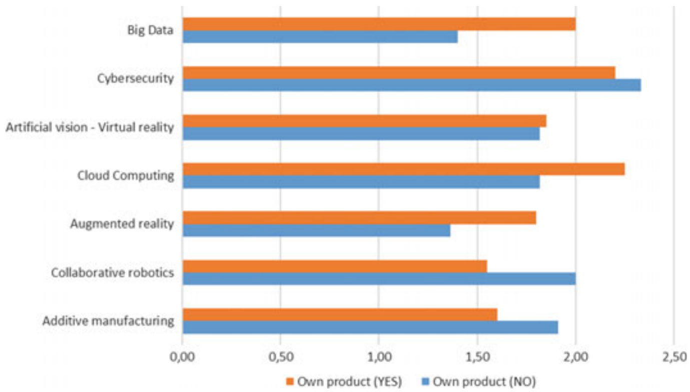

Fig. 5 Industry 4.0 technologies and business model

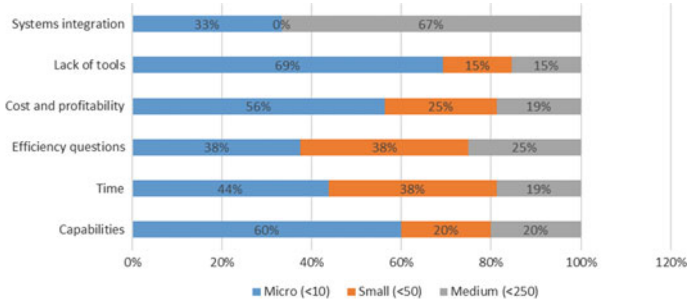

Fig. 6 Barriers when implementing Industry 4.0

Thus, MicroSMEs point out that the most important barriers are those related to their capabilities, lack of tools, and cost and profitability issues. On the other hand, Medium companies highlight Systems Integration as their most important barrier; while Small SMEs address barrier related to efficiency and time.

5 Conclusions and Further Research

Companies and, in particular, industrial companies are suffering from a series of pressures and tractions that flow from market and customers, through the challenge of business models or the irruption of technologies that are transforming SMEs' activities, their logic of business and structures.

In this context, Industry 4.0 encourages the introduction of a set of technologies that, far from configuring sci-fi scenario, are realities nowadays. Therefore, the capacity of SMEs to manage this whole revolution will affect the industrial future of many SMEs. The results in this paper show that the comparison among firms of the Industry 4.0 phenomena is different depending on the size and the nature of the value proposition developed by the company (product-based vs non-product-based), and their associated business model.

Nevertheless, it is also clear that regardless of the current situation of a SME about Industry 4.0, a focus objective and strategy is needed in order to become a beneficiary of this revolution. The aptitude and capability of SMEs to configure an Industry 4.0 strategy, to focus the objectives pursued by its implementation, and to select the most efficient technologies to achieve it will determine the success of SMEs in their Industry 4.0 challenge. Managers are a key element in this process, and their awareness, understanding, and direction are vital for Industry 4.0 to become a success on SMEs.

SMEs' managers need support to understand, assess, and analyze the impact and challenges concerning Industry 4.0, and governments, universities and other agents should assist them in this achievement, while supporting our industrial and economic future. Managers' expectations, mind-set, believes, and assumptions regarding Industry 4.0 need to be managed and coached with the help of all these active actors.

Statement on Compliance with Ethical Standards The Ethics Committee of the Faculty of Engineering of Mondragon University (ref. KO20191210–6) approved the entire procedure used in the research process. Participation in the sessions was voluntary, participants being informed about the process during all sessions. Data was also anonymized. Authors declare that they have no conflict of interest.

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Promoting Circular Economy Through Industrial Symbiosis Platforms: A Comparative Analysis

C. Jaca, J. Rincón-Moreno, P. Barrenechea, and M. Ormazabal

Abstract Circular economy has been claimed as an approach to foster a systemic change in the current model based on disposability. Though, many companies have sprout to deliver circular solutions through either new business models, products or services, a full shift away from the entire system is lacking. In other words, in order to experience a fully transition toward a circular economy model, an inter-organizational approach needs to be deployed. This approach has been named industrial symbiosis whereby interactions among companies are crucial to start developing a circular economy in the so-called meso level. Collaboration among organizations rises as one of the most important factors in developing industrial symbiosis. In that sense, different projects have developed digital platforms with the idea of promoting active participation and collaboration between organizations. Those sorts of platforms ideally enable industrial symbiosis through gathering information about resources and potential substitutes in order to recommend waste-to-resource exchanges. However, depending on the context the platform was built certain characteristics may not apply. Thus, this paper is focused on the characteristics and usefulness of different available platforms that facilitate the exchange of waste as a resource, product or good. Based on this research, it is likely that none of the existing platforms and the upcoming ones will be one-size-fits-all, thus, for industrial symbiosis to succeed it is still important for companies to determine what their needs are and then explore which platform best covers their requirements.

Keywords Industrial symbiosis · Circular economy · Platforms

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1 Introduction

The circular economy is a system that seeks to change the way that human society interrelates with nature, with the objective of preventing the depletion of resources and facilitating sustainable development by closing energy and materials loops, at the micro, meso, and macro levels implementation [1]. At the microlevel, organizations work toward the sustainable production of goods and services as separate companies. Then, as more companies are integrated, it is possible to build the meso level, where industry or business associations, clusters, and eco-industrial parks may interact to stimulate industrial symbiosis (IS) [2]. Lastly, at the macrolevel, we find the governments and institutions that may trigger the CE in cities and countries through a suitable legal framework [3].

The concept of IS was introduced in the early 90s as industrial ecology, as a way to explain that industrial systems, just like natural ecosystems, can be described as a distribution and flow of materials, energy, water, and information [4]. Industrial symbiosis is based on the metaphor of a sustainable natural ecosystem as a model for evolving unsustainable industrial systems into materially closed ecosystems that are ultimately sustainable [5]. The most popular definition of IS is a system that "engages traditionally separate industries in a collective approach to competitive advantage involving physical exchanges of materials, energy, water and/or by-products" [6]. IS has contributed to the improved integration of companies through the creation of shared economic opportunities, improved ecosystems and innovative paths toward responsible business, as different IS projects across the globe have demonstrated: Kalundborg park in Denmark [7]; Kwinana, Gladstone in Australia [8]; and Nanjing Chemical Industrial Park and Suzhou New District in China [9].

Nevertheless, successful IS implementation is more than a mere exchange of materials in order to deliver widespread application. Indeed, researchers have been studying IS in a broader context and they have determined the key factors in promoting it from the technical, economic, organizational, social, and institutional perspectives [10]. One of the most important factors in developing IS relationships is collaboration among organizations [11, 12]. For this reason, different projects have developed symbiosis platforms with the idea of promoting active participation and collaboration between SMEs and local stakeholders [12]. Platforms traditionally enable two or more sides on board and enable interactions between them (such as those used by individuals: Airbnb, eBay, Uber, XBox, etc.), and they are now attracting more attention from companies [13].

In terms of collaboration platforms focused on IS, Raabe et al. [14] pointed out that a collaboration platform that enables IS should include a mechanism for gathering information about resources and potential substitutes in order to recommend waste-to-resource exchanges. In the same manner, Fraccascia and Yazan [15] stated that despite the well-documented barrier to information-sharing to boost the exchange of resources, the performance of IS might be improved if online information-sharing platforms played a relevant role. By doing so, the barriers to the waste-to-resource exchange could be overcome [16].

This paper is focused on the characteristics and usefulness of different available platforms, and more specifically on some of the platforms that facilitate the exchange of waste as a resource, product, or good. Section 2 introduces the methodology used in this research, Sect. 3 presents the available platforms, and the main conclusions of this study are discussed in Sect. 4.

2 Methodology

Different methodologies were used to identify and analyze the available platforms for industrial symbiosis. First, Google was used to search for online platforms using different terms related to IS, via Google. The two search terms that gave the best results were "industrial symbiosis project" and "materials market place". Then, the websites that allowed firms to interact and collaborate with each other were selected, which included at least exchange of resources between companies. This step yielded 13 active online platforms. Next, the features that were more relevant for facilitating industrial symbiosis between companies were analyzed. Features included aspects such as geographical proximity, legal information, and transaction ease.

In order to analyze each platform's operating characteristics and services offered, the information published on the website was examined and we contacted the platforms by electronic mail. Five of the 13 platforms responded to the e-mail, although not all the information requested was provided, as in many cases they considered it confidential. Using all the above information and the previously defined criteria, we grouped and analyzed the characteristics of the different platforms.

3 Results

In order to analyze the different platforms available to help companies to collaborate with each other in industrial symbiosis systems, we created a list of the platforms and their main characteristics, namely the year founded, the organizations that launched or supported the platform, the geographical area in which it operates, and its main objectives. Table 1 shows this list for the 13 selected platforms.

Most of the platforms analyzed operate in Europe and are supported by European or national public organizations through open calls, such as the H2020 program. Government support is vital when an open network is developed [17]. That most of the platforms (11) have been launched during the last 5 years is significant.

The oldest platform is NISP, which was established in 2005 in Birmingham, England. At first, this business network was open to any company. Now this organization has a data management and analysis platform called SYNERGIe. NISP has worked with companies in 30 different countries, and the opportunities generated through this network have generated €1.1 billion in sales and €1.3 billion in cost reductions for participating companies. Other platforms have a large number

Table 1 Platforms and their main characteristics and objectives

Platform (year)	URL	Founded/ supported by	Geographical area	Main objectives
ASTER (2017)	https://www.clustercollaboration.eu/cluster-organisations/aster-energy-and-environment-platform	The European Cluster Collaboration Platform, funded under COSME	International	Facilitate industry-research collaboration and develop innovative products and services
AUSTIN MATERIALS MARKETPLACE (2014)	https://austinmaterialsmarketplace.org/	US Business Council for Sustainable Development/ Austin/Austin resource development	United States	Help businesses and organizations to connect and find reuse and recycling solutions
CIRCULAR ECONOMY CLUB (2012)	https://www.circulareconomyclub.com/	–	International	Promote circular economy by building strong local networks to implement circular local strategies
EREK (2018)	https://www.resourceefficient.eu/en/erek-network	European Commission	Europe	Help European companies, especially SMEs, save energy, material and water costs
FISSAC (2016)	https://fissacproject.eu/	European Commission	Europe	Facilitate industrial symbiosis networks
INEX CIRCULAR (2014)	https://www.inex-circular.com/	–	Europe	Improve resource efficiency by connecting companies to share waste and resources
MAESTRI (2016)	https://maestri-spire.eu/	European Commission	Europe	Implement a management system for IS focused on material and energy exchange

(continued)

Table 1 (continued)

Platform (year)	URL	Founded/ supported by	Geographical area	Main objectives
MARKETPLACEHUB (2016)	https://marketplacehub.org/	World Business Council for Sustainable Development	International	Establish a network of circular economy practitioners for businesses and policy-makers
NISP (2005)	https://www.nispnetwork.com/	International Synergies	International	Information, support and systems to implement industrial symbiosis network(s)
RECIRCULAR (2017)	https://www.recircular.net/	–	Europe	Improve resource efficiency through connecting companies to share waste
SDR (2016)	https://www.smartdeltaresources.com/nl	Impuls Zeeland/Zeelnad	Europe	Reduce the use of energy and feedstock through industrial symbiosis
SIMBIOSY (2014)	https://www.simbiosy.com/	–	Europe	Help businesses and organizations to connect and find reuse and recycling solutions
TENNESSE MATERIALS MARKETPLACE (2017)	https://tennessee.materialsmarketplace.org/	US Business Council for Sustainable Development/ Tennessee D. of Environment and Conservation	United States	Help businesses and organizations to connect and find reuse and recycling solutions

of companies as members: Circular Economy Club has 3100 registered members from over 100 countries; Austin Materials Marketplace has registered 439 companies, 335 of which are active participants; Tennessee Materials Marketplace, which is very similar to the Austin Materials Marketplace, has 203 users and more than 130 materials listed in the marketplace. EREK does not work with companies directly; instead this platform operates organizations, clusters, and chambers of commerce, and currently, there are 63 members from more than 20 countries.

In terms of the platforms' features, Table 2 shows the ones considered by authors to be most relevant for facilitating IS. Intermediation by external agents or experts is very helpful for promoting IS [18]. Other facilitating factors are geographical proximity [11] and information about the availability of products [19], which we show in

Table 2 Platforms and their main features

Platform	Interme-diation	Map location	Waste transac-tions	Search tool	Info /legal require-ments	News	Events	Eco-innova-tion
ASTER	✓					✓		
AUSTIN		✓	✓	✓		✓	✓	✓
CE CLUB		✓	✓	✓		✓	✓	
EREK	✓			✓		✓		✓
FISSAC	✓	?				?	✓	✓
INEX CIRCULAR	✓	✓	✓	✓	✓			✓
MAESTRI			✓			✓	✓	✓
MARKETPLACE HUB	✓	✓	✓	✓				
NISP	✓					✓	✓	?
RECIRCULAR	✓		✓					✓
SDR	✓	✓		✓		✓	✓	✓
SIMBIOSY	✓	✓	✓			✓	✓	✓
TENESSE		✓	✓	✓		✓	✓	✓

Table 2 as "map location", "waste transactions", and "search tool". We also analyzed the regulations that affect waste transactions, shown in Table 2 as "info about legal requirements" [20]. Other features that can facilitate connections and co-creation actions between companies are an important factor for IS facilitation [21]. For that, best practices, examples, and info about IS is shown as "news", events organized for its members as "events", and information about projects as "eco-innovation".

As can be seen in the table, most of the platforms are related to promoting the circular economy, facilitating the exchange of waste as a resource for closing material cycles, and promoting eco-innovation projects among organizations. Publishing news items is an important element, as it is a way to give visibility to successful projects and nudge other organizations to initiate similar projects. Legal requirements, which can sometimes hinder transactions, appear in only one of the platforms.

4 Conclusions

In recent years the number of IS platforms has increased, as has the number of symbiotic networks between companies. Based on the characteristics of the platforms studied, the ideal IS platform should have the following characteristics:

- Be available for different companies from different sectors and have free registration.

- Allow search segmentation in order to find the products that can fit a company's needs.
- Incorporate geospatial location, such as maps, to allow companies to explore different exchange possibilities.
- Provide information about the legal requirements associated with waste and resource exchanges.
- Provide statistics about the number of exchanges, number of companies, material saved, CO_2 emissions avoided, and cost savings for companies.
- Publish successful stories and upcoming projects as a way to illustrate opportunities.
- Have a calendar of events related to IS.

Although, it is likely that none of the existing platforms and the upcoming ones will be one-size-fits-all, for industrial symbiosis to succeed it is still important for companies to determine what their needs are and then explore which platform best covers their requirements.

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MCUBO. A Sustainability and Industry 4.0 Project

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Abstract It is expected that the so-called Industry 4.0 brings a multitude of benefits toward more sustainable industrial value creation. However, scientific literature presenting success stories related to Industry 4.0 and sustainability are limited. Using some technologies included in the Industry 4.0 strategy, we present a research project application based on three-step methodology to offer an efficient water/energy management. We illustrate our approach with a case study in a company of the agri-food sector.

Keywords Industry 4.0 · Sustainability · Agri-food

1 Introduction

The Fourth Industrial Revolution can be defined as a combination of different technological developments that allow companies to improve, simultaneously, different aspects in the factory: data acquisition by sensorization [15]; digitalization of processes by IoT-Internet of Things [2]; material consumption reduction by additive manufacturing; analysis by big data [7]; productivity improvement by robotization; and reducing the costs of analyzing improvement alternatives by simulation [11].

Most of the published case studies in the scientific literature are focused on productivity [11]. However, there are few success stories which combines Industry 4.0 and sustainability [12]. This paper will present a case study, centered in the sustainability in the agri-food sector. The work is framed in the European project called LIFE

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MCUBO and combines some of the Industry 4.0 technologies to offer an efficient water management proposal.

2 Theoretical Framework

2.1 Industry 4.0

It is difficult to find the first scientific reference that defines the 4.0 industry and to mark out the technologies included in this strategy. One of the first scientific papers published in an indexed journal dates back to 2015, and it is related to the application of digitization in coal mines [18].

Industry 4.0 has been spread throughout the world, adapted to the regional technologies to offer different infographics. All the representations maintain three common elements: Technology, connectivity, and artificial intelligence.

The scientific literature includes many case studies that deploy each strategy in a company, presenting their benefits [11]. Due to space limitations, this paper will briefly describe only those technologies related to the MCUBO project that will be presented in the following section:

1. Sensorization: Consists in the establishment of a communication channel with a resource (machine, vehicle, or product) that allows registering the behavior of a variable over time [6].
2. Big Data: The indiscriminate collection of data based on the availability of sensorization generates the need to develop analysis methods that allow interpreting the data collected [17].
3. Simulation: With the data captured by the sensors, a virtual reproduction of the process can also be developed [16]. Thanks to the simulation technique, it is possible to explore operation, and/or distribution alternatives that improve the real process.
4. Augmented reality: Thanks to this technology, it is possible to link the real and the virtual worlds [16]. This strategy can be used in the training of operators and, in that case, it is considered a gamification strategy, as the serious games [14].

2.2 Environmental Sustainability

When these modern information technologies (i.e. Industry 4.0) are coupled to process innovations like lean-green manufacturing, there is a development of a sustainability culture in business and industrial supply chains [9]. The term sustainability integrates social, environmental, and economic responsibilities.

The assumption that natural resources are infinite and that the regenerative capacity of the environment is capable of compensating global production is no longer acceptable [1]. In this scenario, it is necessary to combine some advances in Industry 4.0 and put them at the service of environmental sustainability, identifying the impacts [3], the challenges and opportunities [10], and finding the trends [12].

However, there are few studies that present holistic proposals to a specific environmental problem, and there are mainly focused on energy consumption. In the agri-food sector, one of the most important environmental impacts is related to the high level of water consumption. In this sense, MCUBO project proposes a set of technological tools, supported by traditional principles such as continuous improvement and lean manufacturing, to improve the efficient management of a necessary and scarce resource such as water.

3 MCUBO Project

The LIFE MCUBO Project (https://lifemcubo.eu/en/about-life-mcubo/) is a European project framed within the LIFE 2015 call, with demonstrative character. The main objective of the MCUBO Project is to reduce the environmental impact associated with water management in the three agri-food subsectors that consume more water (meat, canned vegetables, and soft drinks).

3.1 Proposed Methodology

MCUBO project proposes a three-step methodology (Fig. 1). The methodology can be applied starting from any of the three steps and for this reason it is represented as a circle. However, it is also true that, in a general case, without monitoring it is not possible to improve, and it is not possible to calibrate any model; without optimizing the model it is not possible to know how far the process can be improved.

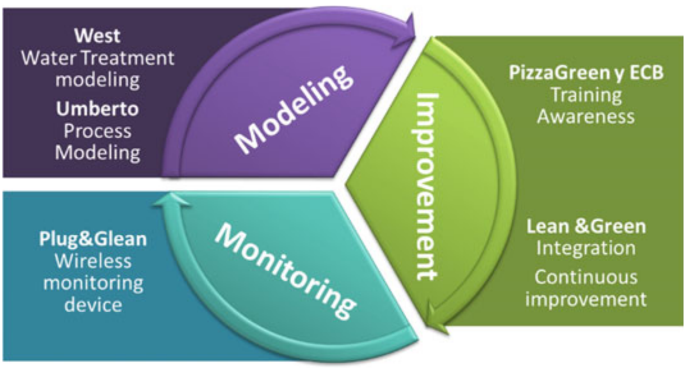

Fig. 1 Methodology and tools proposed in MCUBO

Fig. 2 Elements included in the monitoring Kit (Plug&Glean)

Monitoring (Technology and Connectivity).

The device adapted to the project, called Plug&Glean (Fig. 2), integrates a set of probes, sensors, and commercial devices with a wireless transmission system [13]. The device allows collecting information on water quality, water flow, energy consumption, production cycles, and events that stop production.

Modeling (Artificial Intelligence).

Since the publication of the ASM1 model in the 1980s [4], wastewater treatment mathematical models have been widely used. In this sense, different works have been published; the reference being the ASM models [5] and ADM1 model (Batstone et al. 2002) for the description of active sludge and anaerobic digestion processes, respectively.

The project has developed, implemented, and verified a library of dynamic mathematical models that describe the behavior of the most relevant and promising technologies for the recovery of resources from wastewater.

In addition, using these bookstores, the wastewater treatment plant (WWTP) of the three demonstration companies have been modeled. In the example at the end of the paper, one of those models is presented. The models have been mathematically implemented and verified in the simulation platform called WEST-DHI, which is a commercial software generally used in the study of water and waste treatment in the urban context.

Improvement.

The LIFE MCUBO methodology will support the traditional improvement teams implemented in companies, to integrate improvement actions aimed at the simultaneous improvement of productivity and environmental impact.

Using a new training approach, in which the organization focuses first on the analysis of environmental comfort (ECB) and enhance habits in the worker. Next, the ECB stimulates participation, consensus, and shared reflection in the face of a

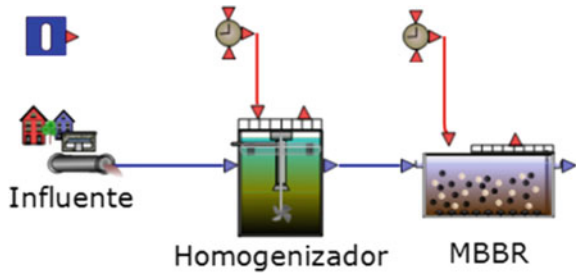

Fig. 3 West layout of company's WWTP

problem. ECB is based on a well-known participative tool called Logical Framework Approach (LFA).

Although the data capture devices are simple, they require an explanation (operation, data integration, etc.) and minimum maintenance (charge batteries, check the correct capture). Therefore, the improvement framework derived from the analysis of the captured data requires a specific training, carried out through a Serious Game and focused on the importance of making decisions based on the analysis of the data.

3.2 Application of the Methodology to a Case Study

One of the three demonstration companies in the project process and package vegetables. Once the water is used in the production or cleaning process is sent to a WWTP to treat the wastewater (Fig. 3). Then is sent, through a collector, to the public WWTP.

The improvement team analyzed three scenarios in the WWTP.

1. Decrease the airflow operating time while keeping the airflow.
2. Decrease the airflow power provided by the blowers.
3. Operation with two bioreactors instead of four.

In order to analyze the improvements proposed in the operation of the WWTP, a data campaign was carried out from October 22 to November 6 of 2018 (Fig. 4).

The recorded data (Fig. 5 shows an extract) identified an operating problem, since one of the blowers, after a breakdown, was operating in manual mode, and the other blower was not operating with the specified program (operate only at night). The simulation study will start from the regular operation.

As a result of the simulation, the parameters of chemical oxygen demand (COD), total suspended solids (TSS), and filtered COD (CODf) of three specific periods have been calculated and compared experimentally (high variation according to production). Due to space limitations, only the second improvement will be presented, which would have the greatest impact on energy saving.

Exploring the limit case, it is observed that it is possible to reduce the power of the blowers by 50% guaranteeing the effluent quality for any concentration. Even

Fig. 4 Problem Oriented Monitoring campaign for the three scenarios

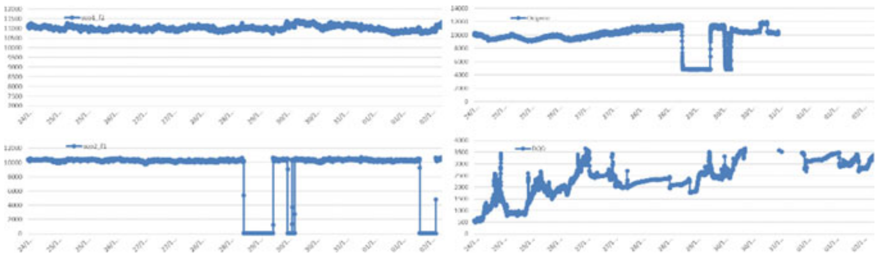

Fig. 5 Electrical consumption of the two blowers, dissolved oxygen, and COD, respectively

so, at high COD concentrations, the process will work at lower dissolved oxygen concentrations, which could generate agitation and homogeneity problems (Fig. 6).

The three scenarios were simulated in a similar way. The results of the three simulated improvements could be summarized:

- It would be possible to save 15% of electrical energy by decreasing the production cycles (or air cycles) by increasing the output flow of the WWTP.

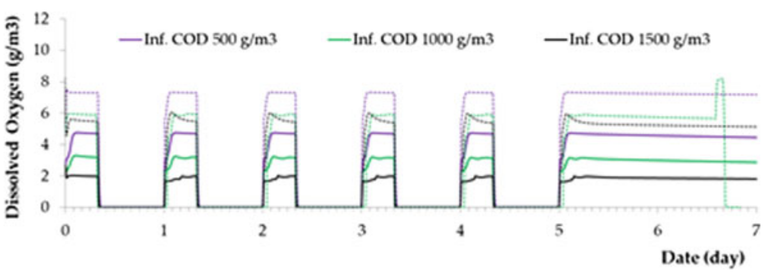

Fig. 6 Weekly DQO results when reducing the airflow power provided by the blowers

- It would be possible to save a maximum of 50% of electrical energy by decreasing the power of the blowers.
- It would be possible to save 50% of electrical energy driving the entire wastewater through two of the four bioreactors.

The company is currently analyzing these three options to implement those that are simpler without putting the current operations of the treatment plant at risk.

4 Conclusions

This paper has presented the methodology developed in the MCUBO project and has shown the results of its application in one of the three demonstration companies involved in the companies. The case study combines simulation and data acquisition by sensorization to reduce the environmental impact of water management. This, in turn, reduces the energy consumption associated with water treatment.

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Toward the Circular Economy: An Initial Analysis Framework

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Abstract The growing relevance of circular economy (as an approach that can help both to improve the competitiveness of the organizations that apply it, and the future quality of life on Earth) has strongly increased the awareness of companies and academics regarding this subject. This paper tries to identify the bases of a circular economy model that attempts to capture and measure the key elements that organizations should include when formulating their strategy to attain a certain level of circularity. This model could also form the basis for establishing a comprehensive "circularity" assessment system of the level achieved by a certain organization that is still a gap in research. This research seeks to establish a preliminary model as the basis to start the study of its application to several processes of three companies (two Spanish and one European multinational), with the aim of verifying to what extent their processes are aligned with the so-called "circular economy" objectives, as they are described in the mentioned proposed model.

Keywords Circular economy · Process circularity · Circularity assessment

1 Introduction and Proposed Model

Since the industrial revolution, the western economy has been developed along what could be called a linear economy model, in such a way that consumers are immersed in an environment where the "single use" of the goods and services they buy is widespread and theoretically affordable. Global supply chains are organized around a "take, make, dispose" model [1], in such a way that, in the unidirectional production model, natural resources are used to feed the factories that generate large quantities of products that form the basis of global mass consumption all around the World.

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The circular economy concept development has introduced a new vision into the economic ecosystem when it has been studied from different angles: the company (micro), the industry (meso), and the country or region (macro) levels. Under circular economy perspective, the economic growth could be partially or totally decoupled from the use and application of the resources and materials, severe polluting emissions and discarding waste that would surely happen at the end of the products' life, even considering waste as an opportunity for manufacturing of new products or reducing the need of additional resources or raw materials for new products manufacturing. As consequence, all this means a strong opportunity, both for the reduction of new raw materials needs to maintain working the production process and for the reduction of the treatment of waste generated sat the end of the products' useful life, according to the study published by the European Environment Agency (EEA) that could be considered as a strong starting point and key milestone for the development of circular thinking within European Union area [2].

Circular economy concept today could be considered as a new fashionable term, used both among executives and academics, and it has been developed, and mainly reinforced by the current policies of the European Union and China [3, 4]. According to some studies [5], more than one hundred articles have been published in 2016 related to the circular economy, which means that they have multiplied by a factor three compared to 2014 [6]. But circular economy could be considered a great opportunity to do things better now as a fashion or a politic vision, and this could jeopardize their real applications and benefits.

It is important to highlight certain key academic studies such as those published by Kipping and Clark [7], Lacy and Rutqvist [8], and Korhonen [9]. The relevance of the topic has led the European Union to include, among its strategies, certain aspects related to the circular economy, particularly issues related to the management of waste at the end of the life cycle of products [2]. It is also possible to highlight the strategies of the United States on issues related to "waste management" [10]. Beyond this, emerging economies such as China have developed ambitious strategies to achieve reasonable levels of circular economy [11]. According to the McKinsey Global Institute [12], the circular economy is advancing and more and more companies are working within business models that could be considered as circular economy practices, which implies a way to make more viable the future development of the global economy.

However, considering an aspect so relevant as "the level of circularity" could be remarked that still there are few limited studies focused on how to measure the "level of circularity" achieved by a product/service, a company, or certain specific supply chain as a whole. And that's sounds very important, since only stablishing certain criteria and checking if they are fulfilled it would possible to recognize someone as "circular economy" practitioner.

The aim of this study is to get a proper assessment in a global, clear, transparent, and efficient way of the level of circularity achieved by an organization. While the concept of circular economy has been widely studied by academic research and its different ways of application into companies or sectors has been widely described, the definition of a system (based on suitable performance indicators and proper tools) that could allow to measure the level of circularity achieved is still in an early and starting development phase [13, 14].

Ghisellini et al. [15] found that only ten studies out of a set of more than one hundred and fifty-one, related to the topic of circular economy, mentioned the need to make a clear measurement of it through indicators. The existing methods are incomplete and generally focused on certain very partial aspects. Some authors have tried to advance in this direction, pointing out the relevance of achieving a clear system of indicators that would allow measuring the transition from linear to circular economy [16, 17].

The present study tries to bridge, even if partially, this gap in the research. In order to define an effective system for measuring the level of circular economy achieved, the key application areas must be established. In this direction, the European Environment Agency [2] identifies five areas as circular economy practice platforms: eco-design, production, consumption, waste recycling, and reuse [2].

Elia et al. [14] proposed to establish a four-level model to measure the level of circular economy reached: the processes to be controlled, the requirements to be measured, the actions involved, and the levels of implementation of the circular economy paradigm. Based on this framework, the authors have defined a model that they consider to be more integrative and global (see Fig. 1) based on objectives, process design criteria, and processes.

All of them are within a given level of implementation (micro/company and macro/country). All of them, supported by a system of evaluation and assessment, in order to be able to measure the level of circularity achieved.

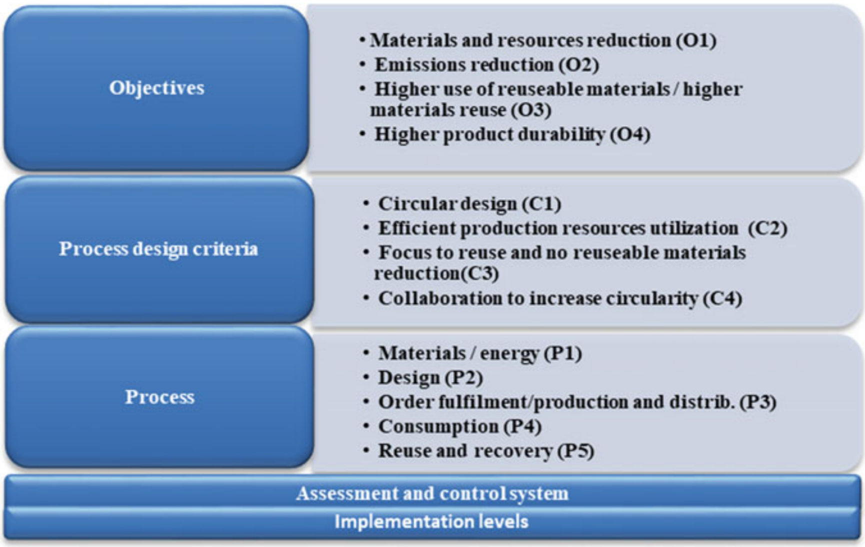

Fig. 1 Circular economy framework. *Source* authors own elaboration, based on Elia et al. [14]

The objectives correspond to those defined as circularity objectives by the evaluated organization and the design criteria correspond to those that have been enunciated to design the processes in such a way that allows the company to reach the stated objectives. Regarding the processes, they must be evaluated to measure to what extent they have a behavior that could be considered as circular according to the design criteria and established circularity objectives. The process design criteria derive from the statements made by the McArthur Foundation [18], which has defined some blocks that support the adoption of the circular economy paradigm:

(a) Design, production, and circular distribution of products, including everything that enables an increase in the circularity of goods and services
(b) Introduction and dissemination of new business models (For example, product-use service systems instead of property, collaborative consumption …)
(c) Recovery capacity, thus evolving toward closed-loop cycles of production/use/recovery, in order to avoid part of the waste being not reusable.
(d) Collaboration in the supply chain, including new agents to improve reuse, even promoting symbiotic business ecosystems.

Additionally, Public Administration intervention often contributes as a catalyst for the establishment of standards [2, 18, 19] and that can help to bring processes aligned more quickly. In the case of the objectives, they have been defined based on those that the European Environmental Agency considers as relevant to reach a certain level of circularity, and can be classified into five categories [2]:

(a) Reduce the use of resources, including natural resources
(b) Reduce the level of direct and indirect emissions
(c) Reduce the loss of materials in the process, evolving toward closed cycles (closed-loop cycle). This implies increasing the reuse of materials
(d) Increase the use of renewable and recyclable resources
(e) Increase the durability of the products.

In this study, based on previous description and in order to simplify it has been defined four main objectives to search if they are applied within processes or not: resources reduction, emission reduction, reuse of materials, and durability. All of these categories, as mentioned above, are applicable in three levels of implementation (company, industrial area and region or country).

2 Objective and Study Methodology

An important question is to determine which methodology, among the existing ones, could reflect in a better way the level of circularity of a company, sector, or country. The authors have reviewed different methodologies and concluded that there is not a unique answer to this question. Authors will try to propose an alternative in successive further research within a broader line of research. The current study tries to measure whether or not the model (Fig. 1) properly captures what is actually happening in

Table 1 Sample of companies

Company	Sector	Size	Ownership	Supply chain
A	Retail (textile)	Multinational	Public	Global
B	Electronic/medicine	Multinational	Public	Global
C	Retail (food)	Large local company	Private	Local

Source own elaboration

terms of circularity practices within processes and objectives in a set of companies. In other words, whether the companies that explicitly indicated their serious commitment on circularity objectives are really busy to apply circular economy strategies/practices. Also the study tries to check and prove if these three companies really manage their business in order to implement circular economy, and whether they really achieve in their processes, at least to some extent, certain objectives identified as specific to the circular economy general practices. Given the nature of the topics to be investigated, it was decided to carry out a case study, a method that according to Eisenhardt [20] is suitable for issues that have to do with strategic decisions of business management. Yin [21] advises using the case study where the boundaries between the context and the phenomenon to be observed are not evident. The information was collected through in-depth interviews with executives (one per company) of the companies studied, using semi-structured questionnaires. In addition, certain published information (company annual reports) about the same companies has been used.

Given the nature of the topic and the difficulty in accessing this type of information, often considered as confidential by companies, a selection of companies was made following criteria of relevance of the company and considering the feasibility of access to company's executives by the authors. Sample of companies is based on two Spanish and one Dutch companies, all of them of similar size (Table 1).

All of them are leaders in their respective sectors (textile retail and food retail in the case of the Spanish companies and electronics/electro medicine for the Dutch company) and they have a relevant presence and share on respective markets. Company A and B are public companies and their shares are listed on top capital European markets, while company C is a family-owned company. The three companies communicate openly through their communication policies that they are actively working and promoting practices focused on improving their respective circularity levels since more than a decade. Being the circular economy for them a strategic part of their company vision for next future.

3 Circular Economy Objectives within Processes: Case Studies

This section summarizes the information collected from both the interviews and published information of the studied companies. In this study, the research is focused on identifying to which extend the analyzed companies really apply circularity objectives in their own processes according to the theoretical preliminary model enunciated in Fig. 1. The three companies have been analyzed, and based on findings have been created a matrix with outcomes per company (see Table 2) where it is possible to identify whether the processes outlined above are working in line with the four main circular economy objectives defined or not (see Table 2).

In company A, active in the textile retail business, it stands out that the objective of reduction of materials and resources is specifically applied in the processes of materials/energy, design, and production, while the objective of reducing emissions is particularly applied in the design process of their textile products and in their manufacturing. No clear evidence has been found about the application of the objectives of reuse and durability in any process of this organization. Both lack of objectives (reuse and durability) in this company have a lot to do with their relationship and commercial experience with customers that is lagging in those areas.

Table 2 Processes versus Circularity objectives

Company A	Resource reduction	Emission reduction	Reuse	Durability
P1_Materials and energy	X			
P2_Design	X	X		
P3_Order fulfillment	X	X		
P4_Consumption				
P5_Reuse and recovery				
Company B				
P1_Materials and energy	X	X	X	
P2_Design	X	X		
P3_Order fulfillment	X	X	X	
P4_Consumption				
P5_Reuse and recovery	X		X	
Company C				
P1_Materials and energy	X	X		
P2_Design	X	X		
P3_Order fulfillment	X	X	X	
P4_Consumption	X			
P5_Reuse and recovery	X			

Source own elaboration

Regarding company B (electronics and high tech electro-medicine products manufacturer), it might be inferred from the analysis carried out that the objective of reduction in the use of resources is applied in all processes except in the consumption process. The objective of reducing emissions is evident in the materials, design, and order fulfillment processes. In this company, there is clear evidence of having applied reuse objectives in the materials, order fulfillment, and reuse/recovery processes. Regarding durability, there is not a formulation of objectives by the company, and consequently, it has not been identified any practices related to this objective.

In company C, active in the food retail business, the objective of resource reduction (which is very much in line with their efficiency in supply chain process management) is widely applied in all their processes, even in the consumption process with practices that induce final consumers to buy simpler and easily recoverable materials (promoting more simple packaging). The reason why resource reduction objectives are applied at all the processes in company C, unlike what happens in the other companies, is probably related to the company's philosophy of total efficiency from its foundation, with particular focus on integral efficient supply chain management. This company applies in its own organization, and in its entire supply chain, objectives of reuse of materials and waste reduction in line with those included in the circular economy model described above within the model proposed by the authors (Fig. 1). In this company has not been identified any proof of been working on durability objective, nevertheless its range of products (mainly food) is not the most appropriate for that objective that could fit better within the other two analyzed companies.

4 Conclusions

To a broad extent, the linear path that runs contrary to the circular economy paradigm has been increasingly applied in recent decades, thus promoting the use of materials that, after their use, markedly increased the level of waste. It is an economy based on an "apparent convenience" for the consumer, but which has led to a progressively increasing consumption level of energy, materials, etc. They were used, and then largely considered waste, without limit.

The authors of this work have tried to establish, within a sample of three companies, to what extent a circular economy model, defined by themselves, could be identified in these companies. For this purpose, it has been analyzed whether the four major objectives of circularity (material reduction, emission reduction, material recovery, and reuse) are present in the identified processes (materials and energy, design, order fulfillment, consumption, and reuse/recovery).

From the analysis carried out, it can be inferred that company B and company C are the companies that focus more on the activities of their processes toward the objective of reducing the overall usage of resources (including energy). This is probably explained by the fact that both companies have been working for many years on process improvement objectives and on the application of lean operations methodologies.

Regarding the objective of emissions reduction, companies B and C also show reasonably high levels on objective implementation, especially in the processes of materials, design, and production/distribution. Company A is working toward this goal, but it is somewhat lagging behind in its application within its processes.

When we contemplate the objective of reuse, company B stands out above the rest, reaching a level of application of this goal significantly better. While in company C is starting to apply it in its production/distribution process. In company A, there are still no significant signs that this objective is considered important and relevant for them. However, there is information suggesting that its most direct competitors are working on the adoption of this objective in their own processes, thus the application by company A might soon become quite relevant.

Regarding the objective of durability, there is no data that allows the authors to infer that it is really a circularity improvement objective considered at the processes of the companies studied, in order to increase their level of circularity. It is baffling to note that durability was a relevant criterion of the main industrial companies in the twentieth century that significantly decreased its relevance in the last decades, when globalization enabled the multiplication of the volume of disposable products, since they were affordable at a much lower price (mainly produced at Far East countries) than in the period prior to globalization. In fact, company B was in the past one of the companies recognized for the high durability of its products range but, like many others, it has already unfortunately abandoned it in an attempt to be "competitive in price". Now, however, they would need to rediscover that goal of durability if they really want to achieve a high level of circularity.

From the study of the previous cases, it may be inferred that the proposed initial model enables capturing a certain degree of circularity of the processes of the organizations to which it is applied, as well as to identify relevant gaps; as exemplified by the identification, in this study, of the lack of interest on durability objective application.

Statement on Compliance with Ethical Standards The Research Ethical Committee of Universidad Carlos III de Madrid approved the entire procedure followed by the authors in the research (ref. CEI2019_ 013_Morcillo_Jesus). The data has been anonymized. Authors also declare that they have no conflict of interest.

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Industry 4.0 for the Development of More Efficient Decision Support Tools for the Management of Environmental Sustainability in the Agri-Food Supply Chain

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Abstract The agri-food supply chain (ASC) has received a great attention in the last decade due to sustainable issues, not only economical but also environmental and social. This implies that the traditional management methods must be reviewed and changed. Therefore, new decision models must arise in which environmental and social aspects will have to be addressed in greater or lesser extent to complement the traditional economical-driven decision models. In this paper, a characterization of the main actors and decisions taken throughout a generic ASC as well as the main environmental issues that could affect those decisions are first reviewed. Then, it is aimed to know how each one of these aspects could be enhanced with the incorporation of Industry 4.0-related technologies to develop more efficient decision support tools for the management of sustainability in ASC.

Keywords Industry 4.0 · Environmental sustainability · Decision models · Agri-food supply chain

1 Introduction

Environmental and social sustainability issues in agri-food supply chain (ASC) are becoming very relevant mainly due to two factors. Firstly, the increasing number of public legislation rules and technical specifications to be met and, secondly,

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the growing awareness throughout the different ASC members (producers, processors, distributors, retailers…) mainly as a consequence of final clients concern about purchasing sustainable products and services [13].

This fact makes that the traditional economic-driven management methods are no longer efficient and must be accommodated to these new sustainable conditions. In order to meet this new scenario, SC decision models/methods that account for environmental and social issues must be developed.

On the other hand, new technologies have emerged in the last years as a consequence of the "Industry 4.0" revolution [5]. However, just a few works have addressed in which extent Industry 4.0-elated technologies have positively contributed to this new sustainable scenario in ASC management (ASCM).

Due to space constraints, in this paper we just focus on environmental issues, and how these technologies have brought important and relevant impacts to environmental sustainability in the practical arena allowing the development of more sustainable decision support tools for ASCM.

The paper is structured as follows: In Sect. 2, a generic ASC is characterized, pointing out the main actors and decisions as well as its main peculiarities. Section 3 focuses on the concept of sustainability, and in which extent SC decision models account for this concept, focusing on environmental aspects. It is in Sect. 4 where the most important technologies addressed by Industry 4.0 are first analyzed and then how they can lead to more sustainable decision support tools for ASCM. Finally, in Sect. 5, some conclusions are drawn.

2 Characterizing the Agri-Food Supply Chain

The term agri-food supply chain (ASC) has been associated to describe the activities from production to distribution that bring agricultural or horticultural products from the farm to the folk [14].

From a process point of view, Verdouw et al. [18] identify the basic transformations in a generic fruit supply chain: growing and harvesting,processing; washing, sorting and grading; packaging and labeling: storage and distribution; retailing. All these processes are carried out throughout the ASC by the different actors/stages (producers/farmers, processors, and distributors) from upstream to downstream.

Some relevant peculiarities of ASC are the following [12]:

1. Limited products shelf-life and the importance that consumers give to aspects such as quality and health.
2. High levels of uncertainty mainly due to weather unexpected variations and products demand and price variability.
3. Increasing awareness in environmental and social issues.

After this characterization of the main processes/decisions taken by the different actors throughout a generic ASC, as well as the main peculiarities that differentiate it from others SC's, the next section focuses on the third one, that is, the increasing awareness about "sustainability". In addition to that, a brief review about how Decision models address sustainable issues for ASCM is conducted.

3 Decision Models for Sustainable Agri-Food Supply Chain Management

The agri-food supply chain (ASC) has received a great attention in the last decade due to sustainable issues, not only economical but also environmental and social. This is reflected in the way in which decision models are formulated since traditional economical-driven ones have incorporated environmental and social aspects to a greater or lesser extent.

Achieving sustainable ASCM is not an easy task. All the actors must prioritize their financial benefits but at the same time considering the increasing demand on environmental or social aspects. This is mainly due to two circumstances: companies are subject to many public legislation constraints and final clients are becoming more concerned about purchasing sustainable products and services, therefore forcing upstream the ASC to meet certain levels [17].

In this third section, a brief review about the extent to which decision models (either conceptual or operations research-based) address sustainable issues in ASCM is conducted. Due to space constraints, this review just has focused on the environmental issues that, in some cases, complement the economical ones.

It must first be remarked that most of the decision models only consider the trade-off between economic and environmental aspects, neglecting social ones. These studies only focus on environmental (known as green ASC by some authors) and economic aspects attempting to turn environmental impact into economic value in their models. Just a few articles, addressing conceptual models, focus on social aspects.

Another aspect to note is that although there are a few decision models considering the three aspects of sustainability [4] and although they point out an enormous number of indicators, the interactions among them are very difficult to quantify and are often ignored [9].

The most addressed environmental sustainability issues [2, 4, 9, 13, 14, 17] have been crop protection, soil management, water management, animal welfare, energy efficiency, pollution control, and waste control.

4 Contribution of Industry 4.0 Technologies for the Development of More Sustainable Decision Support Tools for ASCM

"Industry 4.0" is a relative new paradigm (coined by "Industrie 4.0 Working Group and the "Plattform Industrie 4.0" in 2011) that comprises a set of technologies and related features that allow, among other things, autonomous decision-making, interoperability, agility, flexibility, efficiency, and cost reductions [7].

Industry 4.0 has therefore led to a new form of managing the Supply Chain, also known as "Supply Chain Management 4.0" (SCM 4.0). But SCM 4.0 comprises in turn a broad spectrum of concepts, being one of them of increasing relevance in the last decade, the sustainability concept.

In the previous section, some Decision models for Sustainable ASCM were analyzed with the aim to know which specific environmental issues were the most addressed.

The point is how these Industry 4.0 technologies are contributing to improve, in a greater or lesser extent, the management of this sustainable issues, so that more efficient Decision support tools can be developed for sustainable ASCM.

For a more comprehensible view of this contribution, a classification scheme of Industry 4.0 technologies based on some of this paper's authors [5] is followed (Table 1).

As aforementioned, only the environmental aspects of sustainability will be analyzed, that is, in which extent Industry 4.0-based technologies may affect to the development of more sustainable decision models (from an environmental point of view) for ASC management.

Many works, as the one of Beier et al. [2] affirm that just a little research is devoted to investigating the impact of digitalized industry on relevant industry sustainability aspects. However, Lopes Sousa Jabbour et al. [10] affirm that a few emerging works are providing insight into the integration of Industry 4.0 technologies and environmentally-sustainable manufacturing. In the same line, Müller et al. [11] propose a research model in which empirical results show a positive and highly significant relationship between environmental benefits and Industry 4.0 implementation.

Table 2 shows the contribution of some Industry 4.0-based technologies to enhance the most addressed ASC environmental issues in decision models (Sect. 3). Additionally, the ASC actors (producers-prod; processors-proc, and distributors-dist) being the most benefited of the implementation of these technologies are also shown. Just seven references are quoted here due to space restrictions, each one related to one of the previously selected issues, respectively [1, 3, 6, 8, 15, 16, 19].

Some insights that can be pointed out are the following:

1. Input-oriented issues (crop protection, soil and water management, animal welfare, and energy efficiency) mostly concern to producers/farmers while output oriented (pollution and waste control) concern to the whole ASC.

Table 1 Industry 4.0-based technologies: a classification scheme

Industry 4.0-Esbased technologies	
Cluster	Definition
Internet of Things (IoT)	IoT may be defined as everyday objects which can be equipped with identifying, sensing, networking, and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective **Specific Technologies**: RFID, GPS chips, sensors, smartcards, actuators…
Cyber-Physical Systems (CPS)	CPS are defined as transformative technologies for managing interconnected systems between its physical assets and computational capabilities. By integrating CPS with production, logistics and services in the current industrial practices, today's factories will be transformed into Industry 4.0 factories with significant economic potential. The combination of these technologies will also facilitate the link back from the virtual to the physical world **Specific Technologies**: M2M, machine vision, 3D-printing, Additive manufacturing…
Smart Data	Future plants will produce a large amount of data that will need to be saved, processed, and analyzed. This data management will be possible due to increasing storage capacities, lower computation and data-storing costs and advanced methods and tools to handle big data processing and analyzing **Specific Technologies**: Cloud computing, big data, wireless networks…
Advanced processing analytics	A typical enterprise generates very large and diverse data sets coming from its distributed business locations. These massive amounts of detailed data can be combined and analyzed by predictive analytics, data mining, simulation or statistics. Doing this process in real time creates a business advantage for the company by giving insight into the real-world dynamics of their business **Specific Technologies**: Artificial intelligence, predictive analytics, simulation models, machine learning, automated robots…
Humans–machines interaction	It refers to the interaction and communication between human users and a machine, a dynamic technical system, via a human–machine interface. It studies the ways in which humans make, or do not make, use of computational artifacts, systems, and infrastructures **Specific Technologies**: Smart mobile devices, embedded computation, augmented reality, smart glasses, touch interfaces…

Table 2 Industry 4.0 for environmental sustainability in ASCM

	Industry 4.0 for environmental sustainability in aSCM
Crop protection	PROD: (1) **Digital probes** (with GPRS technology) of solar radiation, temperature and humidity, gases and wind conditions; (2) **Sensors** in the "silobag" that control seeds and via GSM signals are sent to farmers; (3) **Genome editing**: A technique that enables scientists to hack into genomes, make precise incisions, and insert desired traits into plants; (4) **Cloud computing** that allows the farmer to create prediction models in real time and non-linear relationships between ecological groups of pests; (5) **Drones** flying over the farms and detecting diseases in the leaves; they then send images and warning messages to farmers
Soil management	PROD: (1) **Robots** capable of microdot application of fertilizer; (2) **Smart tractors GPS controlled** steering and optimized route planning to diminish soil erosion and saving fuel costs; (3) **Aerial drones** to map weeds, yield and soil variation; (4) **Sensors and GPS** incorporated to the agricultural machinery to achieve samples of soil characteristics and elaborate maps that help the farmer to know which crop variety would have a better yield and to establish plans for the application of fertilizers according to the insufficiencies that the analyzed area presents
Water management	PROD: (1) **Intelligent ultrasound sensors** as a mechanism for the detection and measurement of parameters related to the flow of liquid in crops. This system has a direct and automatic connection with the "Cloud" generating a **Big Data** in real time and online (2) **WSN networks** for the implementation of Intelligent Irrigation Systems, which can detect temperature, light, humidity, and pH measurements through the sensors. (3) **Wireless microelectro-mechanical sensors** (MEMS) placed on the leaves of the plant, which transmit data in real time to a server for further analysis and interpretation
Animal welfare	PROD: (1) **Sensors** attached to livestock allowing monitoring of animal health and well-being; (2) **RFID** systems for tracking animals throughout the lifecycle and tracing individuals following a disease outbreak; (3) **Bioacoustics devices** (microphones or hydrophones) in enclosures or via collars so that health and/or welfare status can be monitored continuously via sound; (4) **Microwave Doppler radar or laser distance** sensors for monitoring respiratory activity; (5) **Infra-red thermography** (IRT) devices measure radiated heat from particular body parts, without the need for restraint or handling
Energy efficiency	PROD: (1) **Sensors** to capture data about energy consumption and then transmit it to a **smart-phone app** PROC: (1) **Automated Systems** that allow equipment to run faster or slower depending on the demand saving energy; (2) **Automated Systems** to recycle unavoidable food waste through anaerobic digestion (AD) capturing the biogas produced and using it to generate heat and electricity DIST: (1) **Smart Data** captured by sensors to have an on-line monitoring of the fleet energy consumption

(continued)

Table 2 (continued)

	Industry 4.0 for environmental sustainability in aSCM
Pollution control	**PROD**: (1) **Advanced bio-f** broad spectrum of products based on naturally occurring micro-organisms for pre-and post-harvest application. The solutions reduce chemical pollution to land and water, help address biodiversity decline, and mitigate risks to human health and well-being from conventional agri-chemicals **PROC**: (1) **Renewable energy-based technology** to generate electricity and reduce carbon emissions **DIST**: (1) **Intelligent algorithms** to minimize the shipments distance and therefore save fuel emissions; (2) **Electric trucks** to distribute to reduce the CO2 emissions
Waste management	**PROD**: (1) **Precision agriculture leveraging technologies** for decisions related to planting and harvesting time; (2) **Smart labeling/packaging** solutions; (3) **ICT** to the development and operation of radically new farm business models, such as "production on demand" **PROC**: (1) **Cloud computing** platform to share data with suppliers to synchronize orders and shipments and reducing stock; (2) **Intelligent equipment** allows in-process quality detections that lead to smaller failure rates and thus less rejects and material consumption **DIST**: (1) **Internet** for the automatic collection of real time data on the consumption patterns of the final customer; (2) **Point of sale (POS) applications** that collect and transmit sales information at the point of sale in real time by reading their respective barcodes; (3) **Automatic control of temperature** to reduce product spoilage; (4) **Artificial intelligence** applied to consumers trends to reduce waste

2. Some of the Industry 4.0-based technologies allow the producers/farmers the so-called "precision agriculture". This has an immediate effect in the economic benefit since less resources/inputs for obtaining the same outputs are used (for example, crop yield), while meeting the environmental objectives/constraints. No trade-off is done in this case between economical and environmental sustainability.
3. Some of the Industry 4.0-based technologies can help, specially to producers/farmers, to reduce the uncertainty in the behavior of external variables. For example, the reduction of the demand uncertainty allows producers/farmers to take more accurate decisions about growing, harvesting, and storing/transporting. This results in not only economical benefits (more efficient production, better post-harvest deterioration control, higher product quality, longer permanence in the market…), but also environmental, because waste is reduced drastically.

5 Conclusions

In this paper, a generic ASC is characterized with the aim to focus on environmental sustainability issues and how the different decision models approach them.

The main contribution is to analyze in which extent the most considered environmental issues could be enhanced with the incorporation of Industry 4.0-related technologies to develop more efficient decision support tools for the management of sustainability in ASC.

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