Lecture Notes in Management and Industrial Engineering

Fethi Calisir
Emre Cevikcan
Hatice Camgoz Akdag *Editors*

Industrial Engineering in the Big Data Era

Selected Papers from the Global Joint Conference on Industrial Engineering and Its Application Areas, GJCIE 2018, June 21–22, 2018, Nevsehir, Turkey

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ISSN 2198-0772 ISSN 2198-0780 (electronic)
Lecture Notes in Management and Industrial Engineering
ISBN 978-3-030-03316-3 ISBN 978-3-030-03317-0 (eBook)
https://doi.org/10.1007/978-3-030-03317-0

Library of Congress Control Number: 2018960458

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

Preface

This book compiles extended versions of a selection of the best papers presented at the Global Joint Conference on Industrial Engineering and Its Application Areas (GJCIE) 2018 held in Ürgüp, Nevsehir, Turkey. They represent a good sample of the current state of the art in the field of industrial engineering and its application areas.

The papers presented in this book address methods, techniques, studies, and applications of industrial engineering with the theme of "Industrial Engineering in the Big Data Era." Big data refers to the ever-growing volume of structured and unstructured data, increasing speed in the generation of that data, and increased diversity of types of data. Big data is also a developing topic and has attracted the attention of many researchers and practitioners in industrial engineering. Big data may play an enabling and vital role in the design of products and systems by making them more productive, better connected, more intelligent and autonomous, and extensively accessible. But big data research is still in its early stages. Its focus is rather uncertain, and related studies are not well integrated. This book will shed new light on the role of industrial engineering in this endeavor. Contributions have been arranged in three parts:

- Industrial Engineering
- Engineering and Technology Management
- Healthcare Systems Engineering and Management

We would like to express our gratitude to all the contributors, reviewers, and international scientific committee members who have aided in the publication of this book. We would also like to express our gratitude to Springer for their full support during the publishing process. Last but not least, we gratefully acknowledge the sponsors (Turkcell, Aselsan, Elginkan Foundation, Vakıf Bank, Ak Çelik, and Entertech) of GJCIE 2018.

Ürgüp, Nevsehir, Turkey
June 2017

Fethi Calisir
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Conference Chairs

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Part I
Industrial Engineering

An Expert System Methodology for Planning IT Projects with Hesitant Fuzzy Effort: An Application

Ayfer Basar

Abstract Delivering the projects on time and in accordance with the customer requirements is a crucial process for almost all software companies due to the budget and schedule constraints. Effective time planning provides optimum usage of all resources (i.e., people, time, budget, etc.). This study presents a new integrated decision support methodology for planning software projects. For this purpose, we identify the most important factors by expert judgments and literature review, find priorities of factors by Hesitant Fuzzy Linguistic Term Pairwise Comparison, and estimate time effort (duration) for the projects, respectively. Subsequently, we develop a hybrid metaheuristic by using the priorities of factors and estimated time efforts of the projects. As an experimental study, we apply this methodology to determine time planning of software projects in a Turkish company. We analyze that the proposed methodology gives very efficient plans with less delayed projects and higher award in comparison with the initial solutions.

Keywords Time effort estimation · Time planning · Hesitant fuzzy weighting Hybrid metaheuristic · Case study

Introduction

Accurate time planning is a determining factor in the competitive strength of software companies. Therefore, after making the feasibility analyses and showing that the project is feasible, time planning activities have to be undertaken in information technology (IT) projects. Project time planning mainly involves determining time effort/duration of the project showing how long it will take to complete all the project activities and scheduling decisions including the starting and ending points of the project. Estimating time efforts accurately and planning the

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_1

project effectively affect time to market and customer satisfaction directly by means of optimum resource usage, better risk management, appropriate monitoring and controlling the projects. Therefore, these decisions are fundamental for both software companies and their customers (Aguilar-Ruiz et al. 2001). The effort required to develop IT projects can be estimated in man-hour/day/months depending on the project size. Moreover, the most common metrics used for estimating software project size are lines of code (LOC), function points and object points (Heemstra 1992).

There are wide ranges of methods to estimate the time effort required for software development in the literature. These methods fall under mainly three categories as expert judgment, algorithmic estimation, and machine learning. Expert judgment is the most widely used effort estimation technique for software projects. In this method, experts estimate how long the project will take and related development parameters. Thus, the method is relatively cheap and easy to understand. On the other hand, finding experts may be difficult in most cases. Moreover, the accuracy of the estimates highly depends on the experience and knowledge of the experts. Recent studies indicate that there is a high degree of inconsistency in the estimations found by the expert judgment due to the lack of objectivity and consistency (Dave and Dutta 2011). Pairwise Comparison is used to overcome the inconsistency problem with the expert judgment (Miranda 2001). In algorithmic estimation, historical information is used and some software metrics are associated with the required effort by the help of mathematical models. Analytical models are generally used for time effort estimation by relating dependent and independent variables. Thus, selected factors and type of function in these methods directly affect the accuracy of the result. Lastly, machine-learning techniques have been widely used for estimating the effort required to develop software in the last two decades. The most common machine learning methods in the literature are artificial neural networks, genetic algorithm, and rule induction (Srinivasan and Fisher 1995; Huang and Chiu 2006; Bilgaiyan and Mishra 2016).

After estimating the time effort, software projects are planned by using different techniques to meet the deadline. If the project includes non-repetitive activities, bar charts or network methods can be used to plan the project. If the project has deterministic activities, Critical Path Method (CPM) is applied to the network methods (Turan and Guner 2013). On the contrary, the PERT technique is applied to plan the projects with probabilistic activities (Réveillac 2015). CPM and PERT methods are used to find the critical path and the probability of finishing all critical activities in a specified period depending on the earliest/latest starting and completing time of each activity.

It is clear that the estimation (expert judgment, algorithmic and machine learning techniques) and time planning methods (CPM, PERT) have some shortcomings. For instance, the accuracy of estimations found by expert opinion will be low if experts are not fair and objective enough. Furthermore, algorithmic methods require a good definition of function and factors to obtain an accurate estimation. Obviously, CPM and PERT only depend on simple mathematical and probabilistic analyses without considering the deadline for the projects. Therefore, we use a

Multi-Criteria Decision Making (MDCM) technique based on hesitant fuzzy evaluations considering both expert judgment and mathematical analyses to estimate the time effort.

This paper presents a decision support methodology for planning software projects having hesitant fuzzy durations. To this end, with the assistant of literature survey and expert judgments, we specify the most effective factors on the duration of the software projects. Object points generally provide better estimation than LOC and function points, especially in the early stages of the development process. In addition, they overcome function points because of new development languages such as object-oriented techniques (Costagliola et al. 2000). Object points are also used in the most known effort estimation (i.e., COCOMO II) (Boehm 1996). On this account, we decide to estimate the time effort of the software development using the object points specified by the help of literature review and expert judgment. Ultimately, we decide the number of clients, database, client, batch, and data objects as the most important object points among different alternatives (i.e., reports, third party tool/web integration, etc.).

Since expert opinion is very important to estimate the time effort of IT projects, a subjective technique is required to specify the importance of the object points. Among many subjective prioritization techniques (i.e., Ranking, Point Allocation, Direct Rating, etc.) in the literature, the pairwise comparison is found as an efficient weighting method (Basar et al. 2016). On the other hand, experts are generally exposed to the uncertainties at the time of evaluating the factors with the pairwise comparison. Therefore, we decide to use hesitant fuzzy sets for the experts' evaluation of effort factors and Ordered Weighted Averaging operator for aggregation of all the experts' judgment to absorb the uncertainty. Thus, we construct Hesitant Fuzzy Linguistic Term Pairwise Comparison to determine the priorities of five factors and estimate the time effort of the software projects in an uncertain environment. Later, we develop a new hybrid model to find the best plan of the projects using some features of Tabu Search and Genetic Algorithm different from CPM and PERT methods. Proposed algorithm starts with two feasible initial solutions from the earliest deadline to the latest and the largest net award to the smallest. At each iteration, it develops initial solutions by using a tabu list, crossing, and diversification.

Ultimately, we apply our methodology to plan the software projects of a big Turkish company. We analyze that time effort estimation found by Hesitant Fuzzy Linguistic Term Pairwise Comparison are very efficient; most of the projects are completed before their deadline, and proposed methodology gives acceptable results for the company and its customers. Moreover, experts working as the top managers in the Turkish company approve the results. Thus, it is seen that suggested effort factors, weighting technique, and hybrid metaheuristic are all practicable and efficient for time planning of software development. The contribution of this study to the literature can be defined as follows:

- Introducing a new decision support methodology which uses the outputs of each phase in the subsequent steps for planning software projects,

- Specifying common factors affecting time effort required to complete software projects,
- Constructing Hesitant Fuzzy Linguistic Term Pairwise Comparison to find the importance of the factors in case of uncertainty,
- Developing an efficient hybrid metaheuristic to schedule the projects,
- Integrating subjective and analytical techniques by the expert judgment, Hesitant Fuzzy Linguistic Term Pairwise Comparison and hybrid metaheuristic,
- Developing a case study of the proposed methodology in a big Turkish company.

The latter parts of the paper are developed as follows: Section "Hesitant Fuzzy Linguistic Term Pairwise Comparison" is dedicated to present Pairwise Comparison with fuzzy and hesitant extensions used for weighting effort factors. Section "Proposed Hybrid Metaheuristic" gives the details of proposed hybrid metaheuristic for time planning of software projects. Section "Experimental Study in a Turkish Company" includes a case study by the application of the proposed methodology in a Turkish company. Lastly, conclusions and future research are provided.

Hesitant Fuzzy Linguistic Term Pairwise Comparison

Pairwise comparison is based on the hierarchical structure of criteria in MDCM problems (Saaty 1980). The method uses a decision hierarchy with a goal, factors and sub factors defined. Then, the pairwise comparison matrix is built where each entry shows the importance of a factor over another. The scale defined in Analytic Hierarchy Process (1 for equal, 3 for moderate, 5 for strong or essential, 7 for very strong, 9 for extreme, and 2–4–6–8 for intermediate values) is used to obtain relative weights of the factors (Saaty 1990) Finally, relative weights of the factors are obtained by calculating the eigenvector value of pairwise comparison matrix. Obviously, the pairwise comparison may be insufficient if the experts are imprecise while evaluating the factors. Therefore, fuzzy sets are generally used in the case of imprecision (Zadeh 1965; Buckley 1985). Different from the traditional sets, an element can be addressed with a degree taking a value between 0 and 1. In fuzzy set theory, the relative weight of a factor over another can be obtained by triangular fuzzy numbers defined as $a_{ij} = (l_{ij}, m_{ij}, u_{ij})$. In this representation, l, m, and u show the lower, most promising and the highest value, respectively (Buckley 1985). Since experts can easily reflect their decision and show their optimistic or pessimistic emotion by using a range of values instead of a single one, fuzzy pairwise comparison is begun to be used in the recent studies (Zhu and Xu 2014; Oztaysi et al. 2015; Wang et al. 2016). Similar to the traditional pairwise comparison technique, the fuzzy pairwise comparison also uses expert judgments this time based on the fuzzy scales and linguistic expressions. After, the relative weights of each factor over another are calculated.

Obviously, experts may have difficulty in evaluating importance of factors relatively if they are hesitant. Therefore, hesitant fuzzy sets are developed in the literature (Torra 2010). A hesitant fuzzy set on a fixed set X is a subset $A = \{ < x, h_E(x) > | x \in X\}$, where $h_E(x)$ is the membership degree of $x \in X$ in E having value between 0 and 1. The lower and upper bound values are obtained by $h^+(x) = \max h(x)$ and $h^-(x) = \min h(x)$. Basic operations of hesitant fuzzy sets h, h_1, and h_2 are as follows:

$$h^{\lambda} = \bigcup_{\gamma \in h} \{\gamma^{\lambda}\} \tag{1}$$

$$\lambda h = \bigcup_{\gamma \in h} \left\{1 - (1 - \gamma)^{\lambda}\right\} \tag{2}$$

$$h_1 \cup h_2 = \bigcup_{\alpha 1 \in h1,\, \alpha 2 \in h2} \max\left\{\alpha^1, \alpha^2\right\} \tag{3}$$

$$h_1 \cap h_2 = \bigcup_{\alpha 1 \in h1,\, \alpha 2 \in h2} \min\left\{\alpha^1, \alpha^2\right\} \tag{4}$$

$$h_1 \oplus h_2 = \bigcup_{\alpha 1 \in h1,\, \alpha 2 \in h2} \left\{\alpha^1 + \alpha^2 - \alpha^1 \alpha^2\right\} \tag{5}$$

$$h_1 \otimes h_2 = \bigcup_{\alpha 1 \in h1,\, \alpha 2 \in h2} \left\{\alpha^1 \alpha^2\right\} \tag{6}$$

In order to aggregate evaluations of the experts, an Ordered Weighted Averaging (OWA) operator is calculated by OWA $a_1, a_2, \ldots, a_n = \sum_{j=1}^{n} w_j b_j$ where b_j *is* the jth highest of the values of $a_1, a_2, \ldots, a_n$; $w_i \in [0, 1]\ \forall i$; and $\sum_{j=1}^{n} w_j = 1$. For a triangular fuzzy membership function shown as $\tilde{A} = (a, b, c)$, each element is calculated as follows:

$$a = \min\left\{a_L^i, a_M^i, a_M^{i+1}, \ldots, a_M^j, a_R^j\right\} = a_L^i \tag{7}$$

$$b = \mathrm{OWA}_W\left\{a_M^i, a_M^{i+1}, \ldots, a_M^j\right\} \tag{8}$$

$$c = \max\left\{a_L^i, a_M^i, a_M^{i+1}, \ldots, a_M^j, a_R^j\right\} = a_R^j \tag{9}$$

Hesitant Fuzzy Linguistic Term Sets give the opportunity to experts to provide their assessments by linguistic expressions based on comparative terms such as “between medium and low”, or by linguistic terms such as “low”, “medium”, “high” etc. For this reason, we estimate time efforts required to develop IT projects by both expert opinion and mathematical analyses in uncertain environment applying Hesitant Fuzzy Linguistic Term Pairwise Comparison technique in our study.

Table 1 Scale used in Hesitant Fuzzy Linguistic Term Pairwise Comparison

Linguistic scale	Symbol	Triangular fuzzy number
Absolutely high importance	AHI	7, 9, 9
Very high importance	VHI	5, 7, 9
Essentially high importance	ESHI	3, 5, 7
Weakly high importance	WHI	1, 3, 5
Equally high importance	EHI	1, 1, 3
Exactly equal	EE	1, 1, 1
Equally low importance	ELI	0.33, 1, 1
Weakly low importance	WLI	0.2, 0.33, 1
Essentially low importance	ESLI	0.14, 0.2, 0.33
Very low importance	VLI	0.11, 0.14, 0.2
Absolutely low importance	ALI	0.11, 0.11, 0.14

Step 1: After collecting relative evaluations of experts based on linguistic terms, pairwise comparison matrices are built for each factor and sub-factor. Later, linguistic terms are transformed into triangular fuzzy numbers according to the scale in Table 1, and a Pairwise Comparison matrix showing judgments of each factor over another is constructed.

Step 2: Expert judgments are combined by using the scale in Table 1 and sorting from the minimum e_0 to the maximum e_g (Liu and Rodriguez 2014). This means that it is accepted that $e_0 \leq e_i < e_j \leq e_g$ for expert judgments changing between e_i and e_j. The lowest and highest values of the triangular fuzzy membership (a and c) function $\tilde{A} = (a, b, c)$ are obtained by Eqs. (7)–(9), and the value of b is found by using OWA operator by Eq. (10):

$$b = \begin{cases} a_m^i & \text{Otherwise} \\ OWA_w\left(a_m^i, \ldots, a_m^j\right) & \text{If } i+1=j \end{cases} \tag{10}$$

The weight vector of OWA is found by using α parameter between 0 and 1, g as the number of terms in Table 1 (as 11), j and i as the rank of the maximum and minimum values of expert opinion as follows ($W = (w_1, w_2, \ldots, w_n)$) (Filev and Yager 1998).

$$w_1 = \alpha^{n-1}, w_2 = (1-\alpha)\alpha^{n-2}, \ldots, w_n = (1-\alpha) \tag{11}$$

$$\alpha = (g-j+i)/(g-1) \tag{12}$$

Step 3: After building pairwise comparison matrices separately, a common matrix $\hat{C}$ is constructed by $\hat{c}_i = (c^l_{ij}, c^m_{ij}, c^u_{ij})$. Reciprocal values of matrix $\hat{C}$ are found due to the evaluations with triangular fuzzy numbers, as follows:

$$\hat{c}_{ji} = \left(1/c^l_{ij}, 1/c^m_{ij}, 1/c^u_{ij}\right) \tag{13}$$

Step 4: For each row ($\hat{r}_i$), the fuzzy geometric mean is computed as follows:

$$\hat{r}_i = (\hat{c}_{i1} \otimes \hat{c}_{i2} \ldots \otimes \hat{c}_{in})^{1/n} \tag{14}$$

Step 5: Fuzzy weight ($\hat{w}_i$) is found for each factor.

$$\hat{w}_i = \hat{r}_i \otimes (\hat{r}_1 \oplus \hat{r}_2 \ldots \oplus \hat{r}_n)^{-1} \tag{15}$$

Step 6: Finally, triangular fuzzy numbers are changed into crisp values, the ranking of factor i is found by using Eq. (16), and the weights are normalized.

$$n_i = w^l_i + 4w^m_i + w^u_i/6 \tag{16}$$

Proposed Hybrid Metaheuristic

Although project management methodologies have improved in recent years, software developers and project managers mostly have difficulties in meeting the deadline because of the unplanned workforce, insufficient knowledge, bad customer relationships etc. Thus, resources may be wasted; customer credit and satisfaction may be lost (Kerzner and Kerzner 2017; Zwikael et al. 2018). This means that scheduling the projects properly is fundamental for IT companies. The most common methods in the literature used to plan the projects (CPM and PERT) may be insufficient about finding efficient schedules showing the best time to start and finish the project for meeting the deadline. In order to meet this deficit in the literature, we develop a hybrid metaheuristic using the estimations obtained by a hesitant fuzzy approach with OWA operator (Wei et al. 2016).

Tabu Search and Genetic Algorithms are known as the best metaheuristics to solve the NP-Hard problems in the literature (Glover 1977; Goldberg 1989). In our study, we apply some features (tabu list, crossing, diversification) of Tabu Search and Genetic Algorithm, thus take advantage of both methods. The algorithm starts with two feasible initial solutions including a sequence of the projects according to their starting time: (i) All projects are sequenced from the earliest deadline to the latest, (ii) All projects are sequenced from the largest difference between the bonus and penalty to the smallest. Firstly, an order of the projects in the first initial solution is randomly selected and the project in this order is found. Then the set of projects in two initial solutions coming after this project are wholly replaced with. Without breaking the feasibility, recurring projects are eliminated by starting from the beginning of the first and second projects, respectively, thus new solutions are obtained. An example with six projects is given in Table 2.

After finding new feasible candidate solutions, total cost (the total cost of labor + penalty for late completion—a reward for early completion) of two plans are calculated. Moreover, the project which was in the randomly selected order in the previous solution's first initial situation is added to the tabu list. The algorithm continues to search for new solutions. If the new randomly selected candidate order in the first initial solution involves the project in the tabu list and improves the best objective function obtained so far, the solution is accepted. Otherwise, another sequence is randomly selected to cross two solutions own between. This means that, changing the sequence of the projects coming after a specific one is forbidden during a specific number of iterations based on the tabu list size (n_1).

It is known that Tabu Search can get trapped at a local optimum after a number of iterations, and may not find a better solution for a while. As a diversification approach to prevent this problem, after a number of consecutive iterations (n_2) which do not improve the best-solution, selecting a project randomly is applied in the second initial solution instead of the first one. Obviously, the algorithm continues for a long time if the number of projects to be planned is high, which is true especially in large companies. Finally, the algorithm terminates at the end of a number of iterations set as a parameter (n_3) or when the two initial solutions get same.

Table 2 Searching new solutions with proposed hybrid metaheuristic

Initial solution 1 (feasible)	Initial solution 2 (feasible)	Randomly selected sequence in the first initial solution	Replacement	New feasible solutions after eliminating recurring projects
5-3-1-4-**2**-6	4-**2**-1-5-6-3	5	Solution 1: 5-3-1-4-**2**-1-5-6-3	Solution 1: 4-**2**-1-5-6-3
		(replacing the projects after 2 in the solution 1 and 2)	Solution 2: 4-**2**-6-1-5-6-3	Solution 2: 4-**2**-6-1-5-3

Bold value (2) in inital solutions shows the randomly selected project, and the underlined projects after the bold one (6 in solution 1 and 1-5-6-3 in solution 2) indicate the projects to be replaced

Experimental Study in a Turkish Company

The proposed methodology is applied to the 2-year software project planning problem of a Turkish company by using the real data. Both the factors indicated in the literature and expert judgment are considered to specify the criteria. Six experts are selected among the top managers of the company. Among many alternatives (i.e., testing, reporting, technology, staff capability, complexity of requirement, integration, business process flexibility, integration, warning etc.), the most fundamental objects affecting the development duration are decided to be categorized on five main factors with the number of: *client* including user interface, screen, user control; *application* including operation, entity, facade; *batch* including operating system batch, database job; *database* including index, user defined function, stored procedure; *data* including view, table, field, dimension, sequence objects. These factors cover almost all the functions required to develop a project. They are also used in different studies in the literature (Antoniol et al. 2003).

Later, five main factors (shown as f_1 for the number of client, f_2 for the number of application, f_3 for the number of batch, f_4 for the number of database, and f_5 for the number of data objects) are evaluated by six experts based on Hesitant Fuzzy Linguistic Term Pairwise Comparison approach according to the fuzzy linguistic scale presented in Table 1. Pairwise Comparison evaluations of six experts are summarized in Table 3.

OWA operator is used and triangular fuzzy sets are calculated by Eqs. 7–9 by using pairwise judgments. These sets are given in Table 4. As an example, the calculation for the factor 1 over 2 in Table 4 is found as follows: The fuzzy expert judgment for factor 1 over 2 ranges between ESHI and EHI (i = 6 and j = 8). Based on Eqs. 10 and 12, a = 1 and c = 7 as the smallest and highest values of $\{a_L^i, a_M^i, a_M^{i+1}, \ldots, a_M^j, a_R^j\} = \{1, 3, 5, 7\}$. b is obtained as follows:

$$\alpha = (g - j + i)/(g - 1) = (10 - 8 + 6)/(10 - 1) = 0.889$$
$$w_1 = \alpha^{2-1} = 0.889 \text{ and } w_2 = (1 - \alpha)\alpha^{2-2} = (1 - 0.889) = 0.111 (n = 2).$$

$OWA_w\left(a_m^i, \ldots, a_m^j\right)$ is used to obtain parameter b, since $i + 1 \neq j$, according to the Eq. 10 as follows: $b = 0.889 \times 5 + 0.111 \times 3 = 4.778$. As a result, fuzzy envelope for factor 1 over 2 is found as (1, 4.778, 7).

Afterwards, the geometric mean of fuzzy values for each row is computed by the Eq. 14. The calculation for the first row is as follows:

$$a_g = (1 \times 1 \times 1 \times 0.14 \times 1)^{1/5} = 0.675$$
$$b_g = (1 \times 4.778 \times 5.864 \times 5.811 \times 5.224)^{1/5} = 3.854$$
$$c_g = (1 \times 7 \times 9 \times 9 \times 9)^{1/5} = 5.515$$

Table 3 Expert opinion by Hesitant Fuzzy Linguistic Term Pairwise Comparison

Exp. 1	f_1	f_2	f_3	f_4	f_5	Exp. 2	f_1	f_2	f_3	f_4	f_5
f_1	EE	EHI	ESHI	VHI	AHI	f_1	EE	WHI	WHI	WLI	EHI
f_2		EE	EE	VHI	VHI	f_2		EE	VHI	ELI	ESHI
f_3			EE	ELI	WHI	f_3			EE	EHI	EHI
f_4				EE	VHI	f_4				EE	AHI
f_5					EE	f_5					EE
Exp. 3	f_1	f_2	f_3	f_4	f_5	Exp. 4	f_1	f_2	f_3	f_4	f_5
f_1	EE	WHI	EHI	EE	AHI	f_1	EE	ESHI	VHI	ESLI	VHI
f_2		EE	VHI	VHI	VHI	f_2		EE	ESHI	EHI	WHI
f_3			EE	ESHI	WHI	f_3			EE	WLI	EE
f_4				EE	VHI	f_4				EE	ESHI
f_5					EE	f_5					EE
Exp. 5	f_1	f_2	f_3	f_4	f_5	Exp. 6	f_1	f_2	f_3	f_4	f_5
f_1	EE	EHI	VHI	WHI	VHI	f_1	EE	ESHI	VHI	WHI	ESHI
f_2		EE	ESHI	AHI	WHI	f_2		EE	ELI	WLI	EHI
f_3			EE	WLI	EE	f_3			EE	VLI	WLI
f_4				EE	ESHI	f_4				EE	VHI
f_5					EE	f_5					EE

Table 4 Triangular fuzzy sets

	f_1	f_2	f_3	f_4	f_5
f_1	(1, 1, 1)	(1, 4.778, 7)	(1, 5.864, 9)	(0.14, 5.811, 9)	(1, 5.224, 9)
f_2	(0.143, 0.209, 1)	(1, 1, 1)	(0.33, 4.9, 9)	(0:2, 4.928, 9)	(1, 5.864, 9)
f_3	(0.111, 0.171, 1)	(0.11, 0.204, 3.03)	(1, 1, 1)	(0.11, 4.021, 7)	(0.2, 1.741, 5)
f_4	(0.111, 0.172, 7.143)	(0.111, 0.203, 5)	(0.143, 0.249, 9.091)	(1, 1, 1)	(3, 5.222, 9)
f_5	(0.111, 0.191, 1)	(0.111, 0.171, 1)	(0.2, 0.574, 5)	(0.111, 0.191, 0.333)	(1, 1, 1)

This means that, the geometric mean of the first row is (0.675, 3.854, 5.515). The biggest value in Table 1 (9 in AHI) is selected as $(\hat{r}_1 \oplus \hat{r}_2 \ldots \oplus \hat{r}_n)^{-1}$ to reduce the deviation and normalize the means. Thus, normalized values of the first factor are:

$$a_w = 0.675/9 = 0.075$$
$$b_w = 3.854/9 = 0.428$$
$$c_w = 5.515/9 = 0.613$$

The triangular fuzzy weights of all factors are presented in Table 5. The final weight of each factor is obtained by defuzzification using the Eq. 16 and normalization. As an example, the defuzzified weight of the first factor is calculated by: n_1 = (0.075 + 4 × 0.428 + 0.613)/6 = 0.400. Table 5 presents normalized weights of all factors.

It is obvious that f_1 is the most fundamental factor to estimate the duration required for software development with its weight 43.7%. f_2 is also an important factor with 24.3% weight, while f_3 and f_4 have similar weights by 11.7 and 15.1%. Simply, f_5 is the least important factor while estimating the time effort needed to develop IT projects.

The efficiency of the proposed fuzzy estimation method is also analyzed by collecting the values of five main factors for 416 projects completed in 2017 in the

Table 5 Triangular fuzzy weights of factors to estimate development duration

Factor	Fuzzy weights	Defuzzified weights	Normalized weights
f_1	(0.075, 0.428, 0.613)	0.400	0.437
f_2	(0.044, 0.219, 0.415)	0.223	0.243
f_3	(0.021, 0.084, 0,282)	0.107	0.117
f_4	(0.039, 0.060, 0.548)	0.138	0.151
f_5	(0.022, 0.036, 0.123)	0.048	0.052

Table 6 Estimated time effort for 785 projects

Interval of estimated time effort (man-day)	Number of projects	Average estimated time effort (man-day)
$0 < x < 50$	106	35.81
$50 \leq x < 100$	431	69.08
$100 \leq x < 250$	196	156.83
$x \geq 250$	52	315.21

company. Time effort for each project is estimated by using the weights of the factors given in Table 5 and the number of objects developed in the project. The difference between the estimated and actual time effort is averagely found 1.45% for 416 projects. This shows that Hesitant Fuzzy Pairwise Comparison gives efficient estimations in comparison with the actual effort. Experts who are selected to evaluate the factors and managers responsible for developing these projects also approved the quality of estimations.

In order to decide starting and finishing time of the software projects carried out in the company by the help of proposed hybrid metaheuristic presented in the previous section, we decide to make a daily plan for 2-year between January 2018 and 2020 in compatible with the requirements of the company's customers and senior managers. The number of working days in each year is assumed to be 240 after extracting legal holidays, weekends etc. There are 680 software developers in the company and 785 projects to be worked. The estimated time effort and number of projects in a specific interval are presented in Table 6. Hesitant fuzzy pairwise estimations are used to estimate the required effort, which shows the integration between the steps of the methodology.

For each project, required resources (analyst, developer, tester etc.) are decided by service managers who are responsible for releasing the project. It is accepted that each employee can work 8 h daily. Moreover, paid leaves, training etc. are taken into consideration while determining the availability of each resource. Deadline claimed by customers are handled as the finishing time of projects. Thus, a penalty will be imposed in case of a delay in the delivery of a project. On the contrary, finishing a project earlier than its deadline will be awarded. The penalty for late completion and reward for early completion of each project is determined by the customer at the time of labor demand. Finally, fixed cost is decided in man-hour for each type of resource and project by the senior project managers and human resource manager of the enterprise regarding the required budget, experience, quality, and technology.

In order to find an efficient time planning for 785 projects in a 2-year period, proposed hybrid metaheuristic algorithm is applied on the real data belonging to the company and estimated time efforts found by the hesitant fuzzy approach. After a detailed analysis, the parameters of the algorithm n_1, n_2, and n_3 are set by 8, 14, 2500 which give the most efficient plans, respectively. The problem on each project is solved with C# and the solution is found in almost 10 min on the average at the

Table 7 Results of planning problem obtained by proposed algorithm

		Initial solution-1				Hybrid algorithm			
	Average estimated time effort (man-day)	Number of projects with early completion	Number of projects delayed	Award gained by early completion ($)	Penalty imposed by delay ($)	Number of projects with early completion	Number of projects delayed	Award gained by early completion ($)	Penalty imposed by delay ($)
0 < x < 50	35.81	83	23	13.28	3.519	98	8	20.776	832
50 ≤ x < 100	69.08	384	47	93.312	11.045	412	19	101.352	5.852
100 ≤ x < 250	156.83	175	21	53.375	6.888	183	13	62.403	4.745
x ≥ 250	315.21	43	9	16.598	3.717	46	6	12.696	2.502
Total		685	100	176.56	25.169	739	46	197.227	13.931
		Initial solution-2							
		Number of projects with early completion	Number of projects delayed	Award gained by early completion ($)	Penalty imposed by delay ($)				
0 < x < 50		61	45	25.979	3.825				
50 ≤ x < 100		327	104	103.33	12.792				
100 ≤ x < 250		113	83	44.296	7.968				
x ≥ 250		25	27	10.4	5.616				
Total		526	259	184.007	30.201				

end of 2500 iterations. Table 7 presents the results for 785 projects found by every two initial solutions and proposed metaheuristic applied by initial solutions.

As seen in Table 7, the proposed hybrid method gives efficient plans for 785 projects with regard to the initial solutions. While there is latency in totally 100 and 259 projects with the first and second initial solutions, respectively, only 46 projects are completed later than their deadline with proposed algorithm. Moreover, while plans obtained by initial solutions provide $17,656 and 184,007 award, hybrid structure gives $197,227. Similarly, while initial solutions cause $25,169 and 30,201 penalty, only $13,931 penalty is imposed by the hybrid algorithm. This shows that the proposed method gives efficient solutions for time planning of IT projects having hesitant fuzzy time efforts. Furthermore, senior managers and the requesters of the projects approve the plans obtained by a hybrid algorithm which supplement the increase in customer satisfaction and total profit for the company.

Conclusions and Further Research

This paper presents a novel method to determine schedules of IT projects. Time effort required to complete these projects are estimated by hesitant fuzzy approach integrating mathematical analysis and expert judgment with the pairwise comparison. Obviously, considering only expert opinion or algorithmic methods for time effort estimation may cause some problems if experts are not fair and experienced enough or factors and relations are not well defined, respectively. Therefore, estimation obtained by hesitant fuzzy technique provides more acceptable and realistic results by combining subjective and algorithmic methods in an uncertain environment. Moreover, as the most common methods used to plan the projects, CPM and PERT are insufficient about considering the deadline of the customers. Therefore, we propose a hybrid metaheuristic algorithm using some properties of Tabu Search and Genetic Algorithm and estimated time effort found by the hesitant fuzzy method to schedule projects. The method permits completing the project earlier or later than the deadline requested by the customer in reply to award or penalty using two different initial solutions. Finally, the proposed novel methodology is applied in a Turkish company to schedule pending 785 projects in a 2-year planning period. It is analyzed that the method provides efficient results with fewer projects delayed, higher award, and lower penalty showing that the methodology is effective while dealing with the planning problem for IT projects. The solutions obtained by the method are also confirmed by the experts and senior managers of the company.

In the future, a mathematical model can be developed and proper exact algorithms or metaheuristics can be applied to find the solution in the deterministic or uncertain environment.

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Comparison of Isotropic and Anisotropic Models for Solar Radiation on Sloped Surfaces Under Fuzzy Logic

Veysel Coban and Sezi Cevik Onar

Abstract Energy is a vital necessity that ensures the continuity of life. It is also important to ensure the existence and continuity of the energy. Solar is the most important source of energy among renewable energy sources that are being developed as an alternative to fossil fuels that are consuming. This study develops models for the evaluation of solar energy systems and allows calculation of radiation values in the sloped surface for isotropic and anisotropic sky conditions. In literature, the effects of extraterrestrial, atmospheric, and terrestrial uncertainties are usually ignored. In the proposed fuzzy models, these uncertainties inherit in the solar energy production capacity are considered. These newly developed isotropic and anisotropic fuzzy models help to determine the most appropriate solar energy system by providing more realistic calculations.

Keywords Solar energy · Isotropic conditions · Anisotropic conditions
Fuzzy logic · Insolation

Introduction

The growing population and the resulting industrialization are leading to an increase in energy use and energy demand (U.S. Energy Information Administration (EIA) 2016). Fossil fuels are used as the first source to meet the energy demand. When fossil fuels burn, that is, when they enter the energy conversion process, carbon dioxide and other greenhouse gases (methane, nitrous oxide) are spreading around. These gases cause the harmful radiation to reach the earth by thinning the ozone layer. These situations have led mankind to turn to new

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_2

energy sources for a habitable world on a social, economic and ecological scale. Renewable energy, which constitutes the most important part of this energy direction, does not cause any swing that harms the environment by feeding on natural sources such as the sun, wind, wave, tide and geothermal (Twidell and Weir 2015). Special advantages distinguish the sun from the renewable energy sources and make the sun a promising energy source.

Solar energy, the sole source of energy until fossil fuels were discovered, has become important again with the disadvantages of fossil fuels (Silvi 2008). Although the importance of solar energy is unknown, low technological efficiency and high cost have prevented adoption and diffusion of solar energy systems. Developments in solar energy technology increase system efficiency and reduce costs, so solar energy systems are expected to become widespread in the long run. Solar energy is considered as a healthy and reliable source of energy generation with environmental sensitivity (Energy and Natural Resources Ministry (ENRM) 2017). Increased efficiency and reduced costs have led to an increase in the installation of solar energy systems in countries and solar energy capacity established in 2014 have grown by 38% (BP 2017).

Solar energy systems are sloped at a certain angle so that solar radiation scattered directly and radially from the sky and the terrestrial can be achieved at the highest level (Myers 2005). In calculating the design and performance of solar systems, it is very important to measure and estimate the solar radiation on the sloped surface. Uncertainties arising from extraterrestrial, atmospheric, and terrestrial factors cause the potential of solar energy to reach the sloping surface to be ambiguous. By incorporating these uncertainties into account with the fuzzy logic method in this study, more realistic results can be obtained for solar energy systems on sloping surfaces. In this way, solar energy systems on sloped surfaces under uncertain conditions can be evaluated in different sky conditions.

Fuzzy logic, fuzzy logic arithmetic operations, and membership functions are mentioned in the second part of the study. Section "Radiation on Sloped Surfaces" focuses on radiation and isotropic and anisotropic sky conditions on sloped surfaces. In Sect. "Solar Radiation on Sloped Surfaces under Fuzzy Logic", radiation on curved surfaces is calculated and compared based on fuzzy logic under isotropic and anisotropic sky conditions. In the conclusion section, the study is terminated with a general evaluation and future study proposal.

Fuzzy Logic

The fuzzy clusters were introduced by Zadeh (1965) with the aim of clarifying the classes of completely unidentified objects. It is suggested that objects may have properties defined at a grade between classical 0 and 1. Fuzzy logic helps to understand and solve the real life problems by considering the intermediate alternatives between proposals. Fuzzy sets (X) and subsets (eg. $\tilde{A}$) are defined by the membership function $(\tilde{\mathrm{A}}(\mathrm{x}))$ and can be defined by any number in the [0,1] interval. For example, $\tilde{\mathrm{A}}(0.3)$ represents that x has membership value 0.3 in $\tilde{\mathrm{A}}$. $\tilde{\mathrm{A}} \geq \tilde{\mathrm{B}}$ means that $\tilde{\mathrm{B}}$ is a fuzzy subset of $\tilde{\mathrm{A}}$. Some fuzzy set arithmetic operations are expressed as (Kosko 1986);

$$\text{Union of two fuzzy sets: } \mu_{\tilde{\mathrm{A}} \cup \tilde{\mathrm{B}}} = max\left[\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\right] \tag{1}$$

$$\text{The intersection of two fuzzy sets: } \mu_{\tilde{\mathrm{A}} \cap \tilde{\mathrm{B}}} = min\left[\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x)\right] \tag{2}$$

$$\text{The complement of a fuzzy set: } \mu_{\tilde{A}^c} = 1 - \mu_{\tilde{A}} \tag{3}$$

Fuzzy sets can be divided into discrete and continuous fuzzy sets that reflect the states of the fuzzy membership functions.

Fuzzy numbers are an important step in fuzzy operations, Gaussian, triangular (Fig. 1) and trapezoidal fuzzy numbers are widely used in applications. The fuzzy membership function of the triangular fuzzy set $\tilde{\mathrm{B}}$ can be defined as;

$$\mu_{\tilde{B}}(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{d-a}, & a \leq x \leq d \\ \frac{e-x}{e-d}, & d \leq x \leq e \\ 0, & x > e \end{cases} \tag{4}$$

where $\tilde{A} = (x_1, x_2, x_3)$ and $\tilde{B} = (y_1, y_2, y_3)$, fuzzy arithmetic operations for triangular fuzzy numbers can be defined as:

$$\tilde{A}(+)\tilde{B} = (x_1, x_2, x_3)(+)(y_1, y_2, y_3) = (x_1 + y_1, x_2 + y_2, x_3 + y_3) \tag{5}$$

$$\tilde{A}(-)\tilde{B} = (x_1, x_2, x_3)(-)(y_1, y_2, y_3) = (x_1 - y_3, x_2 - y_2, x_3 - y_1) \tag{6}$$

$$-(\tilde{A}) = (-x_3, -x_2, -x_1) \tag{7}$$

$$\tilde{A}(\cdot)\tilde{B} \cong (x_1 * y_1, x_2 * y_2, x_3 * y_3) \tag{8}$$

$$\tilde{A}(/)\tilde{B} \cong \left(\frac{x_1}{y_3}, \frac{x_2}{y_2}, \frac{x_3}{y_1}\right) \tag{9}$$

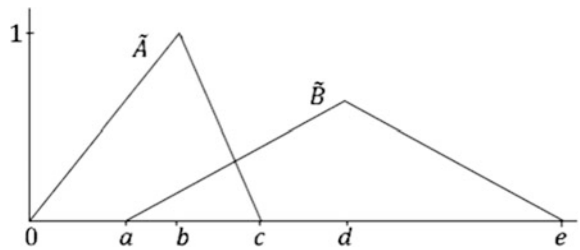

Fig. 1 Continuous triangular fuzzy sets $\tilde{A}$ (approximately b) and $\tilde{B}$ (approximately d)

In this study, solar radiation values on sloping surfaces under isotropic and anisotropic sky conditions are calculated by using the triangular fuzzy membership function. The extraterrestrial, atmospheric and terrestrial factors which are the main sources of uncertainty are defined as fuzzy numbers and the solar radiation calculations on the sloped surface are made on these values. At the end of fuzzy calculations, fuzzy radiation values are obtained according to different sky conditions. These fuzzy values are transformed into crisp values by using the most appropriate weighted average method for our study between different defuzzification methods (Ross 2009).

$$z^* = \frac{\sum \mu_A(\bar{z})\bar{z}}{\sum \mu_A(\bar{z})} \tag{10}$$

where z is the centroid of each membership function.

Radiation on Sloped Surfaces

Solar radiation passing through uncertain and ambiguous atmospheric and environmental conditions spreads on the earth as a beam, scattered and reflected. Incoming solar radiation is the sum of a series of radiation flows, including beam radiation, three components of scattered radiation from the sky, and radiation reflected from the surfaces. Thus, the total radiation reaching the earth on the hourly basis (I_T) is defined as follows (Duffie and Beckman 2013);

$$I_T = I_{T.beam} + I_{T.diffuse} + I_{T.reflected} \tag{11}$$

For the efficient operation of solar energy systems installed on the earth, it is necessary to obtain this triple solar distribution at the highest level. Therefore, the reflectors and the collectors of the solar energy systems need to be sloped at certain angles according to the conditions they are in. Different computing models have been developed to achieve I_T value the that has a complicated substance. Differences arise from the methods of processing the scattered radiation terms. Models developed for this purpose are divided into two as isotropic and anisotropic according to the evaluation of the radiation scattered in the sky. These methods reflect different assumptions about the distribution of scattered radiation from the tilted surface (Crawley 2016; Duffie and Beckman 2013).

Isotropic Sky (Liu-Jordan Model)

In this model, it is assumed that the combination of scattered and reflected radiation is isotropic (Hottel and Woertz 1942). The scattered and reflected radiation from the sky over the sloped surface is considered the same regardless of direction and I_T on the sloped surface is the sum of the beam and diffuse on the horizontal surface (Liu and Jordan 1963). In the model involving beam (I_b), diffuse (I_d) and reflected radiation values, the hourly total radiation on the sloped surface is calculated as:

$$I_T = I_b R_b + I_d F_{c-s} + I \rho_g \left(\frac{1 - \cos\beta}{2} \right) \tag{12}$$

The view factor of the tilted surface with β angle to a the sky (F_{c-s}) and the ground $\left(F_{c-g}\right)$ are expressed as follows;

$$F_{c-s} = \left(\frac{1 + \cos\beta}{2} \right) \text{and}\, F_{c-g} = \left(\frac{1 - \cos\beta}{2} \right) \tag{13}$$

If the environment has a diffuse reflection rate for total solar radiation, the reflected radiation from the ground $\left(I_{gr}\right)$ to the sloped surface is as follows;

$$I_{gr} = I \rho_g F_{c-g} \tag{14}$$

R_b is the ratio of the beam radiation on the sloped surface $(G_{b.T})$ to the beam radiation on the horizontal surface (G_b). By multiplying R_b with hourly beam radiation, the beam radiation value on the sloped surface is obtained as $R_b = G_{b.T}/G_b$. The isotropic model, which is widely used and gives the most flexible estimates of the radiation on the sloped surface, is the simplest method among the models.

Anisotropic Sky

Although the isotropic model is easy to understand and to apply, it does not take into account circumsolar diffuse and horizon brightening components which are effective on a tilted surface (Duffie and Beckman 2013). Therefore, researchers have been looking to develop new models so that calculations on the sloped surface can be done more accurately. In this regard, HDKR (Hay, Davies, Klucher, Reindl) model (Hay and Davies 1980; Klucher 1979; Reindl et al. 1990) was generated and I_T redefined as;

$$I_T = (I_b + I_d A_i) R_b + I_d (1 - A_i) F_{c-s} \left[1 + f \sin^3 \left(\frac{\beta}{2} \right) \right] + I \rho_g F_{c-g} \tag{15}$$

A_i is the anisotropy index as a function of the transmittance of the atmosphere for direct radiation. Value refers to the ratio between hourly beam radiation on the ground and extraterrestrial hourly radiation on the horizon. The value of f in the $1+f\sin^3\left(\frac{\beta}{2}\right)$ the correction factor, which accounts for cloudiness, reflects the ratio of beam radiation in the total hourly total radiation on earth.

$$A_i = \frac{I_b}{I_o}\ \text{and}\, f = \sqrt{\frac{I_b}{I}} \tag{16}$$

Another model developed under the anisotropic sky is the Perez model. Perez model (Perez et al. 1990) is based on a detailed analysis of the three diffuse components (sky-diffuse, circumsolar, horizon brightening).

$$I_T = I_b R_b + I_d(1-F_1)\left(\frac{1+\cos\beta}{2}\right) + I_d F_1 \frac{a}{b} + I_d F_2 \sin\beta + I\rho_g\left(\frac{1-\cos\beta}{2}\right) \tag{17}$$

F_1 and F_2 are circumsolar and horizon brightening coefficients. The terms a and b are tilted and account for the incidence of circumsolar radiation in horizontal surfaces.

$$a = maks(0, \cos\theta)\ \text{and}\ b = maks(\cos 85, \cos\theta_z) \tag{18}$$

Brightness coefficients F_1 and F_2 defining the sky conditions are functions of the zenith angle (θ_z), clearness (ε) and brightness (Δ) parameters. Brightness and clearness are defined based on radiation values as following:

$$\Delta = m\frac{I_d}{I_{on}}\ \text{and}\ \varepsilon = \frac{\frac{I_d + I_{b.n}}{I_d} + 5.535 * 10^{-6}\theta_z^3}{1 + 5.535 * 10^{-6}\theta_z^3} \tag{19}$$

where m is the mass of air and I_{on} is the extraterrestrial normal radiation.

For the ranges of clearness coefficients, F_1 and F_2 are calculated according to the brightness factor values obtained from the Table 1.

$$F_1 = maks\left[0, \left(f_{11} + f_{12}\Delta + \frac{\pi\theta_z}{180} f_{13}\right)\right],\ F_2 = \left(f_{21} + f_{22}\Delta + \frac{\pi\theta_z}{180} f_{23}\right) \tag{20}$$

This section refers to the calculation of hourly total radiation values on the sloping surface in isotropic and anisotropic sky conditions. Despite all these efforts, atmospheric and terrestrial uncertainties prevent the development of an absolute correct model. This study aims to remove the uncertainties in the models by describing the uncertainties in atmospheric and terrestrial factors in isotropic and anisotropic models with fuzzy numbers and functions.

Table 1 Brightness coefficients for the anisotropic sky (Perez et al. 1990)

ε ranges	f_{11}	f_{12}	f_{13}	f_{21}	f_{22}	f_{23}
1–1.065	−0.008	0.588	−0.062	−0.060	0.072	−0.022
1.065–1.23	0.130	0.683	−0.151	−0.019	0.066	−0.029
1.23–1.5	0.330	0.487	−0.221	0.055	−0.064	−0.026
1.5–1.95	0.568	0.187	−0.295	0.109	−0.152	0.014
1.95–2.8	0.873	−0.392	−0.362	0.226	−0.462	0.001
2.8–4.5	1.132	−1.237	−0.412	0.288	−0.823	0.056
4.5–6.2	1.060	−1.600	−0.359	0.264	−1.127	0.131
6.2–…	0.678	−0.327	−0.250	0.156	−1.377	0.251

Solar Radiation on Sloped Surfaces Under Fuzzy Logic

The rays of the sun that come to the earth as a beam and diffuse are reflected from the earth and spread again to the sky and the earth. Solar radiation shows a very complex and different distribution in atmosphere and earth. Therefore, solar energy systems need to be installed at the right angle to benefit from solar energy at the highest level. Models (Liu-Jordan, HDKR, Perez models) for the calculation of solar radiation in the sloped surface in isotropic and anisotropic sky conditions have been developed. These models that predict atmospheric and terrestrial expectations are insufficient to account for uncertainties. In this study, the total radiation on the sloped surface is calculated on the basis of fuzzy logic for isotropic and anisotropic sky models using fuzzy logic based total terrestrial calculations on the horizontal surface.

Firstly, hourly clear-sky horizontal beam $\left(\tilde{I}_{cb}\right)$ and diffuse $\left(\tilde{I}_{cd}\right)$ radiation are calculated and summed to find the total radiation on the horizontal surface $\left(\tilde{\mathrm{I}}\right)$. The process steps followed at this stage are as follows:

1. Extraterrestrial normal radiation by using fuzzified solar constant $\left(\tilde{\mathrm{G}}_{\mathrm{sc}}\right)$ for nth day of the year (Spencer 1971);

$$\begin{aligned}\tilde{\mathrm{G}}_{\mathrm{on}} = \tilde{\mathrm{G}}_{\mathrm{sc}}(&1.00011 + 0.034221 \cos \mathrm{B} + 0.00128 \sin \mathrm{B} \\ &+ 0.000719 \cos\ 2\mathrm{B} + 0.000077 \sin 2\mathrm{B})\end{aligned} \tag{21}$$

$$B = (n-1)\frac{360}{365} \tag{22}$$

2. The atmospheric transmittance of the beam and diffuse radiation calculated using climatic correction factors is defined by the triangular fuzzy membership function according to regional differences (Duffie and Beckman 2013).

$$\tilde{\tau}_b = a_0 + a_1 * e^{-\frac{k}{\cos\theta_z}} \tag{23}$$

The a_0, a_1 and k values used for the standard atmosphere at 23 km are calculated by using a_0^*, a_1^* and k^* for less than 2.5 km altitudes (h).

$$a_0^* = 0.4237 - 0.00821(6 - h)^2 \tag{24}$$

$$a_1^* = 0.5055 + 0.00595(6.5 - \mathrm{h})^2 \tag{25}$$

$$k^* = 0.2711 + 0.01858(2.5 - h)^2 \tag{26}$$

a_0^*, a_1^* and k^* are used to reflect the changes in climate types. Correction factors are $r_0 = a_0/a_0^*$, $r_1 = a_1/a_1^*$ and $r_k = k/k^*$ as in Table 2;

$$\tilde{I}_{cb} = \tilde{I}_{on} * \tilde{\tau}_b * \cos\,\theta_z \text{ and } \tilde{I}_{cd} = \tilde{I}_{on} * \tilde{\tau}_d * \cos\,\theta_z \tag{27}$$

Total hourly radiation in the horizontal plane is calculated as;

$$\tilde{\mathrm{I}}\left(MJ/m^2\right) = \tilde{I}_{cb} + \tilde{I}_{cd} \tag{28}$$

The calculated hourly total radiation value for the horizontal surface is used to calculate the slope surface models. The following headings describe the calculation of fuzzified models and the application and comparison of the models.

Liu-Jordan Fuzzy Model (Isotropic-Sky)

The values of beam (I_b), diffuse (I_d) and ground-reflected $\left(I_{gr}\right)$ radiations on the model basis include extraterrestrial, atmospheric and terrestrial uncertainties. Fuzzy numbers and their calculation methods are used to provide a realistic solution to real life problems of the uncertainties based on the sky ambiguities. Therefore, the hourly total radiation $\left(\tilde{I}_T\right)$ on the sloped surface in isotropic sky conditions is calculated as follows:

Table 2 Correction factors for climate varieties (Hottel 1976)

Climate types	r_0	r_1	r_k
Tropical	0.95	0.98	1.02
Mid-latitude summer	0.97	0.99	1.02
Subarctic summer	0.99	0.99	1.01
Mid-latitude winter	1.03	1.01	1

$$\tilde{I}_T = \tilde{I}_b R_b + \tilde{I}_d F_{c-s} + \tilde{I}\tilde{\rho}_g\left(\frac{1-\cos\beta}{2}\right) \tag{29}$$

View factors in the model do not require fuzzification methods because they do not involve any ambiguity. The soil properties and rainfall cover of the earth are very important factors for the ground-reflected part of the radiation. The rate of surface reflection $\left(\text{albedo}, \tilde{\rho}_g\right)$ can be represented as;

$$\tilde{I}_{gr} = \tilde{I}\tilde{\rho}_g F_{c-g} \tag{30}$$

The geometric factor (R_b) does not contain any ambiguity because it depends on the angle of incidence (θ) and the zenith angle (θ_z).

HDKR Fuzzy Model (Anisotropic-Sky)

The HDKR model developed for anisotropic sky conditions accounts for the effect of horizon brightening and circumsolar diffuse. The model under atmospheric uncertainty is defined as;

$$\tilde{I}_T = (\tilde{I}_b + \tilde{I}_d\tilde{A}_i)R_b + \tilde{I}_d\left(1-\tilde{A}_i\right)F_{c-s}\left[1+\tilde{f}\sin^3\left(\frac{\beta}{2}\right)\right] + \tilde{I}\tilde{\rho}_g F_{c-g} \tag{31}$$

As in the isotropic model, total, beam and diffuse radiation values on the horizontal surface include uncertainty due to the extraterrestrial, atmospheric and relative effects. The clearness index has an important influence on the background of these calculations. The A_i reflects the effect of atmospheric transmittance on beam radiation in anisotropic sky conditions. The f-factor in the cloudiness effect in the model includes atmospheric uncertainties. Their fuzzy representations are;

$$\tilde{A}_i = \frac{\tilde{I}_b}{\tilde{I}_o} \text{ and } \tilde{f} = \sqrt{\frac{I_b}{I}} \tag{32}$$

Perez Fuzzy Model (Anisotropic-Sky)

The Perez model clarifies in detail the effects of sky-diffuse, circumsolar and horizon brightening in anisotropic sky conditions. The fuzzy definition of the model covering the radiation calculations is defined as follows;

$$\tilde{I}_T = \tilde{I}_b R_b + \tilde{I}_d\left(1 - \tilde{F}_1\right)F_{c-s} + \tilde{I}_d\tilde{F}_1\frac{a}{b} + \tilde{I}_d\tilde{F}_2\sin\beta + \tilde{I}\tilde{\rho}_g F_{c-g} \tag{33}$$

As with other methods, beam, diffuse and ground-reflected radiation affected by extraterrestrial, atmospheric, and terrestrial uncertainties are calculated on the basis of fuzzy logic. Fuzzy operations are not applied to the view factors and the parameters a and b which depend on the angles. The brightness coefficients $\left(\tilde{F}_1, \tilde{F}_2\right)$ in the model as circumsolar and horizon brightening coefficients are based on the clearness (ε) and brightness (Δ) parameters with atmospheric uncertainty.

$$\tilde{F}_1 = maks\left[0, \left(f_{11} + f_{12}\tilde{\Delta} + \frac{\pi\theta_z}{180}f_{13}\right)\right] \text{ and } \tilde{F}_2 = \left(f_{21} + f_{22}\tilde{\Delta} + \frac{\pi\theta_z}{180}f_{23}\right) \tag{34}$$

Circumsolar and horizon brightening coefficients F_1 and F_2 defining the sky conditions are functions of the zenith angle (θ_z), clearness (ε) and brightness (Δ) parameter. Because the diffuse $\left(\tilde{I}_d\right)$ and normal beam $\left(\tilde{I}_{b.n}\right)$ radiation are effective in calculating The clearness $\tilde{\varepsilon}$ and brightness $\tilde{\Delta}$ values based on radiation values are redeveloped with fuzzy numbers as:

$$\tilde{\varepsilon} = \frac{\frac{\tilde{I}_d + \tilde{I}_{b.n}}{\tilde{I}_d} + 5.535 * 10^{-6}\theta_z^3}{1 + 5.535 * 10^{-6}\theta_z^3} \text{ and } \tilde{\Delta} = m\frac{\tilde{I}_d}{\tilde{I}_{on}} \tag{35}$$

where m is the mass of air and $\tilde{I}_{on}$ is the extraterrestrial normal radiation. The obtained clearness index coefficients are defined from Table 1.

Because fuzzy basically defined models include extraterrestrial, atmospheric, and terrestrial uncertainties, hourly total radiation on sloped surfaces can be more accurately calculated. In order to demonstrate the validity of fuzzy based models, calculations and evaluations are done for a specific location in Turkey.

Application

The application refers to the assessment of the appropriateness of the solar energy system foreseen for the establishment of Turkey in the province of Istanbul $(\phi = 41.0350)$. It is assumed that the slope angle (β) is 45° and the surface azimuth angle (γ) is 0° at the sea level $(h = 0)$. The calculation results of Liu-Jordan, HDKR and Perez Fuzzy models in isotropic and anisotropic sky conditions on September 12 are shown in Table 3.

The calculated hourly and daily total radiation values for the sloped surface differ in the 3 models. Differences arise from the inclusion of the sky-diffuse, circumsolar and horizon brightening radiation values into the calculation method and the method of inclusion. The Perez Model gives the highest hourly and total daily radiation values on the sloped surface, which incorporates all radiation effects

Table 3 Hourly radiation values in the sloped surface for isotropic and anisotropic fuzzy models

Hours	Liu-Jordan	HDKR	Perez	Hours	Liu-Jordan	HDKR	Perez	Hours	Liu-Jordan	HDKR	Perez
00–01	0	0	0	08–09	1.45	1.46	1.68	16–17	0.79	0.78	0.92
01–02	0	0	0	09–10	2.05	2.09	2.35	17–18	0.24	0.23	0.26
02–03	0	0	0	10–11	2.50	2.55	2.84	18–19	0	0	0
03–04	0	0	0	11–12	2.74	2.80	3.10	19–20	0	0	0
04–05	0	0	0	12–13	2.74	2.80	3.10	20–21	0	0	0
05–06	0	0	0	13–14	2.50	2.55	2.84	21–22	0	0	0
06–07	0.24	0.23	0.25	14–15	2.05	2.09	2.35	22–23	0	0	0
07–08	0.79	0.78	0.92	15–16	1.45	1.46	1.68	23–00	0	0	0
					$\tilde{H}_T$(MJ/m^2, daily total)				19.54	19.83	22.29

into the calculation method in detail. The fact that the Perez model incorporates the effects of extraterrestrial, atmospheric, and terrestrial uncertainties in a detailed manner further strengthens the model.

Conclusion

Energy consumption is increasing rapidly with increasing population and developing industries. Fossil fuels used to provide increased energy consumption cause environmental, economic and social problems. The world is turning to renewable energy methods to overcome these problems. The sun is the most important renewable energy source with direct and indirect use. To benefit from solar energy systems at a high level, collectors must be installed at a right angle to the slope. The energy potential obtained from the sloped surface must be accurately calculated to measure system performance. For this purpose, Liu-Jordan, HDKR and Perez models have been developed for isotropic and anisotropic sky conditions.

These models do not account for dynamism, uncertainty, and ambiguity in extraterrestrial, atmospheric and terrestrial conditions. This study is based on the elimination of these deficiencies in the models. New isotropic and anisotropic models developed based on fuzzy will provide more realistic solutions by incorporating uncertainties into their calculations. Because it reflects these uncertainties in detail, the Perez model can produce more accurate solutions closer to reality.

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A Mathematical Programming Model for Maritime Inventory Routing Problem

Elifcan Gocmen, Ebru Yilmaz and Rizvan Erol

Abstract Inventory routing problems (IRPs) have been one of the most important problems in the last thirty years and include inventory management, vehicle routes and distribution sub problems. Several IRPs have been implemented in various sectors. Maritime inventory routing problem (MIRP) has also been tackled widely. The problem includes the distribution of products and holding the inventory levels between upper and lower limits. In this study, MIRP for the distribution of containers considering available inventory levels aiming minimum total cost has been proposed. Distribution amount and the routes under the constraints of routing and inventory levels have been decided. The model is proposed for deciding both optimal routes of the ships and optimum inventory levels. An integer programming approach for the problem has been proposed and solved using GAMS software.

Keywords Maritime inventory routing problem · Maritime logistics
Mathematical programming model

Introduction

IRP is a problem that decides how much inventory is kept in each node and vehicle routing during the period. The aim is to take an integrated distribution, routing, and holding decisions throughout the periods to create the lowest cost plan.

MIRP is also a subproblem of the IRP, tackles with the routing of ships, and keeps the inventory at ports. These processes are critically important to meet the

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_3

demands (Gocmen and Yilmaz 2018). The ports provided in the MIRP are defined like loading port for loading containers to ships and a discharging port for unloading the containers from ships. Each port has specified bounds of containers. Ships travel between ports by picking up containers and delivering it to one or more ports.

Christiansen and Nygreen (1998) formulate a mathematical model for an inventory-routing problem involving inventory management and routing decisions of a single product by a fleet of ships between ports. The quantities loaded are decided according to the production rates at the ports, the possible stock levels, and the moving vessels, and they are solved with a Dantzig-Wolfe and branch-bound approach. Christiansen (1999) provides a maritime problem involving a combination of IRP and a time window routing problem. It is stated that the ship fleet carries a product between the ports and that the loading and unloading quantities and the inventory levels are decided. A branch-bound algorithm is used and it is observed that the method provided gives good results. Hwang (2005) decides on how long each product will go from production ports to consumer ports in every problem and it has been stated that each product inventory level must be maintained at a certain level in each port. It is presented that holding capacities are determined at each port. A mathematical programming model is used. Christiansen and Fagerholt (2009) present a basic MIRP with a mathematical model. A problem has been presented considering inventory storage capacity, production and consumption rates of each port. Li et al. (2010) study maritime transport in chemical logistics and have investigated the inventory problem of chemical companies using multi-chemistry shipping fuels. This problem, which is aimed at maintaining adequate inventory levels, has been tried to be solved by using a new mixed integer model. Christiansen et al. (2011) study the problem of multi-product inventory routing problem and the problem includes multiple unmixed cement products with upper and lower limits transported from manufacturing plants to regional silo stations by heterogeneous fleet cargo vessels. They have tried to find a solution within the framework of the genetic algorithm and have shown good results. Song and Furman (2013) present a MIRP with the solution methods include neighbourhood research and branch-boundary algorithms. The problem aims to create a schedule to route the heterogeneous vessels responsible for cargo transport while maintaining capacities, constraints on inventories between ports. The problem shows that the model's implementation in the case study can also be successful in solving other inventory routing problems. Agra et al. (2015) have addressed a problem of stochastic maritime transport including inventory management of oil in ports and the delivering of these products. In the two-level programming, in the first level, the solutions are given about the routing while in the second level, inventory solutions are given. Hemmati et al. (2015) have tried to determine the quantities to be held at each inventory node and to maximize profits after the routes are decided for the inventory routing problem in freight transport. In the developed two-stage heuristic, firstly inventories are tried to be transformed into loads and solved by searching neighbourhood. Jiang and Grossmann (2015) present a problem of inventory routing problem for a single product based on continuous time and discrete time.

Firstly, a continuous time model is presented with time constraints; a discrete time is presented based on the constant load flow problem for a single product. In the study, production and consumption ports are available and it is stated that each port has inventory capacity. Minimizing cost considering the port times that the vessels visit and freight quantity for each port is aimed. De et al. (2017) present a MIRP considering sustainability that includes the relation between fuel consumption and ship speed. They propose a mathematical model with time windows and penalty constraints. Different heuristic approaches are used for solving the problem. Zhang et al. (2018) present a MIRP with time windows under several disruptions. They develop a heuristic for uncertain conditions and a simulator for the quality of solutions.

In this study, the investigated maritime inventory routing problem with multi port, multi-period, multi-product considers distributing containers and holding inventory levels is provided. The mathematical formulation developed for the problem mentioned above has been applied using a numerical example.

Problem Definition

Inventory routing problem concerned in this paper includes two sub problems: transportation of containers and controlling inventory levels to prevent stock out.

In this study, a new inventory routing model is proposed. The proposed model solved the routes considering the inventory levels at minimum cost. The proposed network is shown in Fig. 1. The network of the paper comprises a loading and discharging ports, ships, and containers. Transportation of the containers is provided by ships. A flow is between loading ports and discharging ports.

The objective function is consisted of:

- Inventory cost: This cost is related to holding cost and inventory levels at ports.
- Routing cost: This cost is related with the distribution of products via ships between loading and discharging ports.

Decision variables are consisted of:

- The decision of routing the ships (binary)
- Number of inventory levels (positive variable)
- Number of quantities and transported quantities (positive variables)

Constraints are consisted of:

- Distribution and routing constraints group of products
- Inventory levels group kept in the ports.

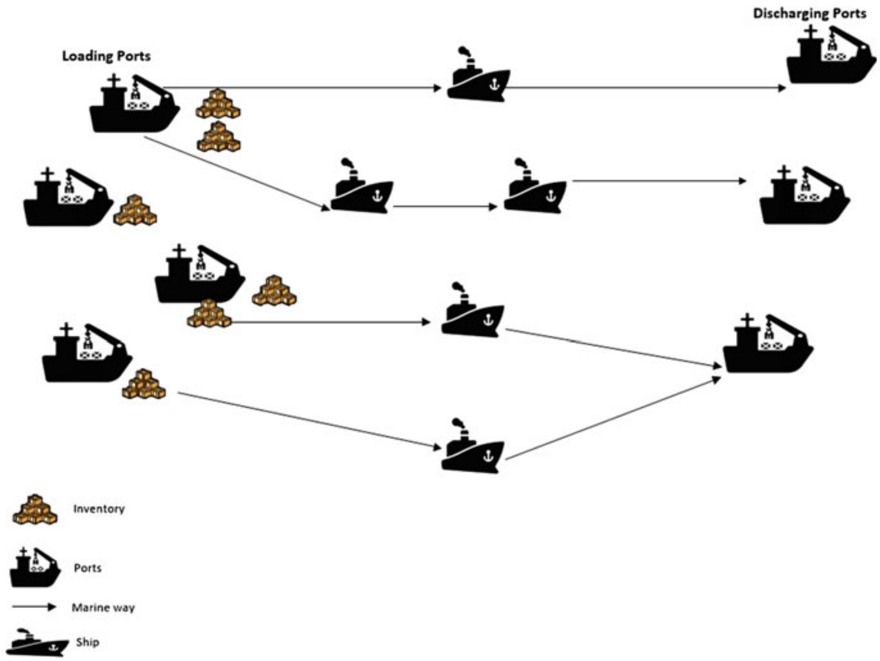

Fig. 1 Proposed network in the problem

Developed Mathematical Model

The indices of the mathematical modeling developed for the problem are as follows;

Indices

N set of ports (loading and discharging ports) ($n, m, r \in N$)
K set of ships ($k \in K$)
P set of products ($p \in P$)
T set of periods ($t \in T$).

Parameters

I_{np}^{upp} upper inventory level of product p on port n (unit)
I_{np}^{low} lower inventory level of product p on port n (unit)
d_{npt} demand for product p on port n at period(unit)
dis_{nm} distance between ports n and m (distance)
c variable cost for transportation (money/distance)
C_p Ship capacity of product p (unit)
h holding cost (money)
L maximum distance in a period for ships (distance).

Decision Variables

I_{npt} Inventory level for container p on port n at period t (unit)
$Y_{npkt} =$ p quantity distributed to port n at period t by ship k (unit)
$Z_{nmkt} = \begin{cases} 1, & \text{if ship k travels from port n to port m at period t} \\ 0, & \text{otherwise} \end{cases}$
$X_{nmpkt} =$ transported a quantity of product p from port n to port m at period t by ship k (unit)

$$\min z = \sum_{t \in T} \sum_{n \in N} \sum_{m \in N} \sum_{k \in K} (c * dis_{nm} * Z_{nmkt}) + \sum_{t \in T} \sum_{n \in N} \sum_{p \in P} h * I_{npt} \tag{1}$$

$$\sum_{n=1}^{N} X_{0npkt} - \sum_{n=1}^{N} X_{n0pkt} = \sum_{n=1}^{N} Y_{npkt} \quad (t \in T), (p \in P), (k \in K) \tag{2}$$

$$X_{nmpkt} \le C_p * Z_{nmkt} \quad (t \in T), (n \in N), (m \in N), (p \in P), (k \in K) \tag{3}$$

$$\sum_{\substack{n=0 \\ n \ne m}}^{N} Z_{nmkt} - \sum_{\substack{r=0 \\ n \ne r}}^{N} Z_{mrkt} = 0 \quad (n, m, r \in N), (k \in K), (t \in T) \tag{4}$$

$$\sum_{n=0}^{N} \sum_{\substack{m=0 \\ n \ne m}}^{M} Z_{nmkt} * dis_{nm} \le L \quad (k \in K), (t \in T) \tag{5}$$

$$\sum_{n=1}^{N} Z_{n0kt} \ge 1 \quad (k \in K), (t \in T) \tag{6}$$

$$\sum_{n=1}^{N} Z_{0nkt} \ge 1 \quad (k \in K), (t \in T) \tag{7}$$

$$\sum_{\substack{m=1 \\ n \ne m}}^{N} X_{mnpkt} - \sum_{\substack{r=1 \\ n \ne r}}^{N} X_{nrpkt} = Y_{npkt} \quad (t \in T), (p \in P), (k \in K) \tag{8}$$

$$I_{np}^{low} \le I_{npt} \le I_{np}^{upp} \quad (t \in T), (n \in N), (p \in P) \tag{9}$$

$$I_{np0} = 0 \quad (n \in N), (p \in P) \tag{10}$$

$$I_{npt} = I_{npt-1} - d_{npt} + \sum_{k=1}^{K} Y_{npkt} \quad (t \in T), (n \in N), (p \in P) \tag{11}$$

$$Z_{nmkt} \in (0, 1), Y_{npkt} \geq 0, X_{nmpkt} \geq 0, I_{npt} \geq 0 \tag{12}$$

The total cost includes total routing and inventory cost elements, is minimized (Eq. 1). Equations 2–8 constraints are for routing of the ships and distribution of the containers. Equation 2 shows that quantity of p product at the starting point equals the sum of the transported quantity and remaining quantity. Equation 3 provides ship capacity cannot exceed. Equation 4 provides the routing of the ships. Equation 5 ensures that total distance cannot exceed. Equations 6 and 7 are related with ship routes and starting port. Equation 8 provides equality between transported quantities. Equations 9–11 is about the inventory constraints. Equation 9 provides the inventory level limits. Equation 10 provides that there are not any inventory levels at the starting time. Equation 11 provides a balance between inventory levels. Equation 12 defines the ranges of decision variables.

Results

The proposed formulation is applied for a developed numerical example. In this example, ships, products, ports, demands, product capacities considered are given in Table 1, and the distance matrix as mille in Table 2.

Table 3 shows that for each port, one unit inventory must be held at each period.

Table 4 shows that for port 2, the first type of product with ship 1 is delivered as 2 and 1 units at periods 2 and 3. The first type of product with ship 2 is delivered as 1 unit at periods 4, 5, 6. The second type of product with ship 1 is delivered as 4 and 1 units at periods 2 and 3. The second type of product with ship 2 is delivered as 4, 2, 4 units at periods 4, 5, 6. The third type of product with ship 1 is delivered as 2 and 2 units at periods 2 and 3. The third type of product with ship 2 is delivered as 1, 1, 1 units at periods 4, 5, 6.

Table 1 Port demands at periods

Port	Products																	
	Period 1			Period 2			Period 3			Period 4			Period 5			Period 6		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Port 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Port 2	0	0	0	1	3	1	1	1	2	1	4	1	1	2	1	1	4	2
Port 3	0	0	0	2	1	1	1	5	4	1	5	4	1	5	1	1	3	2

Table 2 Distance matrix for example (mille)

	Port 1	Port 2	Port 3
Port 1	0	39.6	48.0
Port 2	39.6	0	54.8
Port 3	48.0	54.8	0

Table 3 Inventory levels at ports (unit)

Port/product	Periods				
	2	3	4	5	6
2/1	1.000	1.000	1.000	1.000	1.000
2/2	1.000	1.000	1.000	1.000	1.000
2/3	1.000	1.000	1.000	1.000	1.000
3/1	1.000	1.000	1.000	1.000	1.000
3/2	1.000	1.000	1.000	1.000	1.000
3/3	1.000	1.000	1.000	1.000	1.000

Table 4 Quantity delivered for port 2 (unit)

Product/ship	Periods				
	2	3	4	5	6
1/1	2.000	1.000			
1/2			1.000	1.000	1.000
2/1	4.000	1.000			
2/2			4.000	2.000	4.000
3/1	2.000	2.000			
3/2			1.000	1.000	2.000

Table 5 Quantity delivered for port 3 (unit)

Product/ship	Periods				
	2	3	4	5	6
1/1			1.000	1.000	1.000
1/2	2.000	1.000			
2/1			5.000	5.000	3.000
2/2	5.000	5.000			
3/1			4.000	1.000	2.000
3/2	2.000	4.000			

Table 6 Ship routes from port 1

To Port/ship	Periods				
	2	3	4	5	6
2/1	1.000	1.000			
2/2			1.000	1.000	1.000
3/1			1.000	1.000	1.000
3/2	1.000	1.000			

For port 3, the first type of product with ship 1 is delivered as 1, 1, 1 units at periods 4, 5, 6. The first type of product with ship 2 is delivered as 2, 1 units at periods 2, 3. The second type of product with ship 1 is delivered 5, 5, 3 units at periods 4, 5, 6. The second type of product with ship 2 is delivered as 5, 5 units at

Table 7 Ship routes from port 2

To Port/ship	Periods				
	2	3	4	5	6
1/1	1.000	1.000			
1/2			1.000	1.000	1.000

Table 8 Ship routes from port 3

To Port/ship	Periods				
	2	3	4	5	6
1/1			1.000	1.000	1.000
1/2	1.000	1.000			

periods 2, 3. The third type of product with ship 1 is delivered as 4, 1, 2 units at periods 4, 5, 6. The third type of product with ship 2 is delivered as 2, 4 units at periods 2, 3 (Table 5).

Table 6 shows that from port 1 to port 2, there is a flow by ship 1 at periods 2, 3. From port 1 to port 2, there is a flow by ship 2 at periods 4, 5, 6. From port 1 to port 3, there is a flow by ship 1 at periods 4, 5, 6. From port 1 to port 3, there is a flow by ship 2 at periods 2, 3 (the number 1.000 shows there is a route between two ports).

From port 2 to port 1, there is a flow by ship 1 at periods 2, 3. From port 2 to port 1, there is a flow by ship 2 at periods 4, 5, 6 (Table 7).

From port 3 to port 1, there is a flow by ship 1 at periods 4, 5, 6. From port 3 to port 1, there is a flow by ship 2 at periods 2, 3 (Table 8).

Discussion and Conclusion

IRP is a broad term that encompasses several problems. MIRP is one of these problems. In the literature, MIRP has been solved by different methods and heuristic approaches are generally preferred due to the complexity of the problem. In this paper, a mathematical model for this problem is developed and then solved by GAMS optimization software. The problem is solved optimally in seconds using a developed numerical example. In order to extend this problem, new constraints and decision variables include sustainability concept could be added to the developed model. Uncertainty conditions related to meteorology could be included in the study. In addition, this study could be extended for larger problems by heuristic methods.

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Hinterland Container Transportation Using Mathematical Programming Approach

Elifcan Gocmen and Rizvan Erol

Abstract Container transportation problems include logistics activities conducted in both terminals and hinterland of the terminal. Transferring containers considering cost, time and environmental issues is a difficult problem. Hinterland container transportation (HCT) is defined as the movement of the containers between terminals and customers by different transportation modes. Processes of the hinterland transportation are the most important cost factors for door-to-door services. These problems aim to decide the distribution of the containers considering the cost and time minimization. In this study, a container distribution, routing problem has been proposed in the hinterland. The problem aims to perform the distribution of the containers at minimum total traveling distance. Allocation of containers and the routes under the constraints of routing, capacity is investigated in this study. An integer programming approach has been proposed and solved.

Keywords Hinterland container transportation · Routing problems
Mathematical model

Introduction

Hinterland is defined as an area provided by a port for serving the customers (Slack 1993). Van Klink and Van den Berg (1998) define the hinterland as the inner region served by the port. Hinterland transportation is the most important cost for door-to-door services. Numerous ports have widened the hinterland areas and this brings competition. Although road transportation is still the main transportation mode, alternative modes are also developing to reduce the container traffic.

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_4

Railway-road modes are the most effective mode combination for both financial and the environmental aspects.

This paper presents the HCT which deals with the transportation by trucks, number of customers, terminal. The decision is the best allocation for containers and the best routes to follow. There are several studies of the hinterland transportation. Wang and Yun (2013) address an inland container transportation which includes container movements between a maritime terminal, a depot, and a train station. They offer a multi modal and time window approach where containers are moved by trucks and trains. A graphical model with time windows is presented and the problem is solved by a hybrid tabu search. A similar multi modal problem involving container transportation with a depot, a maritime terminal, and a train station is defined by Yun et al. (2013). A hybrid simulated annealing approach is applied to this problem. Verma and Verter (2010) propose a bi-objective approach to decide the best transportation plan of hazardous and non-hazardous goods in a multimodal network. The decisions regarding selecting the train service and routing the trucks are based on customer based service times. An iterative decomposition based solution methodology is provided for this problem. Cho et al. propose a multi modal multi objective problem and formulate the problem as a weighted shortest path model based on time windows. Taking into account the tradeoff between cost and time, they implement an approach, a type of dynamic programming algorithm. Verma et al. (2012) develop a tabu search approach for the transportation of the hazardous goods by train and trucks. They aim to minimize the total transportation cost and the risk of carrying the hazardous goods. They also examine the traffic rates at different terminals and the load factors on the trains. There are a few studies with one transportation mode that do not only considering vehicle routing and scheduling but also empty container positioning. Sterzik and Kopfer (2013) discuss an inland container transportation problem involving the movement of empty and full containers among the terminals, depots, and customers by trucks. The problem aims to minimize the total transportation time with tabu search approach. Zhang et al. (2009) formulate a problem, including the trucking the containers with time windows and empty container positioning. They use a tabu search approach to solve the problem. Zhang et al. (2010) propose a truck scheduling problem with multiple depots and multiple terminals for container transportation. Total transportation time is aimed to minimize by a window-partitioned approach. Resat and Turkay (2015) develop a mixed integer programming model for transport network design and operational problem. The traffic jam on the routes is also handled separately. In the study, an enhanced method is used to obtain effective pareto solutions for transport cost and delivery time purposes. Demir et al. (2016) develop the multi-objective mixed integer model for the green multimodal service network design problem, which includes the layout of the locomotives. They are also interested in uncertainty about circulation times. They use the average approximation algorithm to provide robust transport schedules, with transport costs, service duration and greenhouse gas targets.

This paper presents an integer model for the hinterland container transportation that does not only consider vehicle routing and allocation of the containers to the trucks. The main contributions of this study are two-folds: (i) proposed a mathematical programming model considers distributing containers from centre depot to customers with delivery routing (ii) this study demonstrates the applicability of the proposed model for a regional hinterland container transportation system using a computer program.

The remainder of the paper is organized as follows. We present the problem definition. Then, we present the mathematical model in detail. We conduct a numerical example to illustrate the effect of the model. Discussion and conclusion are presented.

Problem Definition

HCT is defined as the movement of the full and empty containers between terminals and customers. Figure 1 shows an HCT considered in this study. The problem includes containers, customers, terminals and transportation vehicles. The containers are imported containers. Containers are called outbound containers which are carried to terminals to load them onto the ships (Sterzik and Kopfer 2013). Containers are inbound containers which are carried to hinterland customers. Containers are transferred by trucks among the customers, depots, and terminals. The depots are used for trucks.

The company serves its customer using trucks. Trucks start and end their routes at the depots.

The general characteristics of the problem are summarized below:

- Import containers,
- A centre depot,
- Multiple customers,
- The demands are known.

In the study, the problem can be called as delivery routing problem. Road transportation is used in this stage that the trucks distribute the containers to some locations in Turkey. The capacity and distance constraints are given in this model.

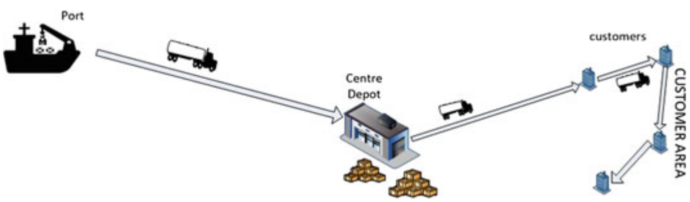

Fig. 1 Proposed network in the problem

Mathematical Model

A container distribution-routing problem consisting of multi-product decisions for hinterland container distribution system is proposed. In this problem, a trucking company serves customers with capacitated vehicles. There are two size containers that are considered in this model. All demands of customers are known in advance. The notation used for mathematical modelling of the problem is as follows:

Indices

- i Indices for all nodes
- l Index for delivery nodes
- k Index for trucks
- I Set of all nodes
- L Set of delivery nodes
- K Set of available trucks.

Parameters

- c_{ij} Distances between i and j (distance)
- Q_k The capacity of truck k (unit)
- p_l Delivery amounts at l point (unit).

Decision Variables

T_{ik} : max limit of unloading amount distributed to the i point with k vehicle (unit)

$$X_{ijk} = \begin{cases} 1, & \text{if k truck goes to j point from i point} \\ 0, & \text{otherwise} \end{cases}$$

$$z_{ik} = \begin{cases} 1, & \text{if k truck delivers to the i point} \\ 0, & \text{otherwise} \end{cases}$$

$$\min z = \sum_{k=1}^{K} \sum_{i=1}^{I} \sum_{j=1}^{J} c_{ij} * X_{ijk}$$

$$\sum_{j=1}^{J} X_{ijk} = \sum_{j=1}^{J} X_{jik} \quad (i = 1, \ldots, I;\ k = 1, \ldots, K) \tag{1}$$

$$\sum_{k=1}^{K} \sum_{j=0}^{J} X_{ljk} = 1 \quad l = 1, \ldots ..L \tag{2}$$

$$0 \leq T_{ik} \leq Q_k \quad (i = 1, \ldots, I;\ k = 1, \ldots, K) \tag{3}$$

$$U_{lk} \geq T_{ik} + p_l * z_{lk} - (1 - X_{ijk}) * Q_k \quad (i = 0, \ldots I,\ l = 1, \ldots L;\ k = 1, \ldots K) \tag{4}$$

$$\sum_{j=1}^{J} X_{jlk} \leq z_{lk} \quad (l = 1, \ldots L;\ j = 0, \ldots J;\ k = 1, \ldots K) \tag{5}$$

$$\sum_{i=1}^{I} T_{ilk} * p_l \leq Q_k \quad (i = 0, \ldots I, l = 1, \ldots L; k = 1, \ldots K) \tag{6}$$

$$X_{ijk}, z_{ik}, T_{ik} \geq 0 \tag{7}$$

The objective function minimizes the total distances. Constraint 1 is that the vehicle returns the starting point. Constraint 2 ensures that every node is visited. Constraints 3 and 4 allow the balancing of the distribution amounts. Constraint 3 provides that the maximum distributed amounts could not exceed the truck capacity. Constraint 5 ensures that the truck distributes if the truck travels between delivery nodes. Constraint 6 allows that the truck capacity could not be exceeded. Constraint 7 ensures that the decision variable is greater than zero points.

Results

Developed mathematical model is tested on a scenario with three vehicles and eight nodes. In this scenario, demands and distances matrix considered are given in Tables 1 and 2 (customer numbers represent the nodes by this order: Adana, Afyon, Aksaray, Ankara, Antalya, Balıkesir, Bursa, Denizli).

According to the vehicle capacity and the delivery constraints of the cities in Turkey, routes are decided. At this stage, an open-source software and Gams program results are provided. By results, it is seen that the same routes and distributed quantities are decided.

Table 1 Numerical example values (unit)

Customer numbers	Demands
Customer 1	2
Customer 2	6
Customer 3	5
Customer 4	4
Customer 5	4
Customer 6	1
Customer 7	2
Customer 8	5

Table 2 Distance matrix for numerical example (distance)

	Depot	c 1	c 2	c 3	c 4	c 5	c 6	c 7	c 8
Depot	0	916	393	645	419	665	287	123	535
Customer 1	916	0	583	274	504	627	934	827	758
Customer 2	393	583	0	356	261	289	347	276	224
Customer 3	645	274	356	0	228	442	706	551	529
Customer 4	419	504	261	228	0	514	573	387	473
Customer 5	665	627	289	442	514	0	527	548	240
Customer 6	287	934	347	706	573	527	0	171	278
Customer 7	123	827	276	551	387	548	171	0	426
Customer 8	535	758	224	529	473	240	278	426	0

Results by Gams Software

The routes obtained from the Gams program are as follows:

Three routes are determined according to the model developed. Objective function aims to minimize the total distance. The total distance is found as 4407 km.

As shown in Table 3, the vehicle's starting point is a depot. It carries out the delivery process for the capacity of the vehicles and the amount of the demands.

Table 3 Routes and distributed quantities

Routes			
Truck 1 Depot-Afyon-Ankara-depot Truck 2 Depot-Adana-Aksaray-Bursa-depot Truck 3 Depot-Balıkesir-Denizli-Antalya-depot			
Distributed quantities (unit)			
Cities	Vehicles		
	1. Truck	2. Truck	3. Truck
Adana		2	
Afyon	10		
Aksaray		7	
Ankara	4		
Antalya			10
Balıkesir			1
Bursa		10	
Denizli			6

Results by ODL Software

Delivery routing problem is solved by an open source coded program called Open Door Logistics. When vehicle numbers, addresses, distributed quantities are entered into the system, routes are created.

Vehicle id and stop id are shown in Fig. 2. For a 2-1 vehicle, P1 (Adana), P3 (Aksaray), P7 (Bursa) stop points are consolidated. For a 2-2 vehicle, P5 (Antalya), P8 (Denizli), P6 (Balıkesir) stop points are consolidated. For a 2-3 vehicle, P2 (Afyon), P8 (Ankara) stop points are consolidated.

Figure 3 presents the latitude and longitude values and distributed quantities.

The vehicles, stop points and numbers are given in Fig. 4.

	vehicle-id	stop-id
1	2-1	P1
2	2-1	P3
3	2-1	P7
4	2-2	P5
5	2-2	P8
6	2-2	P6
7	2-3	P2
8	2-3	P4

Fig. 2 Stop id and vehicle id of Open Door Logistics

	id	name	address	latitude	longitude	service-duration	start-time	end-time	quantity
1	P1		adana	36,992	35,331				2
2	P2		afyon	38,757	30,535				6
3	P3		aksaray	38,369	34,022				5
4	P4		ankara	40,123	32,63				4
5	P5		antalya	36,928	30,784				4
6	P6		balıkesir	39,655	27,889				1
7	P7		bursa	40,269	29,074				2
8	P8		denizli	37,783	29,1				5

Fig. 3 Stop id’s latitude, longitude, quantity via Open Door Logistics

	vehicle-id	stop-id	job-id	vehicle-name	stop-number	stop-name	type	stop-address	stop-latitude	stop-longitude
1	2-1	P1		truck1-1	1		stop	adana	36,992	35,331
2	2-1	P3		truck1-1	2		stop	aksaray	38,369	34,022
3	2-1	P7		truck1-1	3		stop	bursa	40,269	29,074
4	2-1	End_2		truck1-1	4	End_2	depot		40,975	29,257
5	2-2	P5		truck1-2	1		stop	antalya	36,928	30,784
6	2-2	P8		truck1-2	2		stop	denizli	37,783	29,1
7	2-2	P6		truck1-2	3		stop	balıkesir	39,655	27,889
8	2-2	End_2		truck1-2	4	End_2	depot		40,975	29,257
9	2-3	P2		truck1-3	1		stop	afyon	38,757	30,535
10	2-3	P4		truck1-3	2		stop	ankara	40,123	32,63
11	2-3	End_2		truck1-3	3	End_2	depot		40,975	29,257

Fig. 4 The routes via Open Door Logistics

The results are the same by both of the Gams and Open Door Logistics. Both methods give the same routes and a same number of vehicles.

Discussion and Conclusion

Hinterland transportation has been increasingly studied in recent years. This study deals with distributing the demands and routing trucks with distance and capacity constraints. The proposed model considers the import containers. The developed model is tested with a numerical example for Turkey. Problem is solved by two different softwares which are Gams optimization software and Open Door Logistics. Same results are taken from both of the softwares. For future works, heuristic methods can be used when the example is larger. More dynamic and autonomous methods can be applied.

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Implementation of Lean Six Sigma for Airline Ground Handling Processes

Ozlem Senvar and Dilek Akburak

Abstract Lean six sigma methodology offers a broad range of assessments and implementation services to meet the demands and challenges organizations face in today's global marketplace, where improved processes and unobstructed flow are essential elements for reducing costs and maintaining a competitive advantage. So that organizations can maximize profits and increase business value by providing knowledge and guidance on implementing continuous improvement, culture change, methodologies, and tools. From this standpoint, the purpose of this study is to analyze and enhance improvements for the non-value adding processes in airline ground handling operations via lean six sigma methodology and utilization of the appropriate tools.

Keywords Lean six sigma · Airline ground handling operation
DMAIC · Service industry

Introduction

The growth of the global economy has also deeply affected the service sector. For this reason, service quality has become even more important for companies. Being able to survive in a rapidly increasing global competition with globalization, adapting to changing market conditions and effectively meeting differentiated customer expectations can only be achieved by being open to innovations and

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_5

improvements and effectively implementing these two factors in business processes. Some new methods have searched to satisfy the increased number of passengers with a safe and effective flight. Ground handling operations have a big impact on the performance of the service quality of an airline company. Since they are related to speed, efficiency, and accuracy, it is crucial to reduce turnaround time and ground handling costs. This study aims that measuring the service quality by drawing a process chart in ground handling operations for an airline company and statistically analyzing the system. In the post-flight process, the passengers depart the plan and go to baggage claim. In the meantime, the bags are unloaded from the plane and go through a document check after which they are accepted. The bags after acceptance are loaded on the conveyor system so that they can be claimed by theory respective passengers (Ateş and Kağnıcıoğlu 2013). To do so we need to understand the airline service process. There are so many methods used to analyse and improve the airline service quality in a different way. In this context, this paper attempts to examine the airline ground service quality and operation processes. Lean Six Sigma methodology is an effective combination of two useful process improvement approaches: Lean and Six Sigma. At the end of this study, it is aimed to analyse and make some improvements for the non-value adding processes in airline ground handling operations by driving “Lean Six Sigma” tools such as process flowchart, histograms, value stream maps, and process performance analysis. Moreover, statistical analyses, appropriate quality management tools are used to evaluate the process data.

Lean Six Sigma

The fusion of Lean with Six Sigma continuous improvement methods is essential. Six Sigma is a quality improvement methodology that deals with variance and defects reduction, improvement of the process, products and services quality. Reducing waste and cycle time in processes cannot be possible only via the Six Sigma methodology. On the other side, Lean Manufacturing methodology constitutes the second part of Lean Six Sigma. This method is implemented to reduce waste and cycle time in processes; on the contrary, variance reduction cannot be performed only via Lean Manufacturing methodology (Şenvar and Tozan 2010). Furthermore, the use of only the lean method in a system cannot bring the system statistically under control. Process capability and Six Sigma methodology occupy significant places in quality and process improvement initiatives. PCA is used to improve processes, products or services to achieve higher levels of customer satisfaction (Şenvar and Tozan 2010). In order to measure process capability numerically, process capability indices (PCIs) and process performance indices (PPIs) have been developed. The tools of lean six sigma are shown below in Fig. 1. We have examined that in comparison to six sigma methodology, there are more researches with lean six sigma methodology in the literature regarding airline ground handling operations.

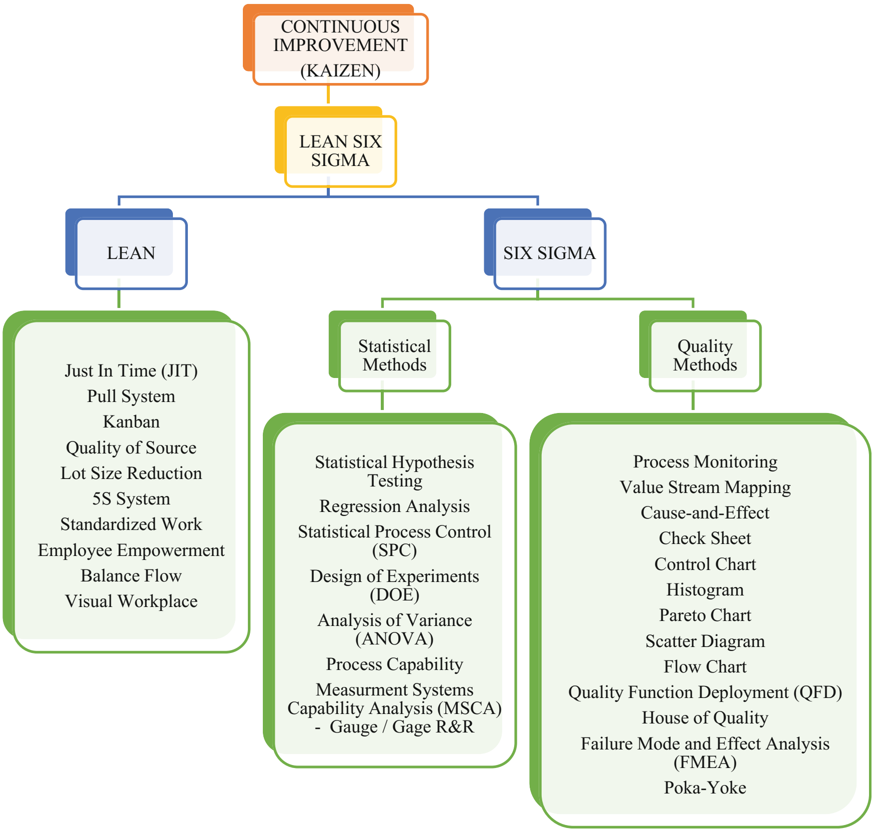

Fig. 1 Lean Six Sigma Tools. Adopted from Şenvar and Tozan (2010)

Application

Six Sigma which aims to increase customer satisfaction and corporate performance use the "define, measurement, analysis, improvement and control (DMAIC)" model. Six Sigma focuses on improving processes, design, and management. DMAIC is a cyclic process and it is desired that each cycle of this cyclic process yield the best result. The five Six Sigma phases (Define, Measure, Analyse, Improve and Control) are defined and their implementation tools are indicated in Table 1. These processes were implemented at ground handling operations for the airline company as mentioned in the following sub chapters.

Table 1 The applicable lean tools for each element of DMAIC

Define	Problem definition
	The voice of the customer (VOC), critical to quality (CTQ) characteristics and target processes along with related processes to set VSM
	Identification of process baseline performance including VSM metrics; inventory; lead time; cycle time; value added versus non-value added activities
	Creating a process flow chart
Measure	Creating current VSM for measuring baseline performance
	Measuring descriptive statistics for target processes
	Identification of improvement acts via Kaizen
Analyse	Implement process capability analysis (PCA)
	Make an analyse of histogram graphs of the target processes
Improve	Optimization and standardization on the process by eliminating wastes on it
	Create the future state VSM
	Implement future process capability analysis
Control	The usage of lean tools to control the system properly
	Visual workplace controls

Define

The first phase in the DMAIC method is the define phase. This part is the base and a critical step of the method since it consists of problem definition, a map of the relevant processes (flowchart), project goals, and customer needs and requirements. In this study, identifying the problem definition and goal statement, and observations, drawing flowchart of an entire process and defining the value stream mapping methodology constitutes the first phase of DMAIC.

Problem Definition and Goal Statement:

Ground handling operations cover the entrance of the customer from the contour to the plane door. Outsource service companies support some ground operation processes. These processes, are complemented by different outsourcers, are separated into counter, catering, cleaning, fuel, luggage transfer department. This project is about observing and improving an airline company's ground operation processes. The scope is observing the ground services in domestic flights at ATATURK airport.

Observations:

Before implementing the lean-six-sigma approach, the current status of the airline company's ground handling operational processes for domestic flights is observed at an international airport located in Turkey.

Fig. 2 Processes of passenger service for departure flights

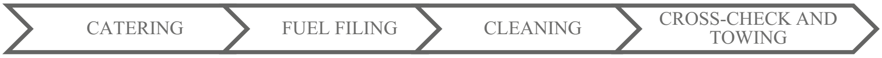

Fig. 3 Processes of baggage handling for departure flights

Fig. 4 Processes for flight preparation for departure flights

Ground Handling Services:

The airport ground services include all the services from the first contact with the outgoing passenger by accepting and guiding to baggage claim areas to the departure of the plane. And also, the other way round is for incoming passengers. This operation is a great deal of ground service work to aircraft, passengers, goods, baggage, such as fueling a plane, cleaning, catering, and loading goods to the plane as in Yin et al. (2015). In this study, passenger services, ground handling, catering, ramp handling, cleaning, fueling are the main categories of ground handling operations in Figs. 2, 3 and 4, respectively.

Process Flowchart:

The process flowchart is another tool that implemented for quality management studies. Whole processes that face passengers from their first step into the airport until departure is terminated. Through the airport company, many ground handling operations are found in the departure flights and this map also used in VSM which is another step of DMAIC. For this study, the flowchart is drawn for the ground handling operations for departure flights and given in Fig. 5.

Measure

In this stage, the necessary information is gathered in a detailed manner. It is important to determine the factors to be measured correctly and to decide which tests should be done after getting enough information. In this step, the current performance of the process must be measured. The main objective at this stage is to ensure that the inputs and outputs of the project are correct and to present the current situation with the help of various visual analyses (Polat et al. 2005).

Data Collection:

The base of the project is to collect the accurate data. Hence, after observing the entire system carefully, a detailed data sheet is created. The critical to quality (CTQs) characteristics that could affect the cycle time of process are discussed and listed for each process. All the characteristics that could be important are determined and a sample of the following data sheet is created in an Excel spreadsheet. For instance, in Fig. 7, the VSM of departure flights is mapped. In this project, all data based on a number of passenger and baggage were examined for 150 passengers and 99 pieces of baggage. In this study, lean six sigma methodology is implemented for the collected data to improve the system speed and quality. Since the cycle time of all processes is not the same, the sample numbers could not be the same. For instance, sample number for check-in process is 157 based on its mean time which is 1.13 min. On the other hand, the mean of the cycle time of the boarding process is 24.4 min, therefore the sample size of the boarding process is 24.

Current Value Stream Map:

The current state value stream map is initiated in Fig. 7. The value added and non-value added activities and times are shown in the timeline. As might be seen at the rightmost side of the timeline, total lead time of ground handling operations in departure flights is about 117 min. However, almost only 70 min are value added for the operation of the system.

Analyse

In the analyze phase, measured problems that have appeared in the previous subsections are analyzed and then some suggestions are provided to resolve them. By using basic problem solving techniques, the main variables that constitute the problem are identified firstly, and then the possible variables which affect the variabilities in the processes are explained. The purpose is to interpret the obtained data and to create an infrastructure for the improvement phase.

In this study, descriptive statistical analysis, histogram analysis, and Process Performance Analysis (PPA) are the tools used in the analyse phase.

Descriptive Statistical Analysis:

Process mapping allows us to see which processes need to examine more deeply. The target processes are check-in queue, check-in progress, and boarding process.

Figure 6 shows the box plots and the standard deviation of check-in progress and boarding process are found as 0.9 and 6.24 min in the current state, respectively. In addition, the mean times are 1.13 and 21.82 min, respectively. Red circle-highlighted samples are determined as outliers. However, there is no outlier for the boarding process (Fig. 7).

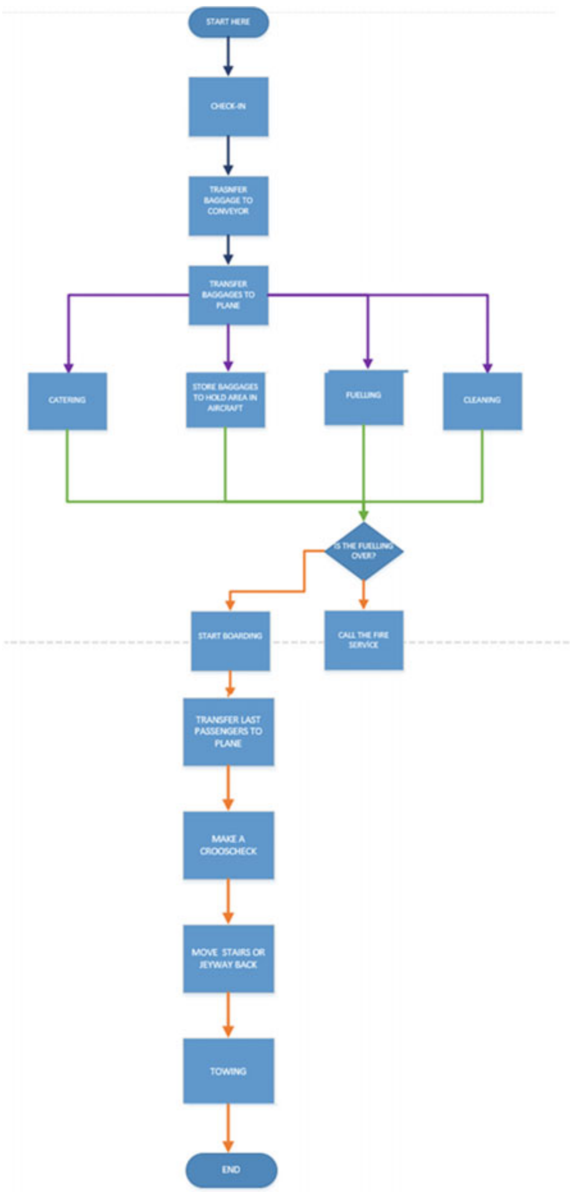

Fig. 5 The flowchart of the ground handling operations for departure flight

Histogram:

The histogram is known as one of the basic quality tools. The histogram is also helpful in estimating process capability. So, to obtain a reliable process capability results, the first histogram graphs are examined. Histogram graphs of the processes are given in Fig. 8.

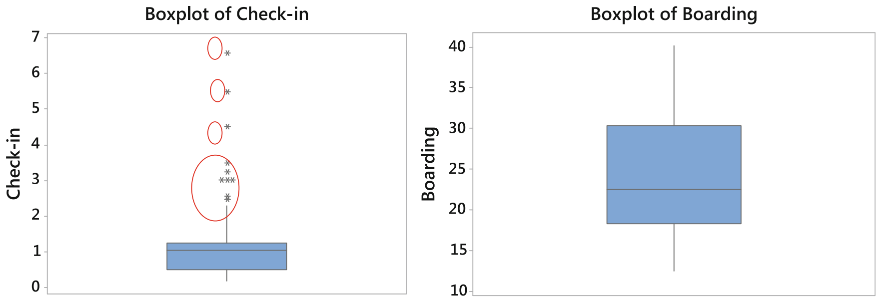

Fig. 6 Descriptive statistics analysis of check-in and boarding progresses

Process Performance Indices:

The process capability ratio is a level of the ability of the process to manufacture or manage a product that meets the specifications when the process is in control. As it could be understood that the check-in process is not a state of statistical control process performance indices are used as PPU and Ppk. The type of the data determines the type of the process performance ratio. In this study, one sided process capability ratio was used for boarding and check-in processes.

The formulation of process performance ratio is shown in Eq. 1:

$$P_{pu} = \frac{\mathrm{USL} - \mu}{3\sigma} \tag{1}$$

where USL stands for upper specification limit, μ corresponds to the mean of the process and σ symbolizes the standard deviation of the process.

In Fig. 9, the report of the process capability analysis (PCA) demonstrates that the one sided process performance for upper specification only (PPU) is 0.66 for current boarding process. Since the value is less than 1, this process does not satisfy the specification limits. For the check-in process, the PCA report is shown and the PPU value is 0.86 which is less than 1. The check-in process performance is also not adequate according to the specification limits.

Improve

In this phase, more efficient processes, better quality products, more satisfied customers and better equipment should be enhanced. In this study, deciding the characteristics of critical to quality and analyzing the improved process performance via PCA are the tools for improving phase of DMAIC.

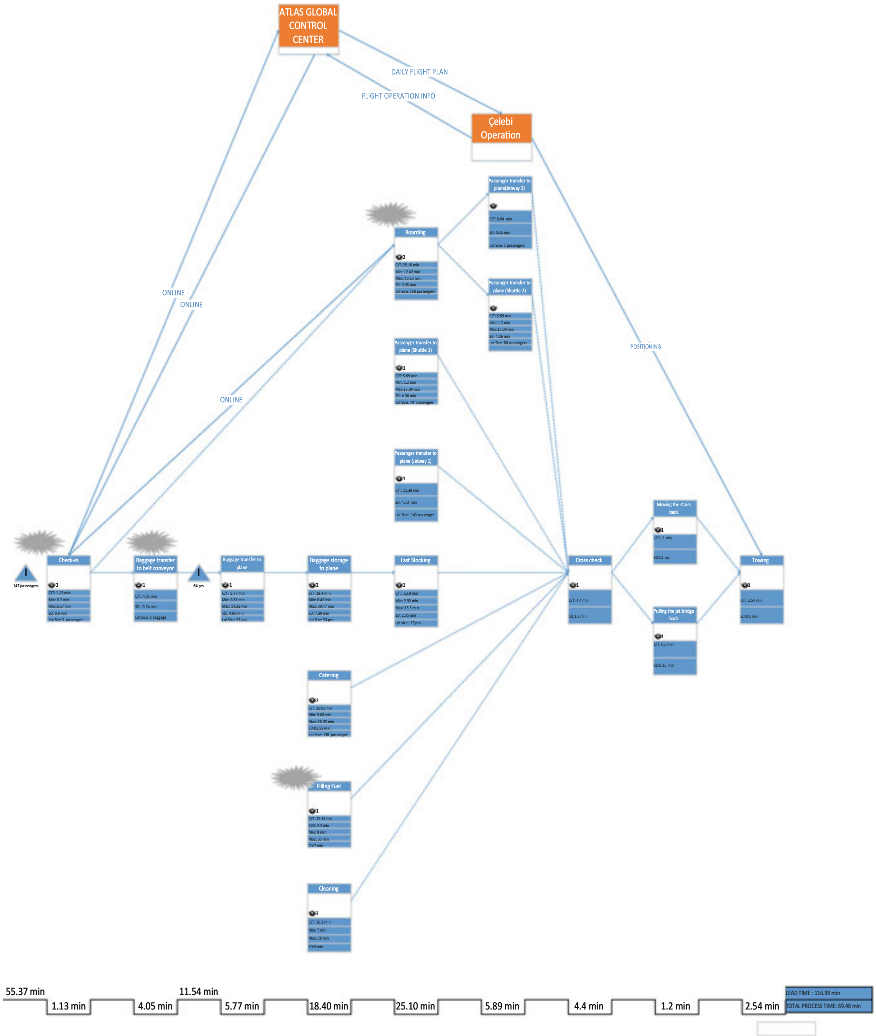

Fig. 7 Current state VSM for departure flights. *Source* Gergin et al. (2017)

Process Performance Analysis:

After proposed improvements, when the PCA reports were examined, the value of PPU has increased the point above 1 for both processes. The report of improved boarding process shows that there are no more data out of specification limits and PPU is 1.03 (>1) implying that processes are improved and fulfilled capability requirements. The process capability report improved boarding and check-in processes are shown as below in Fig. 10.

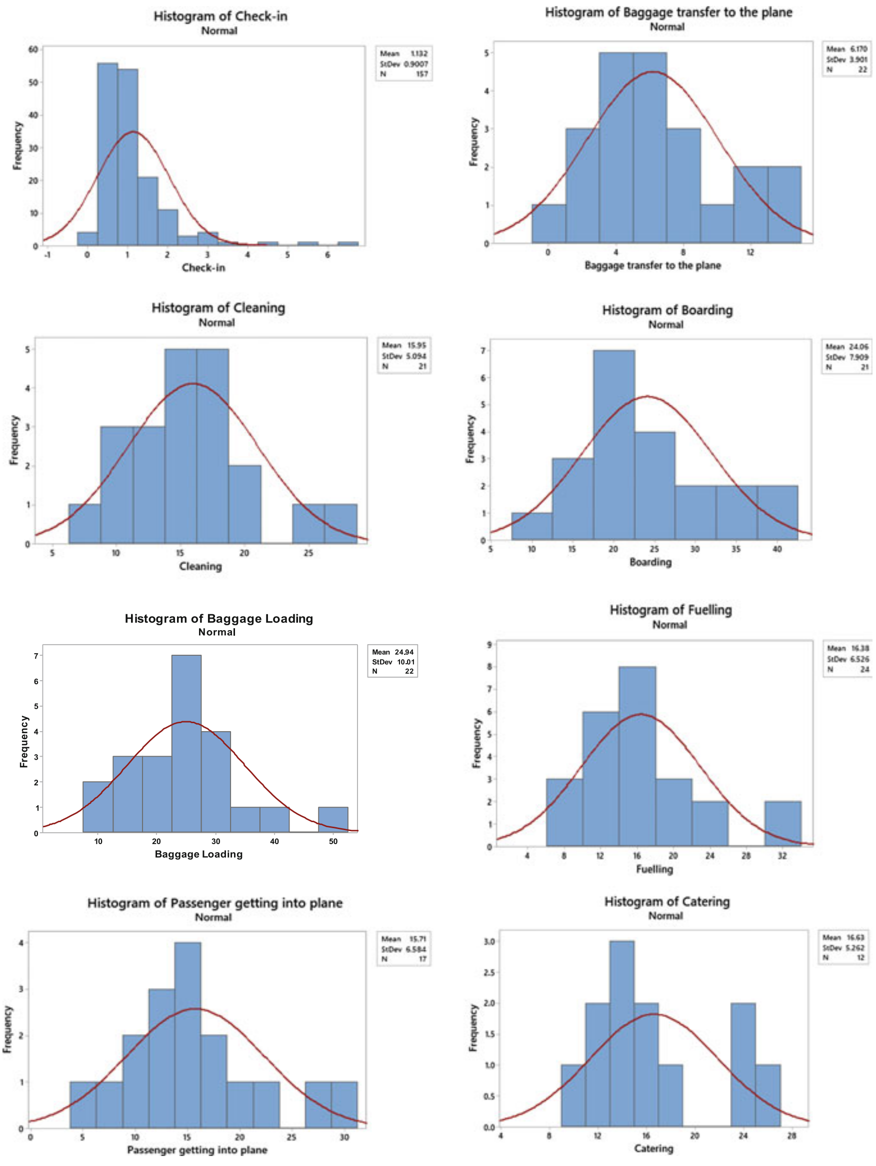

Fig. 8 Histogram graphs of all ground handling operations for departure flights

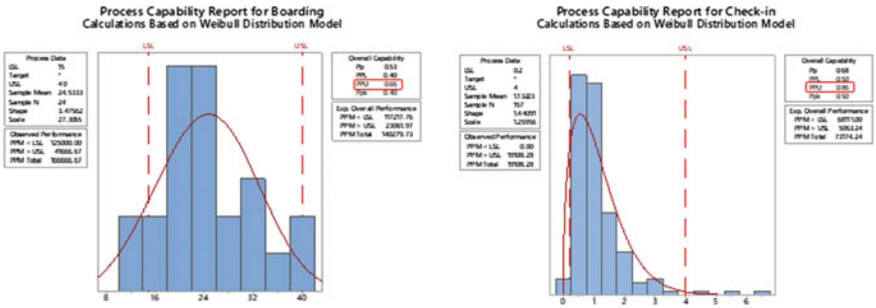

Fig. 9 The PCA report for current boarding and check-in process

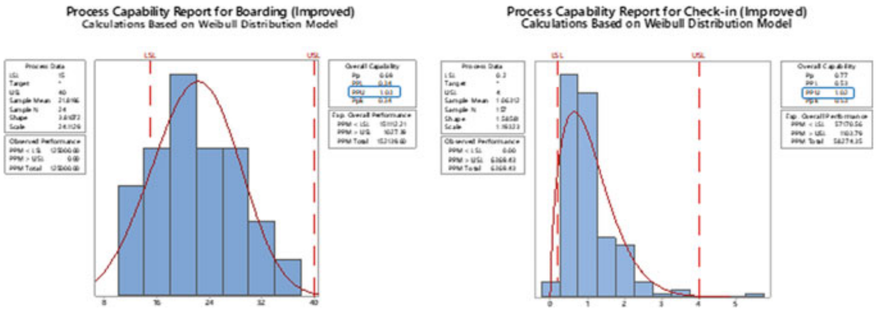

Fig. 10 The PCA report for improved boarding and check-in progress

Table 2 The target processes and their measure units

Target processes	Measure metrics
Check-in queue	Min/flight
Check-in progress	Min/passenger
Boarding	Min/flight

Critical to Quality's (CTO's):

For this study, CTQ's are determined for the considered processes, which need to be improved as in Table 2.

The proposed improvements were given in Table 3 by being associated with the problem and the lean effect in the process.

Future Value Stream Map:

Another tool for improve phase is to create a future state value stream map. After discussions of proposed improvements, the VSM has been created in Fig. 11. The sequence of processes is the same; however, total lead time is reduced.

Table 3 The lean effects of proposed improvements

Process step	Problem	Improvement	Lean effect (reduced waste/increased value)
Check-in queue	In case of excess baggage, passenger unpacks the baggage	Allocate a scale for baggage	(1) Eliminate waiting time in front of the counter to unpack
Check-in progress	At rush hours, waiting time on the queue	Increase the average number of the worker from 3 to 5	(2) Keep the waiting time in a minimum Increase value for the customer
Boarding	Risk of boarding wrong passenger due to manual login	Investment or technical support for a new barcode scanner	(1) Decrease waiting time on the gate (2) Eliminate over motion

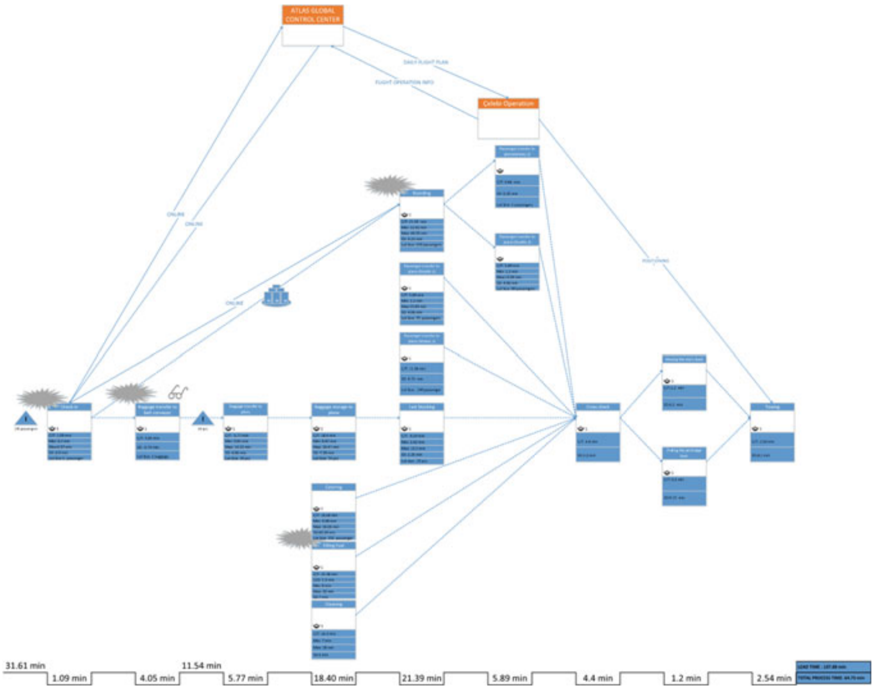

Fig. 11 Future state value stream map of ground handling operations for departure flights

Control

This phase is the standardization and control of processes to ensure that the improvements made are sustainable at the Six Sigma level. At this stage, the

Table 4 Comparative cycle time results for selected processes and their lean effect

Process	Current cycle time	Improved cycle time	Lean effect
Check-in queue	55.37 min/flight	31.61 min/flight	Eliminating waiting time in the queue
Check-in progress	1.13 min/ passenger	1.09 min/ passenger	Prevent over processing and wasting time
Boarding	25.10 min/flight	21.3 min/flight	Standardize work and decrease waiting time at the gate

Table 5 The comparison of results for lead time and total processing time

Lead time	116.99 min	107.88 min	8%
Total processing time	69.48 min	64.73 min	7%

continuity of the performance competencies of the processes is monitored and controlled with statistical process control techniques. The goal of this last phase is to ensure that the key variables of the modified process remain in the highest acceptable range, using tools such as statistical process control or simple markup lists.

In Table 4, the cycle time for the identified processes was compared and afterward a control plan was created after brainstorming among the project team and the airline company. Moreover, the lean effects of each proposed improvement are highlighted in the table.

Conclusion

Consequently, airlines aim to keep the value of their service at maximum level by enhancing profits from time in the air side while declining the costs and time on the ground side. Efficient aircraft ground operations are essential to satisfy customer service expectations and maximizing aircraft benefit. Unfortunately, the turnaround of a modern aircraft in a congested airport is a complex, cross-functional operation. Until existing processes and value streams are truly understood, the other statistical analyses are examined. Afterwards, systemic improvements are proposed and adopted in the future. In this project, Lean Six Sigma methodology is successfully applied to streamline and standardize processes, resulting in a shorter cycle time, and associated several benefits on time and service quality. The DMAIC method is explicitly described to drive each phase of the project to gain the highest rate of efficiency and repeatable achievement. After all, the total lead time of departure flights is decreased as demonstrated in Table 5. At the end of the analyses, the prioritization of process improvement initiatives should be continued to be challenged for processes, which are determined as check-in queue, check-in progress, and boarding process. Some improvements are proposed for departure flights.

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Quality Function Deployment Implementation on Educational Curriculum of Industrial Engineering in University of Gaziantep

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Abstract The education system is one of the most important factors in achieving the level of developed countries. Higher education institutions have a very important place among educational institutions since they lead to the future. For this reason, the way to improve the development level of countries is to increase the quality of education in higher education institutions. For this purpose, in this study, the Quality Function Deployment (QFD) approach is applied to the educational curriculum in Gaziantep Industrial Engineering Department and the results are analyzed.

Keywords Quality function deployment · Educational curriculum Industrial engineering

Introduction

Enterprises are forced to compete in both national and international markets with the elimination of borders in the economies. In this competitive environment, enterprises have to use their competitive strategies effectively in order to ensure continuity. It is not possible to compete without customer satisfaction. Because of this, businesses are obliged to be customer-focused. Competition is everywhere, from the private sector to state institutions and educational institutions.

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*, Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_6

Among the education institutions most affected by this competition, the first order is the higher education institutions. Graduates are trying to prove themselves in entering the real competitive environment. They get a place for themselves according to the quality of education. Therefore, a better quality of education in universities will make individuals more successful. In this study, QFD method is used to determine the correlation between the educational curriculum of Industrial Engineering Department in Gaziantep University and the qualifications required in the industry, and the status of course credit in similar leading universities. The main purpose of the study is analyzing whether the courses taught in Gaziantep University Department of Industrial Engineering meet the expectations of businesses in Turkey from industrial engineers and how much they meet.

QFD is defined as a quality system that ensures customer satisfaction in total quality management (Zultner 1993). The QFD method provides decreasing product and service costs, product and service development times and the number of non-value added businesses, while increasing productivity.

Previously, the QFD method has been applied in many universities to design education modules and to determine the curriculum and these applications have been successfully concluded (Mazur 1996; Chou 2004; Aytaç and Deniz 2005; Savaş and Ay 2005; Singh et al. 2008).

Literature Review

QFD arose in 1972 with Japanese Mitsubishi Company. After 1984 it is studied and used in the USA and today accepted all over the world (Güllü and Ulcay 2002). Since then a lot of applications are made in many sectors. In this section, studies are investigated according to application areas.

Bottani and Rizzi (2006), Uğur (2007), Tu et al. (2010), Huang and Yoshida (2013) use QFD method in the logistic sector in different ways and achieve effective results. In the banking and insurance sector, the QFD method is applied by González et al. (2008), Doğu and Özgürel (2014). The first study is published by Öter and Tütüncü (2001) in the tourism sector and the other studies are implemented by Akbaba (2005), Das and Mukherjee (2008), Ikiz and Masoudi (2008), Doğan and Karakuş (2014) in the same sector. Kılıç and Babat (2011), Yıldız and Baran (2011a, b) applied QFD method to the food industry. Application of QFD to education field is carried out by Mazur (1996), Chou (2004), Aytaç and Deniz (2005), Savaş and Ay (2005), Boonyanuwat et al. (2008), Singh et al. (2008), Garibay et al. (2010), Sahay and Mehta (2010), Hafeez and Mazouz (2011), Ictenbas and Eryilmaz (2011), Sirias (2012), Qureshi et al. (2012).

In this study, it is determined whether increasing or decreasing the course credit or improving the course contents by using the QFD method. This study proposes a novel problem in terms of new course recommendations for Industrial Engineering students.

Methodology

Quality Function Deployment

QFD is a quality system that is used to make customers more satisfied by understanding the demands and needs of the customers. Companies will carry their organizations to their goals as far as they can ensure customer satisfaction. In other words, the success of a decision made by the company will depend on ensuring customer satisfaction. In an organization, the QFD system is applied in four stages. These stages (Akbaba 2000):

(1) Planning
(2) Determination of customer expectations
(3) Creation of house of quality
(4) Analysis and interpretation of the results.

The common representation of the house of quality is given in Fig. 1.

QFD is a process, the house of the quality scheme is part of this process. The steps of the quality house created to meet the expectations of the customer are given below:

1. The creation of customer expectations
2. The creation of the technical requirements section
3. The creation of the relationship matrix
4. Creating a correlation matrix
5. Creating the competition and planning matrix.

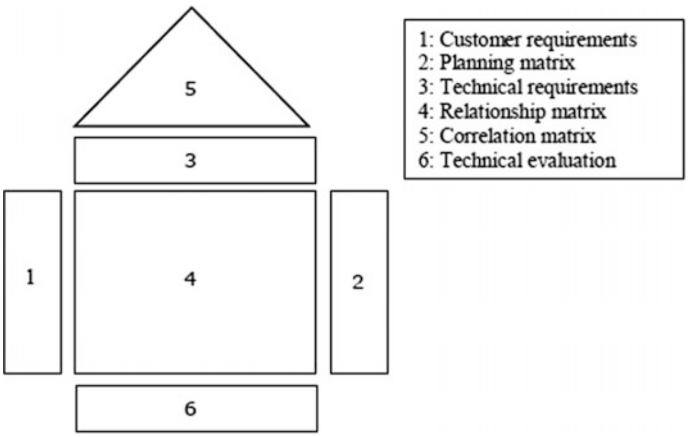

Fig. 1 The common representation of the house of quality (Koç 2015)

Result

In this study, the courses taught at the Department of Industrial Engineering of Gaziantep University have been examined to see whether meet the expectations of enterprises in Turkey. For this reason, it is aimed to provide support to the Department of Industrial Engineering in this regard and critically examine the courses given.

In the implementation phase of the method, existing enterprises in Turkey are accepted as customers. Job advertisements published on the internet are reviewed to determine the customer requests of the enterprises and the required qualifications are determined as customer requirements. In order to determine these qualifications, nearly 250 job advertisements published on the Internet during the period of 15.11.2017–15.12.2017 are examined. After job advertisements are evaluated, the required positions are grouped according to sectors and it is determined whether there is a relationship between these positions and the required qualifications.

There are two different evaluation method for relationship degree in literature. In this study, in order to assign a degree of relationship, the American system is used. The degree of relationship that is used in American and Japanese System is illustrated in Table 1. In order to determine whether Gaziantep University Department of Industrial Engineering satisfies the expectations of the market; customer requirements, technical requirements, relations between them and competitive evaluations are shown in Table 2. In order to determine customer needs and requirements, the market demands are detected by using job advertisements published on "www.kariyer.net". Required qualifications in these job advertisements are accepted as customer requirements. Business requirements and needs will be realized by meeting their requirements through courses given in the school. Therefore, the courses taught in the Department of Industrial Engineering are accepted as technical requirements. As a comparison criterion, the credit numbers of the courses taught in the Industrial Engineering Departments of Adana Science and Technology University (ASTU) and Middle East Technical University (METU) are taken into consideration and shown in Table 2. The target values are determined based on the average number of credits given in the Industrial Engineering Departments of these three universities. Technical importance degree values are determined for all courses and added to the House of Quality created. English course is not a desirable quality for only industrial engineers. Therefore, it is not evaluated within the scope of the technical course.

Table 1 The relationship matrix

Degree of relationship	American system	Japanese system
STRONG	9	5
MIDDLE	3	3
WEAK	1	1

Table 2 House of quality implementation

Qualifications (customers requirements)	Column weight	Percentage degree of importance (%)	CP	ENG	TD	ME	E, OHS	STAT.	WA	OR, MM	SA	PP
			C++, C, variables, arrays	Academic English	Engineering drawings	Materials, materials selection	Ergonomics and occupational health and safety	Hypothesis testing, correlation	Work measurements, activity sampling	Optimization, mathematical modeling	System analysis and design	MRP, scheduling
English	237	12.94		9								
MS office	229	12.51							1			1
Experience	182	9.94										
Planning, reporting	173	9.45				1			3		9	9
Analytical skills	113	6.17	9			9	3	9	9	9	9	9
Teamwork	102	5.57			1		3					3
ERP	96	5.24										9
Communication	88	4.81										
Quality management	64	3.50						9				1
Production management	61	3.33				1						9
Lean manufacturing	53	2.89				1						9
Database	44	2.40										1
Project management	42	2.29										
Work/time study	38	2.08							9			3
Oc. health and safety	36	1.97					3		3			
Sales and marketing	34	1.86				3						1
Cost analysis	32	1.75							3	9		3
SAP	29	1.58										3

(continued)

Table 2 (continued)

Qualifications (customers requirements)	Column weight	Percentage degree of importance (%)	CP	ENG	TD	ME	E, OHS	STAT.	WA	OR, MM	SA	PP
			C++, C, variables, arrays	Academic English	Engineering drawings	Materials, materials selection	Ergonomics and occupational health and safety	Hypothesis testing, correlation	Work measurements, activity sampling	Optimization, mathematical modeling	System analysis and design	MRP, scheduling
German	27	1.47										
Technical drawing	25	1.37			9							
Stock control	21	1.15								9		9
Productivity/ improvement	19	1.04							3	3		9
Computer programming	17	0.93	9							3		
Supply C. management	14	0.76										9
MRP	14	0.76										9
Method development	11	0.60							3			9
Six sigma	9	0.49						1			3	
Material knowledge	8	0.44				9						
Industry 4.0	7	0.38										3
Line balancing	6	0.33								3		
Total	1831	100										
Technical importance degree			63.9	116.5	17.85	80.72	41.12	87.49	131.1	88.47	142.1	337.3
Competitive direction evaluation	METU		4	11	3	3	0	4	3	6	9	6
	GAUN		5	8	3	4	3	3	3	10	0	3
	ASTU		6	4	3	0	6	3	3	9	3	3
	AVG.		5	7.66	3	2.33	3	3.33	3	8.33	4	4
Target value			4	*	3	2	3	3	3	8	4	6

(continued)

Table 2 (continued)

LOG	QPC	FDP	EEC	PM	DBM	PL
Supply chain management	Control charts, quality standards	Facility design, location	Engineering economy, financial	Project planning, CPM, PERT	SQL, access	Assembly line balancing
LOG Supply chain management	QPC Control charts, quality standards	FDP Facility design, location	EEC Engineering economy, financial	PM Project planning, CPM, PERT	DBM SQL, access	PL Assembly line balancing .
	3				3	
						.
		9		9		9
9	9	9	9		9	3
					9	
9						
3	3		3	9		1
	9					
9	1	3			1	9
	1					3
1					9	
				9		
						3
						.
						.
		9	9			
3						
						.
						.
9						
	3					9
					9	
9						1
9						
		9				3
	3					
						.
		9				

(continued)

Table 2 (continued)

LOG	QPC	FDP	EEC	PM	DBM	PL
Supply chain management	Control charts, quality standards	Facility design, location	Engineering economy, financial	Project planning, CPM, PERT	SQL, access	Assembly line balancing
		9				9
						.
185.3	149.2	178.1	85.69	148.9	176.5	177.4
3	3	3	9	3	0	0
3	3	3	9	3	4	3
3	3	3	4	3	2	0
3	3	3	7.33	3	2	1
3	4	4	7	4	4	3

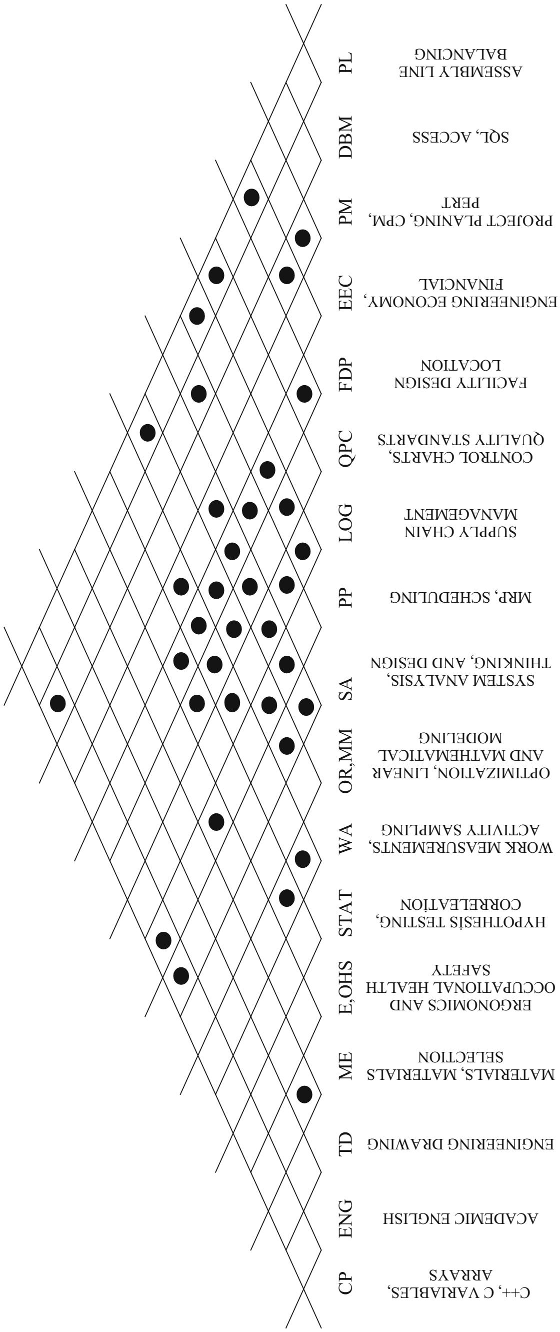

Fig. 2 Correlation matrix

Table 3 Recommendations for curriculum

Courses	Increasing credits	Decreased credits	Added courses	Extracted courses	Elective to compulsory
Computer programming		(−1)			
Principles of material engineering		(−2)			
Operations research and mathematical modeling		(−2)			
System analysis			(+4)		
Production planning	(+3)				
Engineering graphics				(−3)	
Logistics					*
Quality planning and control	(+1)				
Facilities design and planning	(+1)				
Engineering economy and cost analysis		(−2)			
Project management					*
Production line					*

The courses whose credit increase or decrease, courses added or extracted and courses that are suggested compulsory instead of elective are illustrated in Table 3. According to results in Table 2, it is decided to increase Production Planning, Quality Control, and Planning and Facilities Design and Planning's credits and decrease Computer Programming, Principles of Material Engineering, Operations Research and Mathematical Modeling and Engineering Economy and Cost Analysis's credits. Also, it is proposed that extracting Engineering Graphics from the curriculum, since it has a very low technical importance degree. In addition, System Analysis taught at the two universities (METU, ASTU), is above the average of technical importance degree. Therefore, it is suggested this course can be added to Gaziantep University Industrial Engineering curriculum. Finally, Logistics, Project Management and Production Line which is an elective course in Gaziantep University Industrial Engineering Department is suggested to be compulsory, since their technical importance degrees are quite high.

Conclusion

In this study, it is analyzed whether the courses taught in Gaziantep University Department of Industrial Engineering meet the expectations of businesses in Turkey from industrial engineers. As a result of the analysis, it is suggested to increase or decrease the course credits, adding or extracting courses in the curriculum of the Department of Industrial Engineering of Gaziantep University by using the QFD method. The results have shown that the first five courses that have the highest degree of technical importance are Production Planning, Logistics, Facilities Design and Planning, Production Line and Database Management. These courses should be revisited and worked to increase their activities. In addition, according to correlation matrix data (Fig. 2), there is a relationship between Work Analysis and Ergonomics and it may make a study combining these courses under a single roof.

The data in the customer requirements section is limited to information in "www.kariyer.net" in this study. For future studies, data can be obtained from different sources or can be determined through questionnaires. Also, the QFD method can be applied in the curriculum of different departments of universities to improve education quality.

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Artificial Bee Colony Algorithm for Labor Intensive Project Type Job Shop Scheduling Problem: A Case Study

Aslan Deniz Karaoglan and Ezgi Cetin

Abstract Job shop scheduling for labor-intensive and project type manufacturing is a too hard task because the operation times are not known before production and change according to the orders' technical specifications. In this paper, a case study is presented for scheduling a labor-intensive and project type workshop. The aim is to minimize the makespan of the orders. For this purpose, the artificial bee colony algorithm (ABC) is used to determine the entry sequence of the waiting orders to the workshop and dispatching to the stations. 18 different orders and 6 welding stations are used for the scheduling in this case. The input data of the algorithm are the technical specifications (such as weight and width of the demanded orders) and processing times of the orders which vary according to the design criteria demanded by the customers. According to the experimental results, it is observed that the ABC algorithm has reduced the makespan.

Keywords Scheduling · Artificial bee colony algorithm · Labor-intensive project type production

Introduction

Meta-heuristics such as genetic algorithm, tabu search, ant colony, memetic algorithm, particle swarm and etc. are widely used to solve job shop scheduling problems. Artificial bee colony algorithm was first discovered by studies done by Karaboga (2005). This algorithm is a beneficial optimization tool used effectively in project type scheduling problems. The ABC algorithm is an optimization tool that mimics the collector behavior as a flock of honey bees.

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_7

Zhang et al. (2013) proposed a novel artificial bee colony (ABC) algorithm to minimize the total weighted tardiness in JSSP. They discovered the neighborhood property of the problem and then used a tree search algorithm to enhance the exploitation capability of ABC. Wang et al. (2013) proposed a hybrid artificial bee colony (HABC) algorithm for solving the fuzzy JSSP to minimize the maximum fuzzy completion time. Lei and Guo (2013) are considered lot streaming problem in a job shop with consistent sub-lots and transportations and proposed a modified artificial bee colony algorithm (MABC) to minimize the makespan. Yurtkuran and Emel (2016) presented a discrete ABC algorithm for a single machine earliness-tardiness scheduling problem to find a job sequence that minimizes the total sum of earliness-tardiness scheduling. Asadzadeh (2016) proposed a parallel ABC algorithm to solve JSSP.

In this study, a case study is presented that uses an ABC algorithm for minimizing the average makespan of the orders in a labor intensive project type manufacturing environment. ABC algorithm is used to determine the entry sequence of the waiting orders to the mechanical workshop of the manufacturer and dispatching them to the identical welding stations. Different from the methods previously presented in the literature, the initial population was not formed fully randomly. It is determined by considering the waiting times in the queue which were obtained as a result of assignments made under the weight and width constraints of the transformer. Also, an additional constraint is added to the algorithm. In this constraint, the number of welding stations changes according to the technical specifications of the orders (two neighboring stations are combined when long transformer vessels of orders are welded).

The following section gives a brief description of the materials and methods used in this study. The case study and the experimental results for the job shop of the company are presented in Sect. 3. Finally, the conclusions are given in the last section.

Methodology

ABC algorithm is used to find the optimum solution in this study. In this algorithm, the behavior of the honey bees is taken as a reference. The food sources of bees in a real bee colony are called the initial population in the ABC algorithm. Initial solutions found in the initial population are produced using randomness. The interval of search boundaries is given in following Eq. (1) (Karaboga 2005; Zhang et al. 2013; Wang and Duan 2014; Bulut and Tasgetiren 2014):

$$x_{ij} = x_j^{min} + r\left(x_j^{max} - x_j^{min}\right) \tag{1}$$

where $i = 1, \ldots, NP$ *(number of food sources)*; $j = 1, \ldots, D$ *(number of decision variables)* and r is a uniform random number between [0–1]. There are three phases in the ABC algorithm to determine the initial population (the employed bees, the onlooker bees, and scout bees).

In the first step of the algorithm, an initialize population is generated randomly. However, in this case study, the initial population is not generated fully randomly. It is created under certain constraints such as the weight of transformer tank (vessel) related with the crane capacity, and width constraint related with the welding station's length capacity. Also in a welding station, only one transformer tank can be processed at the same time. After all, initial assignments are done; the initialization algorithm is repeated throughout the iterations by assigning the orders to the stations in random sequences. Each solution in the resulting initial population is a bee (Bulut and Tasgetiren 2014).

The second step of the algorithm is to obtain fitness values (FV) from the generated initialize population. In the employed bee phase, the neighboring food source is generated as given in Eq. (2) (Bulut and Tasgetiren 2014):

$$v_{ij} = x_{ij} + \emptyset\left(X_{ij} - X_{kj}\right) \tag{2}$$

where j and k are randomly selected integers between $[1-D]$ and $[1-NP]$ respectively and must be different from the food source x_i. $\emptyset$ is a uniform real random number between $[-1, 1]$. The FV for a minimization problem is given in Eq. (3) (Bulut and Tasgetiren 2014):

$$fitness = \begin{cases} \frac{1}{1+f_i} & if\, f_i \geq 0 \\ 1 + abs(f_i) & if\, f_i < 0 \end{cases} \tag{3}$$

"where f_i is the objective function value of the food source v_i." Then the x_i and v_i are compared and the better one is selected depending on FV. Every food resource is appointed to a counter value 0 ($count_i = 0$) in the initial population and if x_i does not develop, its counter value is boosted by 1. Otherwise, the count is reset to 0. This process is reiterationed for whole employed bees in the population (Bulut and Tasgetiren 2014).

In this study, FV is calculated according to processing times and waiting times in the queue. FV of a bee solution in the initialize population is a numerical measure of quality value. In this case study, the goodness of the FV is influenced by lower processing times and waiting times in the queue. The solutions that are calculated with an adequate goodness value are called employed bees.

Solutions which do not have adequate quality are classified as onlooker bees. In the onlooker bee phase, roulette wheel selection is employed. In this phase each food source is assigned to probability as given in Eq. (4):

$$P(i) = \frac{FV(i)}{\sum_{k=1}^{NP} FV(k)} \tag{4}$$

The third step of the algorithm is calculating probabilities through fitness values. The P_i values are compared with the r values which are generated between [0–1] for every food source x_i and if $r < P_i$ then the onlooker bee generates a neighboring food source utilizing Eq. (2) over again. Probabilistic choices according to fitness values at this stage are called roulette wheel selection (Bulut and Tasgetiren 2014).

In this study makespan is the FV (FV = Makespan). Because of this reason to increase the selection probability of the order schedule with minimum makespan; Eq. (5) is used:

$$P(i) = \frac{1/FV(i)}{\sum_{k=1}^{NP} 1/FV(k)} \tag{5}$$

The greedy choice is still valid for both solutions. If x_i doesn't get better, its counter $count_i$ is boosted by 1, failing this is reset to 0. This process is reiterationed for whole onlooker bees in the population (Bulut and Tasgetiren 2014).

In the scout bee phase, the value of the $counter_i$ is compared with the control parameter *limit* and if $counter_i > limit$ then the food source x_i is deserted and displaced with a new food source generated through Eq. (2). This ensures variegation capability to the ABC algorithm. The pseudocode for the ABC algorithm is as follows (Yurtkuran and Emel 2016):

Step 1: **Initialize** population generated from random whole food sources
Step 2: **Evaluate** of created community
Step 3: **While Not** Termination requirement
    Do Employed bee: forward employed bee to food resources and compute the choice possibilities of food resources utilizing nectar quantities.
    Do Onlooker bee: forward onlooker bee to food resources considering their possibilities.
        If trial > limit **Then Do**
            Scout bee: achieve a new food source.
        End If
    Save essential information
End While

According to Eqs. (1–5) and the given pseudocode, the main steps of the proposed ABC algorithm for this case study is presented in Fig. 1.

Next section presents the case study that is performed to determine the entry sequence of the transformer vessel orders waiting for the welding process at the welding stations which is labor intensive and project type operation.

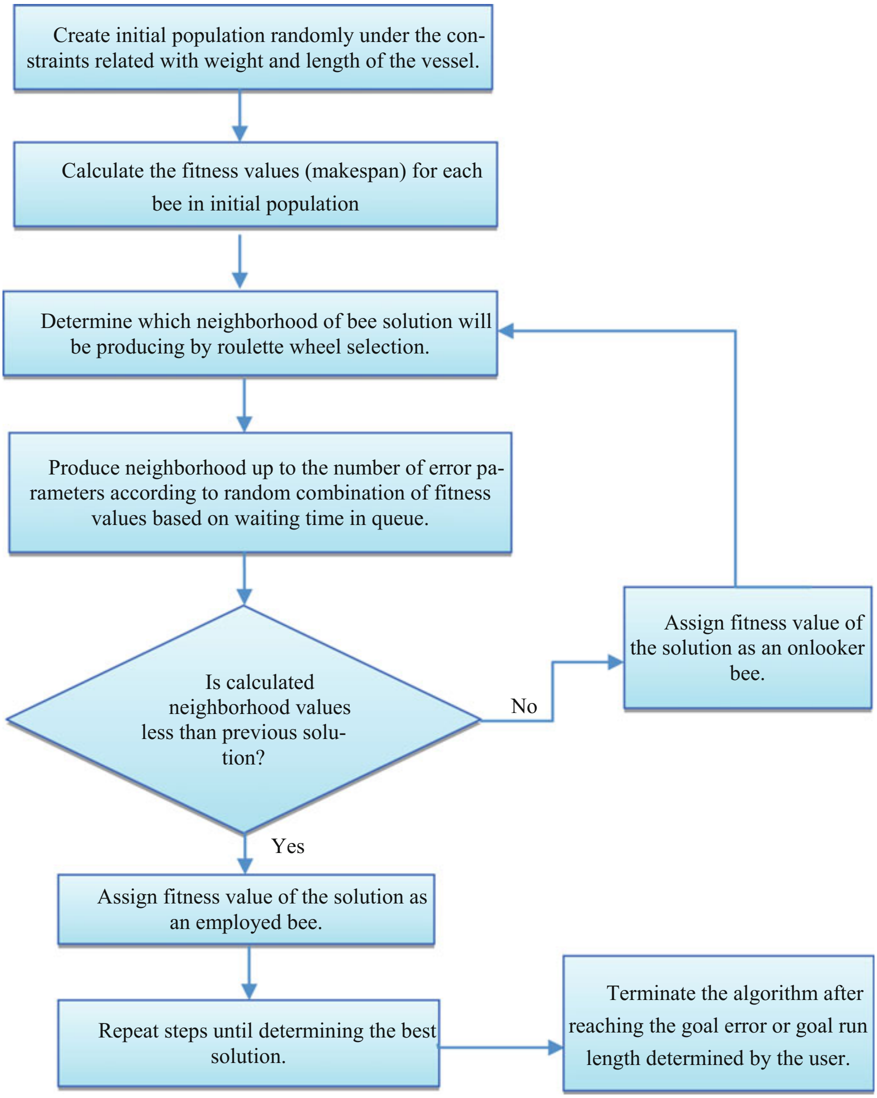

Fig. 1 Main steps of the ABC algorithm for the presented case study

The Case Study

The case study is performed in a transformer manufacturer's mechanical workshop. The company is a transformer producer and produces power transformers, distribution transformers, and dry-type transformers. The production operations of the company for power transformers consist of five main steps. They are; (1) magnetic core production, (2) winding production, (3) active part assembly, (4) mechanical production and (5) final assembly. Mechanical production is performed for power transformers while vessels of the distribution transformers are purchased from suppliers. Magnetic core production, winding production, and mechanical production processes are done in parallel. The magnetic core that is produced by the magnetic core production and the windings that are produced by the winding operation is assembled. This assembled product is called the "active part" of the transformer. The active part is set into the transformer's tank (vessel) which is produced by the mechanical production and the final operations (assembly of the accessories, oil filling, and etc.) are completed (Karaoglan and Karademir 2016; Karaoglan and Celik 2016).

This study is performed at the mechanical production unit of power transformers for scheduling the orders for minimizing the makespan. ABC algorithm is used to determine the entry sequence of the waiting orders to the mechanical workshop and dispatching to the welding stations. The data for a total of 8 orders have been gathered from the company's current waiting orders list, as listed in Table 1. These 8 orders correspond to the production of a total of 18 transformers. 18 different orders (vessels of transformers demanded by 8 different customers) and 6 identical welding stations are used for the scheduling in this case. The input data of the algorithm are the processing times of the orders which vary according to the design criteria demanded by the customers. Constraints and assumptions of this study are as follows:

- There is no discrete job. In other words, the process cannot be interrupted to produce another job.
- At the same time, only one job can be processed on a workstation.
- This algorithm has 1 million iterations. The fault parameter is determined as the best decision-making criterion. 40% of the total number of iterations is the best solution for research in neighborhoods. This value is regarded as an error parameter. Finally, in 1 million iterations, a total of 1,400,000 neighbors were searched and the algorithm was terminated. It keeps the best of these produced

Table 1 Current waiting orders list

Order number	Number of transformers in the order	Transformer ID	The weight of the vessel ($\times$1000 kg)	The width of the vessel (m)
1	2	1, 2	25, 25	6, 5
2	1	3	32	4
3	1	4	27	4
4	2	5, 6	30, 30	7, 3
5	1	7	22	5
6	1	8	33	5
7	3	9, 10, 11	12, 12, 12	3, 2, 2
8	7	12, 13, 14, 15, 16, 17, 18	9, 9, 9, 9, 9, 9, 9	4, 8, 9, 4, 3, 5, 2

values in memory and deletes the bad ones. The same operations are repeated at every step by producing neighborhoods through good solutions held in memory.

– Vessels' weights those are up to 16 tones can be processed at the welding stations numbered by 1, 2, and 3. This is the first group of welding stations. Because the crane that serves to these stations has max 16 tons capacity. However, vessels those are heavier than 16 tons can only be processed by welding stations numbered by 4, 5, and 6. If the station is available, also the orders those weights are less than 16 tones can be processed in this second group of work stations (4, 5, and 6). However, the heavier jobs have priority at the second group of welding stations. The workstations are identical however the crane capacity limits the operations. Additionally; if the widths of the jobs are 6 m and over, the consecutive stations are merged to fit the vessel to the station. In this case, one order occupies two workstations at the same time. For commercial confidentiality, the technical specifications and the original values of crane capacities are given by multiplying by a certain ratio Table 1 represent the orders' technical specifications. A triangular distribution was used to determining processing times.

According to Table 1, the first order has 2 transformers that have to be produced. This means there are 2 identical vessels those have to be produced. The second order has only one vessel to be produced while the 8th order has 7 identical transformers which mean there are 7 identical vessels belongs to this order and etc. In this problem, because of the constraints related to the crane capacity, heavy vessels are assigned to the stations 4–6. Because of this reason, the queueing time for these stations is too long. To minimize the makespan—the neighborhood search was carried out for these stations. In other words, in the onlooker bee phase, the neighboring food source is generated by giving priority to assigning larger vessels to the stations 4–6. Then roulette wheel selection is employed. MATLAB is used for coding the ABC algorithm and calculating the results.

Results

In this study, production times are stochastic (distributed with triangular distribution) and were not presented due to commercial confidentiality. The best schedules those are determined by the company and by the ABC algorithm are displayed in Tables 2 and 3 respectively. According to these tables, the entry sequences of the waiting orders to the stations are determined and the makespans are calculated. If the ABC algorithm had not been implemented in scheduling, orders will be assigned to workstations with the dispatching rule namely longest processing time by the company.

According to Table 2, the total makespan of jobs is calculated as 92.0466 days. Although the processing times of the 1st and 3rd stations are considerably reduced, the workload balances between the work stations are not in accordance. Note that the 1st and 2nd workstations are merged while processing the 13th and 14th

Table 2 Schedule determined by the factory without using the ABC algorithm

Welding station number (i)	Makespan (i)	The sequence of the waiting orders
1	67.8665	13, 14, 17
2	79.05	13, 14, 9, 18
3	68.4607	10, 15, 16
4	87.1248	3, 12, 4, 1
5	92.0466	8, 7, 5, 1
6	89.0252	2, 11, 5, 6

Table 3 Optimum schedule determined by ABC algorithm

Welding station number (i)	Makespan (i)	The sequence of the waiting orders
1	78.921	13, 11, 10
2	78.3655	13, 18, 16, 14
3	85.4843	17, 15, 12, 14
4	69.8357	3, 1, 5
5	85.4435	8, 1, 5, 6
6	85.5238	7, 4, 9, 2

transformers, 4th and 5th workstations are merged while processing the 1st transformer, 5th and the 6th workstations are merged while processing the 5th transformer, because of the width constraint (width of these transformers > 6 m). In other words, 13th and 14th transformers are assigned to 1st and 2nd workstations, the 1st transformer is assigned to 4th and 5th workstations and the 5th transformer is assigned to 5th and 6th workstations at the same time. This issue is valid for the ABC results given in Table 3. Similarly, workstations are merged while 1st, 4th and 8th orders are processing. The best solution of the algorithm was found after 1,399,998 iterations (run length is set as 1,400,000 iterations). The algorithm was run on a personal computer with Intel Core i5-3230M 2.6 GHz processor. It took 35 min for the Matlab code to run 1 million iterations.

According to the optimum schedule given in Table 3, the total completion time of waiting jobs (makespan) is calculated as 85.5238 days. Because of the constraints of this problem, 4th and 5th workstations are merged while processing the 1st and 5th transformers, 1st, and 2nd workstations are merged while processing the 13th transformer, 2nd and 3rd workstations are merged while processing the 14th transformer. 3rd and 8th transformers must be completed before 1st and 5th transformers at 4th and 5th workstations. Because the duration of the 3rd transformer is longer than the 8th transformers, workstations are merged after the 3rd transformer is completed. The time difference between the 3rd and 8th transformers was added to the total completion time of the 5th workstation to find the makespan.

18 jobs are distributed in a balanced manner to welding stations in the optimum solution. The maximum time difference between the stations is reduced from 25 to 16 days by using the ABC algorithm. The results show that the artificial bee colony algorithm is more efficient than the ordinary methods. The Gantt chart for the optimum schedule is given in Fig. 2.

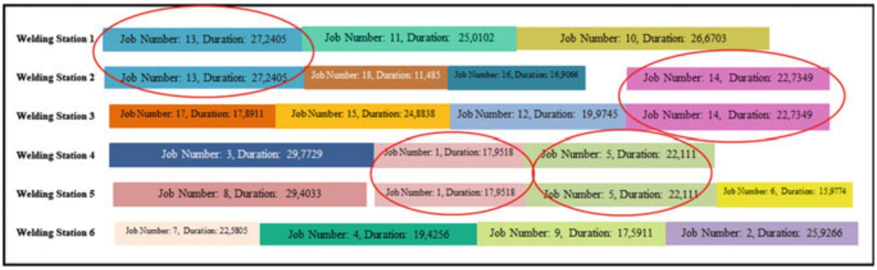

Fig. 2 Gantt chart of the optimal solution found in 1 million iterations

Because of the width constraints, the stations are merged (13th transformer is assigned to 1st and 2nd welding stations, the 14th transformer is assigned to 2nd and 3rd welding stations, 1st and 5th transformers are assigned to 4th and 5th welding stations) and this situation can clearly be seen on the Gantt chart. Also, the jobs are distributed to the stations in a balanced and optimal manner.

Discussion and Conclusion

This study focused on determining the best possible schedule of the waiting orders to minimize the average makespan under the job-shop conditions and several constraints related to design criterias. The novelty is using stochastic processing times to minimize average makespan of the orders in a labor-intensive and project type manufacturing where the operation times are not known before production and change according to the order's technical specifications. For this purpose, the ABC algorithm is used. As results of assignments made under certain constraints, the average makespan is minimized after 1 million iterations for the given problem. It is targeted that the completion time of the tasks in each found solution is less than the previous solution. Better values are kept in memory and neighborhood is generated from these values. Worsening values are deleted from the memory and left out of the algorithm. The optimum point where the recovery of the best value held in memory is fixed and the value at this point is considered as the optimum solution.

It is observed that the computational efficiency of the algorithm is good. According to the experimental results, it is observed that the artificial bee colony algorithm has reduced the average makespan nearly 7% (from 92.0466 to 85.5238 days) for the given order set. Results indicate that the ABC algorithm not only reduces the total completion times of waiting orders, it also accelerates the decision making process of the production system. Thus productivity of labor-intensive project type production systems will increase gradually. In the future studies, the same problem can be solved by genetic algorithm and ant colony algorithm and the results can be compared.

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Multi-criteria Selection Analysis of the City Buses at Municipal Transportation

Fuat Kosanoglu and Alperen Bal

Abstract Public transportation decisions are an important aspect of management of cities. Especially, for the small and midsized cities, bus transportation is more important due to lack of rail transportation. The goal of this paper is to present determination of public transportation vehicle from the municipal corporation managers' perspective by using analytic hierarchy process (AHP). In our analysis, we use 4 main criteria and 9 sub-criteria that are indicated by the experts for the selection of the most suitable bus considering sustainability conditions. A survey is designed about vehicles with internal combustion engines and electric motors that enables each expert to compare the relative priority of each criterion with other criteria. A real world application of a municipal corporation is conducted to illustrate the utilization of the model. The results presented in this study highlight the necessity to integrate analytic and comprehensive decision-making process into public transportation decisions.

Keywords Public transportation · Multi-criteria decision making
Electric buses · Analytical hierarchy process · Municipal management

Introduction

The objective of this study is the selection of a sustainable transportation system in municipalities. The selection process is a Multiple Criteria Decision Making (MCDM) problem since it has contrastive criteria, goals or objectives. Specifically, a successful selection of the public transportation system significantly improves conditions for commuters, decreases the cost for managements, and also produces other positive externalities such as lower carbon emission and traffic safety. There are various decision-making tools are available to decide the most suitable

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_8

transportation vehicle. Due to the many considerations of the selection problem, MCDM methods are preferred in order to achieve a more explicit, efficient and, rational choices.

Municipalities would like to choose the best transportation option as part of their services to the community. The decision process should consider economical, social, and environmental aspects.

Tzeng and Shiau (1987) propose a set of comprehensive energy conservation strategies for city development using multiple criteria analysis. However, their research does not take into account the social aspect. Yedla and Shrestha (2003) compare three different bus options viz. '4-stroke 2-wheelers', 'compressed natural gas (CNG) cars', and 'CNG buses' for selection of alternative transportation options in Delhi. Yet, their study is restricted to compare alternatives with different energy technologies. Browne et al. (2008) compare the ecological footprint of different travel-commuting patterns for the residents of an Irish city-region. Results show that despite technological improvements in fuel economy has a positive effect on reducing greenhouse gas emission, it also necessary to use the physical system more efficiently. Particularly, a reduction in overall demand for physical systems and improvement of technological improvements in fuel economy is the optimal policy mix. Another study presented by Wang and González (2013) reveals that most of the small and mid-sized cities are ideal for electric bus operation. They also mention the indirect impact on the environment (through power generation) and the high cost of electric buses. The main obstacle to the implementation of electric buses is the total cost of ownership that includes manufacturing and maintenance cost, energy distribution infrastructure cost, insurance and end-of-life (Conti et al. 2015). The environmental impact of urban public transportation is studied by some experts using the life cycle assessment method (Chester et al. 2013; Lajunen and Lipman 2016). Recent researches (Lajunen 2014; Lajunen and Lipman 2016; Zeng et al. 2016) and development projects (Corazza et al. 2016; Pihlatie et al. 2014) demonstrate that electric buses are becoming a more suitable option for energy efficient and sustainable public transportation.

There are some recent studies, which take into account the initial investment cost analysis. Particularly, a recent study by Wang et al. (2014) concludes that the payback period of infrastructure investment of electric buses is still very long. Plug-in hybrid buses can be considered as the main competitor to fully electric buses since they require a relatively lower capital cost and have partly emission free operations (Lajunen and Kalttonen 2015). Zhou et al. (2016) implement an on-road test for buses with different types of engine and results show that on average, an electric bus reduces petroleum consumption with the rate of 85% compared to diesel bus and reducing 20–35% of CO_2 emission in a life-cycle. In the selection process of transportation type of municipalities, a comprehensive evaluation needs to be done in terms of bus configuration and charging method. Because understanding the best technical solutions are very important in terms of the environment and comfort of community. Lifecycle operation cost of a bus fleet is rarely taken into consideration in scientific studies. Wang and González (2013) and Mahmoud et al. (2016) show that it can be challenging to integrate economic and technical aspects of electric buses into a research considering different operating conditions in cities.

In this study, we study a transportation vehicle type selection problem for small and mid-sized cities. The AHP method is used to analyze structure vehicle requirements and choosing the most suitable alternative.

The unique aspect of this study is we use MCDM approach to choose the appropriate bus for small and midsized cities taking into account not only economic but also environmental and social responsibilities of the municipalities to the public.

Methodology

Identifying the Main Criteria, Sub-criteria, and Alternatives

AHP methodology is used to evaluate different buses with alternative fuel-modes for public transportation (Tzeng et al. 2005). The identified four main aspects of criteria are social, economic, technological, and transportation. In order to evaluate alternatives, 11 evaluations criteria's are used: energy supply, energy efficiency, air pollution, noise pollution, industrial relationship, cost of implementation, cost of maintenance, vehicle capability, road facility, the speed of traffic flow, and sense of comfort. Shiau (2013) uses AHP to evaluate different sustainable transportation strategies for the districts of Taiwan. The proposed sustainability compound index includes society, economy, environment, energy, and finance main criteria. The social aspect includes accessibility for elderly and handicapped people, transportation services for long distant areas, and traffic safety. The economic aspect involves transportation intensity and energy intensity. The environmental aspect considers emission of air pollutants and noise perception. The energy aspect reflects energy consumption alternatives. Finally, the financial aspect has a single criterion of cost.

In our study, we identified and grouped evaluation criteria for public transportation vehicle selection into four main categories: economic, technical, environmental, and social. The detailed description of sub-criteria is as follows:

Infrastructure preparation: The infrastructure preparations necessary for construction of the bus fleet.

Purchase cost: The cost of buying the bus from the manufacturer.

Fuel economy: The cost of fuel consumption per kilometer of the bus.

Ease of maintenance: The degree of difficulty in bus maintenance.

Accessibility of technical staff: The ease of accessing technical staff in sustaining the bus.

Range: The maximum distance that the bus can reach with a full charge or with a full tank of fuel.

Emission: The amount of harmful gas emission that the bus cause per kilometer.

Table 1 Defined criteria and alternatives to select the transportation system

Main criteria	Sub-criteria	Alternative
C1: economic	C11: substructure preparation	A1: diesel bus
	C12: purchase cost	A2: electric bus
	C13: fuel economy	
C2: technical	C21: ease of maintenance	
	C22: accessibility of technical staff	
	C23: range	
C3: environmental	C31: emission	
	C32: used material	
	C33: noise	
C4: social	C41: reputation	
	C42: a sense of comfort	

Used material: The structure of the materials used in the production of the bus and their impact on the environment.

Noise: The level of noise caused by the bus during operation.

Reputation: The perception of a municipality's reputation from the perspective of the public for using electric or diesel buses.

The sense of comfort: The comfort level perceived by users of the bus.

Table 1 shows the main, sub-criteria, and alternatives that are obtained by taking into account the prevalent scientific literature and opinion of experts.

The AHP Model

The analytic hierarchy process (AHP) is a decision making technique for complex decisions based on mathematics and psychology. The technique is originally developed by Saaty (1977) and extensively studied and refined since then. The AHP incorporates quantitative data with more concrete and, qualitative considerations such as values and preferences (Saaty 1977, 1980; Saaty and Ergu 2015; Vaidya and Kumar 2006; Zahedi 1986; Vargas 1990; Liberatore and Nydick 2008; Dolan and Frisina 2002). Implementation of AHP involves the following key and basic step:

- clarify the problem
- determine the goal of the problem
- determine criteria, sub-criteria and alternatives
- construct a hierarchy of the problem in regard to goal, criteria, sub-criteria, and alternatives.
- create a comparison matrix for each element in the corresponding level, and define superiorities on the numerical scale.

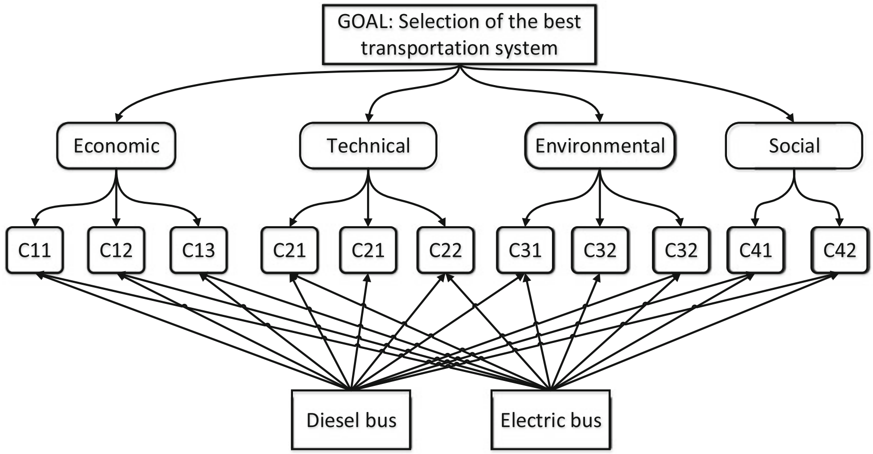

Fig. 1 Schematic representation of the hierarchy for the selection of the most appropriate transportation vehicle

- calculate the normalized eigen value, and consistency ratio (CR) of the various criteria/alternative being compared.
- determine the relative ranking of each alternative and choose the best.

Figure 1 shows the selection hierarchy for the most suitable transportation vehicle for municipal transportation.

Questionnaire

In this study, we aim to determine the most suitable bus type to be used for public transportation in a small or mid-sized city. Two types of buses are compared; two minibuses of the same brand, one has the internal-combustion engine and the other one is the electric version. We create a questionnaire, which has demographic questions that enable each expert to compare the relative priority of each criterion with other criteria within the same category and also with the alternatives. The final version of the questionnaire put into final form after discussion in the transportation department of the municipality.

For each pair of criteria, the experts are asked the following question: "in the selection of a public transportation bus, considering the related criteria, how important is each element on the right hand side compared with each element on the left hand side?" In order to determine the importance level of the criteria, we apply Saaty's pairwise comparison (Saaty 1980). Therefore, the respondents were asked to indicate their answers for each factor using the nine-point scale shown in Table 2.

Table 2 Saaty's nine-point scale

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	For compromises between above

Table 3 Demographic information of respondents

Age (year)	Min: 38	Max: 59	Avg: 46.5
Workplace (%)	Municipality: 50		University: 50
Occupation (%)	Geomatics engineer: 17	Transportation engineer: 50	Urban and regional planning engineer: 33
Work experience in public transportation (year)	Min: 4	Max: 26	Avg: 16.5
Work experience in municipality (year)	Min: 0	Max: 31	Avg: 10.3

The members consisted of six experts from both university and municipality. The detailed information about respondents is given in Table 3.

Results

In this section, we present our analytical results. We use data provided by six respondents and analyze them in Super Decision software. We calculate general CR value and also CR values for each survey. We find that CR values are lower than 10% for a general score and also individual survey scores. Based on the calculation of Normals score, we conclude that the electric vehicle is preferred with 0.631133 scores (Table 4).

The normalized weights of main and sub-criterions are given in Tables 5 and 6 respectively. Based on the priority of these four main criteria, the Economic aspect is the most important criterion with a weight of 0.45. The results confirm that the economical aspect of candidate vehicles has an important role in the selection of a public transportation vehicle.

Table 4 Priority of alternatives

Alternative	Ideals	Normals
Diesel bus	0.584452	0.368867
Electric bus	1.000000	0.631133

Table 5 Priority of criteria

Criteria	Priority weight
Economic	0.45
Environmental	0.23
Technical	0.10
Social	0.22

Table 6 Priority of sub-criteria

	Priority weight	Global weight	CR
Economic			
Fuel cons	0.66	0.30	0.027
Purchase cost	0.19	0.09	
Infrastructure cost	0.15	0.07	
Technical			
Ease of maintenance	0.41	0.04	0.051
Range	0.33	0.03	
Reach tech staff	0.26	0.03	
Environmental			
Emission	0.63	0.14	0.100
Noise	0.15	0.03	
Used material	0.21	0.05	
Social			
Comfort	0.67	0.15	Not applicable
Reputation	0.33	0.07	

Discussion and Conclusion

This article is an initial attempt to model use MCDM approach to choose appropriate bus for small and midsized cities that take into account economic, environmental and social responsibilities of the municipalities to the public. The results suggest that the most important criteria among main criterions are economic. Our results suggest that cost is one of the main factors in public transportation decisions. Our results also indicate that high purchasing cost and infrastructure investments are main drawbacks for electric vehicles. Therefore, the government should encourage electric vehicles in public transportation by investing in infrastructure for electric vehicles and reducing purchasing cost with a lower tax on electric vehicles. Our analysis indicates that electric vehicles are preferred with the 63% score. The most important sub-criteria of economic criteria is fuel consumption. The most important sub-criteria of a social factor is a comfort. Although Municipalities care about reputation, due to the consideration of community contentedness they pay more attention to comfort. Due to the new regulations on carbon emission, Municipalities give the priority to emission sub-criteria of environmental factor. Maintenance and distance are two important sub-criteria of technical factor. In particular, respondents prefer Diesel vehicles in terms of distance and maintenance. This is another disadvantage of current electric vehicles. As future research, considering different alternatives such that hybrid and CNG technologies might be a valuable contribution.

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A Mathematical Model and a Matheuristic for In-Plant Milk-Run Systems Design and Application in White Goods Industry

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Abstract Effective material distribution is a vital issue to maintain the assembly lines' operations. So, coordination of the material supply to the assembly lines requires a system design that minimizes total material handling, inventory holding costs and prevents parts shortage. This is called the multi-commodity multi-vehicle material supply system design problem. To solve this, first, a *Single-Vehicle Milk-run Mathematical Model* is proposed. Then, a *Matheuristic* that iteratively employs the proposed model is developed to design a multi-vehicle in-plant milk-run system. The proposed methodology is validated by designing the milk-run system of a real washing machine assembly plant.

Keywords Milk-run · Part feeding · Assembly lines · Mathematical model
Matheuristic

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_9

Introduction

Effective material distribution is a vital issue to maintain the operations of the assembly lines where many parts are assembled. So as to satisfy the customer expectations, parts of the products differentiated considerably, and the distribution of several types of parts at the right time and in the right quantities has become more difficult. Therefore, the coordination of the material supply to the assembly lines requires an advanced system design, so as to minimize both inventory holding and material handling costs at the same time, without causing any parts shortage. The design of such a milk-run system requires that the delivery quantities to each customer are determined, the routes are constructed and the timing of delivery to each customer is decided, simultaneously. However, the cycle time decision affects the delivery quantities, and this influences the route construction since the capacity of the vehicles is fixed (Satoglu and Sahin 2013). So, scheduling and routing problems are coupled to each other. In some former studies, in-plant milk-run systems are designed without considering the component variety of the products of the assembly lines (Satoglu and Sahin 2013). When the parts-feeding literature is reviewed (Kilic and Durmusoglu 2015), there are many papers that deal with kitting and Kanban-based part feeding. However, the design of a milk-run system comprised of routing and scheduling simultaneously is still a challenge.

So, in this study, a Single-Vehicle Milk-Run Mathematical Model is developed for periodic distribution of multiple parts (components) to the stations of the assembly lines. Besides, for designing a multi-vehicle milk-run system, a Matheuristic Algorithm is proposed that iteratively solves the single vehicle milk-run model and includes additional vehicles in the solution, until all nodes are assigned to a route. This Matheuristic Algorithm is a unique aspect of this study.

Another contribution of this study is that parts to be distributed by milk-run routes are distinguished from those to be directly delivered. Hence, direct delivery and route construction are considered, simultaneously, during the design. The proposed methodology is employed and validated by designing the material supply system of a real washing machine assembly system.

The paper is organized as follows: In Section “Literature Review”, the relevant literature is reviewed. Later, the single-vehicle mathematical model (SV-MM) of the multi-part milk-run system is explained. Section “The Solution Methodology”, the Solution Methodology and the proposed Matheuristic Algorithm that employs the multi-part SV-MM are explained. Then, the real application of the proposed Algorithm in a washing machine manufacturing plant is described. The results of the Matheuristic and its performance are discussed, in the fifth section. Finally, the Conclusion is presented.

Literature Review

In this section, the papers that especially deal with the Kanban-based in-plant milk-run systems are discussed. Other part feeding policies such as kitting and sequencing are beyond the scope of this study.

Vaidyanathan et al. (1999) are the pioneers of the parts Just-in Time (JIT) parts delivery problem for the assembly lines. They pointed out that the delivery quantities at each demand node are a function of the route taken. Battini et al. (2009) developed an integrated framework for parts feeding to the mixed-model assembly lines by considering central and decentralized storages, material packing and picking activities. Caputo and Pelagagge (2011) proposed a methodology for deciding the most effective feeding policy for each of the part type, namely, kitting, just in time kanban-based continuous supply and line storage, for the assembly lines. Similarly, Limère et al. (2012) and Sali and Sahin (2016) proposed a cost-based decision approach and a mathematical model for selecting the most suitable parts feeding policy for each part-type.

On the other hand, Kilic et al. (2012) classified the in-plant milk-run systems and proposed mathematical models of each case. Emde and Boysen (2012) have addressed the problem of JIT parts-feeding to mixed-model assembly lines with the help of in-house supermarkets. They developed a nested dynamic programming model and showed the trade-off between train capacity and line stock. Battini et al. (2013) described the terminology of the JIT-Supermarket in detail and emphasized ergonomic aspects of supermarket applications. Boysen et al. (2015) examined all of the design problems concerned with the parts logistics in the automotive industry. They expressed that the total line side buffer quantities and the number of vehicles might be minimized. Golz et al. (2012) proposed a two-stage heuristic for JIT part supply to the mixed-model automobile assembly lines minimizing the number of shuttle drivers. Volling et al. (2013) addressed the in-plant cyclic parts supply problem with multi-product, multi-vehicle and stochastic demand pattern, and developed an exact decomposition approach. Satoglu and Sahin (2013) proposed a mathematical model and a heuristic for the design of a material supply system serving the assembly lines, and an application of a TV assembly plant was explained. The heuristic algorithm assumes that all routes have an equal service period, and all parts requirements of each station are aggregated. Fathi et al. (2015) formulated a multi objective mixed integer linear programing model and a particle swarm optimization model, for the multi-product multi-vehicle milk-run design. Zammori et al. (2015) suggested that the assembly lines must be separated into segments and Kanban system must supply each segment from a decentralized depot, in constrained layouts. Satoglu and Ucan (2015) redesigned the in-plant part supply-system of an automotive supplier, based on lean principles. Besides, Alnahhal and Noche (2015) designed an electronic-kanban milk-run material supply system by considering the disruptive factors.

In addition, Caputo et al. (2015) suggested that the just-in-time (JIT) delivery is more suitable for mixed-model assembly lines than line stocking. Korytkowski and

Karkoszka (2016) analyzed the throughput rate of the production system, utilization of the milk-run operators and work-in process quantities by the simulation. Recently, Zhou and Peng (2017) addressed the problem of material delivery from the decentralized depot to the assembly stations, on a just-in-time basis, and developed a neighborhood search algorithm. Emde and Gendreau (2017) recently developed a mixed-integer model of the tow-train scheduling problem and decomposition heuristic. Besides, Karadayi Usta et al. (2017) developed a methodology for parts-feeding mode selection. Satoglu and Sipahioglu (2018) proposed a two-stage assignment model for milk-run system design, to decide the cycle times and design the routes. Kilic and Durmusoglu (2015) present a part-feeding literature review.

According to this review, several studies that intend to select the most suitable part-feeding policy for the assembly lines were conducted. Only a few studies developed decomposition based heuristics or meta-heuristics for solving the problem. However, effective design of the milk-run systems, especially in multi-part multi-vehicle setting, still needs to be studied.

The Proposed Multi-part Single-Vehicle Milk-Run Model

Aghezzaf et al. (2012) developed a non-convex model for the single-part selective Single-Vehicle Milk-run Model, but the authors reported that they could not solve it, and performed a relaxation. In this study, the model is extended into the multi-part case. Besides, in order to enhance the solution, a set of feasible cycle time values is predetermined, and an exact solution of the model is intended to be reached for these discrete values. This is a novel aspect of the model. First, the notation and the proposed model for the multi-part SV-MM are presented below.

S Set of customers. $S = \{2, 3, \ldots n\}$.
$S^+ =$ $S \cup \{1\}$, where *"1" represents the central depot.*
P Set of commodities (parts)
C Set of possible cycle times
i Node index
j Node index
c Cycle time index
p Part index

Parameters:

Ψ The fixed cost of using each vehicle
Ct_c The value of the cycle time—c ($c \in C$) (min)
t_{ij} The distance between customers i and j (m)
ϑ Speed of the vehicle (m/min)

δ	Cost of the vehicle per meter traveled
η_p	Unit inventory holding cost of part—p
φ_i	The fixed cost of a batch-order for node—i.
B_p	Weight of a full-box of part—p (kg)
V_p	Volume of a box of part—p (m^3)
KV	Maximum volume of boxes that a vehicle can carry (m^3)
d_{ip}	Demand of node—i for part—p (per minute)
LU_{jp}	Load–unload time required per container for part—p at the node—j (min)
K	The capacity of a vehicle (kg)
K_i	The capacity of the node—i (box)
λ_j	The benefit earned by visiting the node—j.
T_{min}	The minimum cycle time.
T_{max}	The largest cycle time.

The Decision Variables:

$$X_{ij} = \begin{cases} 1, & \textit{if node} - j\,\textit{is visited immeadiately after node} - i\,\textit{on the route}; \\ 0, & \textit{otherwise} \end{cases}$$

$$T_c = \begin{cases} 1, & \textit{if the route of the vehicle is repeted once in every cycle} - \textit{time of } Ct_c; \\ 0, & \textit{otherwise} \end{cases}$$

$$Q_{ijp} = \text{Load on the Vehicle for part} - p\,\text{after visiting the customer} - i\,\text{before arriving node} - j;$$

$$Z = Min\,\Psi + \left(\sum_{c \in C} \sum_{i \in S^+} \sum_{j \in S^+} t_{ij} \delta X_{ij} \frac{T_c}{Ct_c} + \varphi_i \frac{T_c}{Ct_c} \right) + \left(\sum_{c \in C} \sum_{i \in S} \sum_{p \in P} \sum_{j \in S^+} \frac{1}{2} \eta_p d_{ip} Ct_c T_c X_{ij} \right) - \sum_{j \in S^+} \sum_{i \in S^+} X_{ij} \lambda_j$$

S.t.

$$X_{ii} = 0; (i \in S^+) \tag{1}$$

$$\sum\nolimits_{i \in S^+} X_{ij} \le 1; (j \in S) \tag{2}$$

$$\sum\nolimits_{j \in S^+} X_{1j} \ge 1 \tag{3}$$

$$\sum\nolimits_{i \in S^+} X_{ij} - \sum\nolimits_{k \in S^+} X_{jk} = 0; (j \in S^+) \tag{4}$$

$$\begin{aligned}&\sum\nolimits_{i\in S^+}\sum\nolimits_{\substack{j\in S^+\\ j\neq i}} t_{ij}X_{ij}/\vartheta+\sum\nolimits_{j\in S^+}\sum\nolimits_{p\in P} Q_{1jp}LU_{1p}\\ &+\sum\nolimits_{\substack{i\in S\\ i\neq j}}\sum\nolimits_{j\in S^+}\sum\nolimits_{p\in P}\sum\nolimits_{c\in C} LU_{jp}d_{jp}Ct_cT_cX_{ij}\leq\sum\nolimits_{c\in C} Ct_cT_c\end{aligned} \quad (5)$$

$$\sum\nolimits_{i\in S^+} Q_{ijp}-\sum\nolimits_{k\in S^+} Q_{jkp}=d_{jp}\sum\nolimits_{i\in S^+}\sum\nolimits_{c\in C} X_{ij}Ct_cT_c;\,(j\in S),(p\in P) \quad (6)$$

$$\sum\nolimits_{p\in P} Q_{ijp}B_p\leq KX_{ij};\,(i\in S^+)(j\in S^+) \quad (7)$$

$$\sum\nolimits_{p\in P} Q_{ijp}V_p\leq KV.X_{ij};\,(i\in S^+)(j\in S^+) \quad (8)$$

$$\sum\nolimits_{p}\sum\nolimits_{i\in S^+} d_{jp}X_{ij}T_cCt_c\leq K_j;\,(j\in S)(c\in C) \quad (9)$$

$$\begin{aligned}&X_{ij}\in\{0,1\}(j\in S^+)(i\in S^+)\\ &T_c\in\{0,1\}(c\in C)\\ &Q_{ijp}\geq 0;\,(j\in S^+)(i\in S^+)(p\in P)\end{aligned}$$

The objective function minimizes the total fixed vehicle usage cost, total material handling, and inventory holding costs minus the benefit earned by visiting the selected customer(s). Constraints (1) stipulate that a node cannot be connected to itself. Constraints (2) imply that a node (except the depot) can be connected to at most one node. Constraint (3) stipulates that the depot should be connected to at least one node. Constraints (4) are the flow balance constraints, and the number of entering arcs must be equal to the leaving arcs for each node, including the depot. Constraints (5) stipulate that the total traveling time between the selected nodes and loading–unloading time at those nodes and at the depot must be smaller than or equal to the cycle time selected. The constraints (6) imply that the quantity of a part delivered to a node must be equal to its demand rate for that product times the selected cycle time, given that this node is included in the route. In other words, if a node is visited, the delivery quantity to it must be equal to its requirement for each part. These constraints serve as sub-tour elimination constraints, as well. The Constraints (7) force that the total amount of load handled between any pair of nodes cannot be greater than the capacity of the vehicle. Constraints (8) imply that the total volume of the boxes handled by the vehicle cannot be greater than the volume capacity of that vehicle. The last constraints (9) imply that the total amount of commodities delivered to a node cannot be greater than the (buffer) capacity of that node. Finally, the (sign) restrictions of the variables are presented.

This is a non-linear mathematical model due to the objective function and the Constraints (5), (6), (9). The non-linearity stems from the product of the two types of binary variables. In order to solve the problem more effectively, it is linearized by defining a new variable Wijc that will replace the term of $X_{ij}*T_C$. The following two sets of constraints are appended into the model due to this linearization:

$$X_{ij} + T_c \leq 1 + W_{ijc}; (j \in S^+)(i \in S^+)(c \in C)$$
$$X_{ij} + T_c \geq 2W_{ijc}; (j \in S^+)(i \in S^+)(c \in C)$$
$$W_{ijc} \in \{0, 1\}; (j \in S^+)(i \in S^+)(c \in C).$$

Hence, the linearized mathematical model is proposed as follows:

$$\left(\sum_{c\in C}\sum_{i\in S^+}\sum_{j\in S^+} t_{ij}\delta\frac{W_{ijc}}{Ct_c} + \varphi_i\frac{T_c}{Ct_c}\right) + \left(\sum_{c\in C}\sum_{i\in S}\sum_{p\in P}\sum_{j\in S^+}\frac{1}{2}\eta_p d_{ip} Ct_c W_{ijc}\right) - \sum_{j\in S^+}\sum_{i\in S^+} X_{ij}\lambda_j$$

S.t.
(1), (2), (3), (4), (7), (8)

$$\sum_{i\in S^+}\sum_{\substack{j\in S^+\\ j\neq i}} t_{ij}X_{ij}/\vartheta + \sum_{j\in S^+}\sum_{p\in P} Q_{1jp}LU_{1p} + \sum_{\substack{i\in S\\ i\neq j}}\sum_{j\in S^+}\sum_{p\in P}\sum_{c\in C} LU_{jp}d_{jp}Ct_cW_{ijc} \leq \sum_{c\in C} Ct_cT_c; (c\in C) \tag{5'}$$

$$\sum_{i\in S^+} Q_{ijp} - \sum_{k\in S^+} Q_{jkp} = d_{jp}\sum_{i\in S^+}\sum_{c\in C} W_{ijc}CT_c; (j \in S), (p \in P) \tag{6'}$$

$$\sum_p \sum_{i\in S^+} d_{jp}W_{ijc}CT_c \leq K_j; (j \in S)(c \in C) \tag{9'}$$

$$X_{ij} + T_c \leq 1 + W_{ijc}; (i \in S^+)(j \in S^+)(c \in C) \tag{10}$$

$$X_{ij} + T_c \geq 2W_{ijc}; (i \in S^+)(j \in S^+)(c \in C) \tag{11}$$

$$X_{ij} \in \{0, 1\}(j \in S^+)(i \in S^+)$$
$$T_c \in \{0, 1\}(c \in CT) \quad Q_{ijp} \geq 0; (j \in S^+)(i \in S^+)(p \in P)$$
$$W_{ijc} \in \{0, 1\}(j \in S^+)(i \in S^+)(c \in C)$$

The Solution Methodology

First, the transportation mode of each component is decided. The run-out time of each container of a component is computed based on the takt-time of the line, # of pieces in each container of each component, and the number of pieces used of each component in the product (based on the bill-of-materials). The parts that have a very short run-out time may not be eligible for milk-run distribution, but direct-delivery is suitable for them. This is due to the fact that their delivery quantities are usually close to the vehicle capacity, and a vehicle must continuously deliver these parts to the associated stations (nodes) (Gallego and Simchi-Levi 1990). In this study, the proposed solution methodology distinguishes the parts that are to be distributed by a milk-run route and those to be delivered directly by using the given equation below. The parameters of this equation are explained above, in notations part of the mathematical model.

$$Transportation\,Type\,(i) = \begin{cases} Direct\,Delivery, & if\,\frac{t_{ij}}{\vartheta} + LUjp > \frac{K_i}{d_{ip}} \\ Milk - run\,route, & otherwise \end{cases}$$

For those parts to be directly distributed, the delivery frequency and quantity are determined based on the buffer capacity of the associated node. For those parts to be distributed by milk-run routes, separate buffer areas are used. For milk-run distribution of the suitable parts, the routes are constructed and the delivery cycle times are decided by using the proposed *Matheuristic*.

The Proposed Matheuristic for the Multi-vehicle Milk-Run System Design

The pseudocode of the proposed Matheuristic is shown in Fig. 1. Initially, all demand nodes and the depot are included in the Node_Set_1. Then, the minimum cycle time (T_{min}) and the maximum cycle time (T_{max}) are determined. Here, T_{min} is considered as the trip time for direct delivery to the nearest node. So as to consider a wide range of cycle time values, T_{max} is computed by considering the minimum of all node capacities divided by the total demand rate for all parts of that node. It is mathematically formulated below. The range of the cycle times start from T_{min} and it is incremented by 15 min intervals up to the T_{max}.

$$T_{max} = Min_{j \in S}\left(\frac{K_j}{\sum_{p \in P} d_{jp}}\right)$$

The proposed Matheuristic algorithm aims to solve a multi-vehicle milk-run design problem, on the basis of the *selective multi-part SV-MM*. In each iteration,

Fig. 1 The pseudocode of the proposed Matheuristic

```
Begin
  Input Node_Set_1
  Input CT_c [T_min, ....., T_max]
  # of vehicle =0
  Do
      # of vehicle = # of vehicle +1
      Solve p-SV-CIRP Model for the Node_Set_1
      Save the objective value of the solution
      Save the route and cycle time of the solution
      Discard the selected nodes of the solution from Node_Set_1
  While Node_Set_1 ≠ Ø
  Bring the saved solutions and # of vehicle as a result.
End
```

the *selective SV-MM* is solved, and some or all of the nodes are assigned to a vehicle. If there are remaining nodes unassigned to a route, the same problem is solved only for these nodes again. At each iteration, while solving the *SV-MM*, the same set of possible cycle time values are considered that vary between T_{min} and T_{max}. This procedure is repeated until all nodes are assigned to a vehicle route. It should be noted that the model makes it possible for a single vehicle to make more than one tour at the same cycle time, and also because of the benefit (λ) coefficient in the objective function, the model may try to serve as many stations as possible in each iteration. However, it is noted that the trade-off between the benefit obtained by serving that node and the cost that incurs (by serving it) affects the decision. When the additional cost of serving a node is higher than the benefit of that node, the model will not include that node in a route. Hence, the proposed Matheuristic constructs the routes determine the cycle time of each route and decide the number of vehicles required, simultaneously. The number of the vehicle is equal to the number of times that the selective SV-MM is run until all nodes are assigned to a route. Hence, the routes are assigned to the vehicles, and the number of vehicles is determined, as well.

A Real Application in the White Goods Industry

In-plant distribution of various commodities or parts of white (durable) goods is considered in this study. There are usually several variants of a specific type of component that complicates the distribution service to the assembly lines. In order to satisfy the requirements of the stations on time, and to decrease the transportation and inventory holding costs, cyclic replenishment of goods is required. Currently, the factory employs twelve forklifts to manage the part feeding, based on direct delivery. This caused an intensive vehicle traffic inside the plant, and occupational safety problems started to arise. Besides, limited buffer capacities and tight layout constraints forced the plant managers to redesign the in-plant material supply system. Therefore, an in-plant milk-run system was intended to be designed to serve the single-model assembly lines.

There are four assembly lines, each comprised of 25 stations. At each station, a specific component type is assembled to the work-piece. In this study, to make an initial pilot design, only seven stations of each assembly line are considered. Therefore, 28 stations and the depot that comprises 29 nodes included in the problem. The facility layout is given in Fig. 2. The vehicle delivers goods to a single point (buffer area) from which the goods are sent manually to the relevant stations. The load–unload times that change according to the specific station and the commodity type (LU_{jp}) is predetermined. To design the milk-run system, the cycle time of distribution must be decided, the delivery quantities of all parts must be determined according to the leveled (smooth) weekly production plan, and the service routes must be constructed.

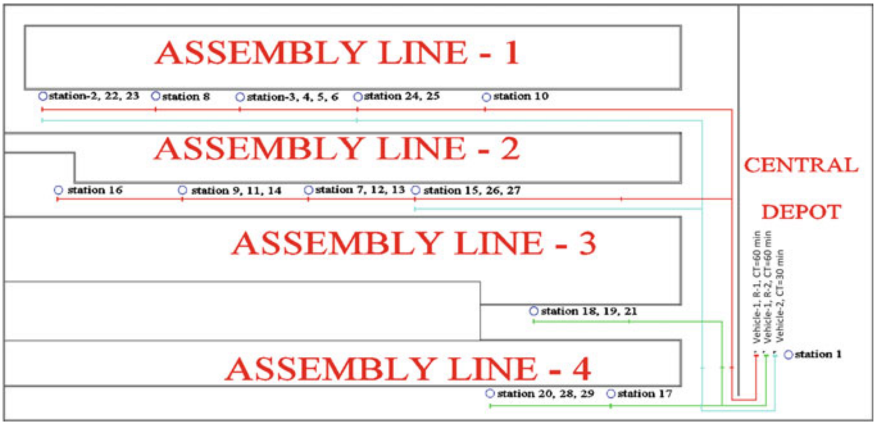

Fig. 2 The layout of the plant and designed milk-run routes

The proposed Matheuristic algorithm aims to solve a multi-vehicle milk-run design problem, on the basis of the *selective multi-part SV-MM*. In each iteration, the *selective SV-MM* is solved, and some or all of the nodes are assigned to a vehicle. If there are remaining nodes unassigned to a route, the same problem is solved only for these nodes again. At each iteration, while solving the *SV-MM*, the same set of possible cycle time values are considered that vary between T_{min} and T_{max}. This procedure is repeated until all nodes are assigned to a vehicle route. It should be noted that the model makes it possible for a single vehicle to make more than one tour at the same cycle time, and also because of the benefit (λ) coefficient in the objective function, the model may try to serve as many stations as possible in each iteration. However, it is noted that the trade-off between the benefit obtained by serving that node and the cost that incurs (by serving it) affects the decision. When the additional cost of serving a node is higher than the benefit of that node, the model will not include that node in a route. Hence, the proposed Matheuristic constructs the routes determine the cycle time of each route and decide the number of vehicles required, simultaneously. The number of the vehicle is equal to the number of times that the selective SV-MM is run until all nodes are assigned to a route. Hence, the routes are assigned to the vehicles, and the number of vehicles is determined, as well.

First, the requirements of the four single-model assembly lines associated with the seven parts are computed based on the pace of production of each line and the number of parts in a box. The plant's net available production time in a shift is seven hours. The paces of production of the lines (from the first to the fourth one) are 1550, 1300, 1250 and 600 products/shift, respectively. These target production quantities are multiplied by the number of required parts per product according to the bill-of material and divided by the available production time (430 min). Hence, the required number of parts per minute by each assembly line is computed.

Table 1 The solution of the proposed Matheuristic for the real problem

Vehicle	Route number	Route	Load weight (kg)	The volume of vehicle load (m^3)	Cycle time (min)	Total load–unload time (min)	Travel time (min)
1	1	1–7–15–26–13–4–10–6–24–5–8–2–3–11–9–12–14–16–1	440.6	1.846	60	33.6	6.42
	2	1–19–21–18–17–29–28–20–1	79.7	0.331		12.1	1.18
2	3	1–27–22–23–25–1	51.6	0.206	30	22.1	3.7

These required quantities are divided by the number of parts per box for each component type. As a result, the numbers of boxes required per minute (d_{ip}) are found.

After the demand quantities have been calculated, the next step is to determine the T_{min} and T_{max} values. The value of T_{min} is 0.3 min because the nearest station is 49.4 m away and the vehicle speed is 160 m/min. However, in order to reach an applicable design, the minimum cycle time value T_{min} was assumed as 15 min, based on the opinions of the factory managers. T_{max} was found as 900 min, approximately. In order to decrease the solution space, T_{max} was limited to the 150 min.

This real problem was solved by means of the proposed Matheuristic. The Matheuristic solved the SV-MM model by using GAMS Cplex solver on i5-M430 CPU 2.27 GHz computer. The Matheuristic reached the solution in two iterations. The first iteration took 276 s while the second one was completed in 4.87 s. According to the two iterations of the Matheuristic, two vehicles are required and three routes are constructed, as shown in Table 1. The first vehicle has two different routes while the second has only one route. As shown in Table 1, the first vehicle's cycle time is 60 min and the second vehicle's cycle time is 30 min. The first route of the vehicle-1 consists of 17 stations while the second route of the same vehicle includes seven stations. The total weight of the material carried by the first vehicle in two routes is 520.36 kg (Note that the vehicle capacity per route is 500 kg). In addition, the total loading–unloading and transportation times of the first two route is 53.42 min that is less than the cycle time of 60 min. The second vehicle has only one route that consists of four stations. The weight of the material carried by this vehicle is 51.69 kg, while the total loading–unloading and transportation time is 25.87 min.

The proposed Matheuristic can be employed by all manufacturing systems that have a high variation of parts and require repetitive and continuous parts supply to their assembly lines. This real application can be exploited by almost all of the white goods manufacturing facilities, automotive and electronics factories that perform an assembly type production.

Results and Discussion

As the proposed model for the SV-MM and the Matheuristic that employs it are based on the multi-commodity case, and the model considers vehicle's volume capacity constraints, the results of them cannot be compared to those of the past studies that merely consider a single commodity. Besides, in real life settings, the in-plant milk-run systems may require multi-vehicles. So, the solution of the proposed Single Vehicle Milk-Run Model by means of the Matheuristic until all nodes are assigned to a route may enhance the solution of especially large size problems. However, the optimality is not guaranteed. In the real problem, the assembly plant used to employ forklifts. However, by means of the in-plant milk-run application, and by eliminating parts distribution by forklifts, the company reduced its total material handling and line side inventories. However, material preparation time in the central warehouse increased, since more frequent deliveries are made and smaller quantities are delivered.

Conclusion

As a result of the component variety of the products, parts distribution to the assembly lines has become a more difficult problem. In this paper, first, the parts that must be directly distributed are distinguished from those that can be delivered in a cyclic manner by milk-run tours. This is called the In-plant Milk-Run System Design, and optimization of this design is intended. A mathematical model for the single-vehicle milk-run model (SV-MM) is developed for the multi-commodity case, for the first time in the literature. Besides, a Matheuristic that iteratively employs the proposed SV-MM is developed to solve the multi-vehicle problem. As a result, the required number of vehicles, the routes and the delivery schedule of the vehicles are determined. However, the optimal solution is not guaranteed.

Besides, the real parts distribution problem of a washing machine assembly line was solved by means of the proposed Matheuristic in short computational times. The routes are constructed, the cycle times are decided and the routes are also assigned to the vehicles. It was found that two vehicles are enough to serve the assembly line. The results of the Matheuristic or the SV-MM could not be compared to those of other studies that exist in the literature, since to the best of authors' knowledge; there is no data set for the multi-commodity (multi-part) case of the SV-MM. In future studies, the results of the Matheuristic can be better assessed based on the new cases of different assembly plants. Besides, a meta-heuristic can be developed to solve the SV-MM of this problem, since it is still hard to solve. Simulation models can be also constructed to analyze the milk-run system in varying demand and dynamic factory conditions, in future studies.

Acknowledgements This study has been financially supported by the Turkish National Science Foundation (TUBITAK), through the 215M143 research project.

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An Optimization Model for Variable Ordering in Qualitative Constraint Propagation

Mehmet Fatih Hocaoğlu

Abstract In this study, a nonlinear optimization model is proposed to determine the constraint propagation (CP) of qualitative constraint sets to minimize search backtracking points. The model gives answers to the questions of what the optimal sequence is in the case that there is a set of variables with known values and, alternatively, what variable sequence is optimal to be able to have an optimal value propagation (what variable values should be known to have optimum variable sequence). In order to improve the solution performance, a constraint activation analysis is initiated for the constraints that are defined for the variables with known values by sign algebraic Karush-Kuhn-Tucker conditions. The optimization model and the qualitative activity analysis carried out can be applied to any constraint propagation problem where the variables have a limited set of values.

Keywords Constraint activation analysis · Constraint propagation
Variable propagation optimization · Variable ordering · Qualitative reasoning
Qualitative simulation

Introduction

Qualitative Reasoning and Qualitative Simulation are the techniques which have been developed for modeling intent in human reasoning. Both techniques deal with the human view of computation without the limitations of algorithms, data structures and ensuring the involvement of the human approach to problem solution. Several approaches and ontologies have been proposed to accomplish this purpose by researchers. Device-Centered Ontology (De Kleer and Brown 2013), Process-Centered Ontology (Forbus 2013) and Constraint-Based Approach (Kuipers 1994), on which this study focuses, are well-known ones. The main

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_10

purpose of the qualitative simulation is to generate predictions for the behaviors of a device by taking an initial state, a qualitative constraint set and a qualitative value set that are related with qualitative state variables of a device or a system. The source of information with qualitative simulation is incomplete in both data and qualitative constraints as a structured deep-behavioral knowledge about the system they represent. The constraints are constructed on qualitative functions, each representing a large function family instead of a well-defined quantitative function between variables. We are faced with a constraint propagation (CP) problem in determining initial state by propagating the known qualitative variable value to compute unknown ones through qualitative constraints. The large set of qualitative values, which has qualitative variables, and the ambiguity in qualitative computations consume propagation processing time.

The objective of this study is to establish an optimization model to optimize variable propagation ordering in a way that all values of variables are determined by a minimum number of propagation steps. Although, the problem, which is known as a CP problem, is taken into consideration in the area of qualitative simulation, it can be easily applied to any other qualitative CP problem. The fundamental point in variable ordering optimization is to minimize the variable width of the sequence of the variable. The width of a variable in a variable sequence is defined by the number of connections between a variable and the previous variables in the sequence. The highest variable width in the sequence determines the whole sequence width, and higher width increases backtracking during the propagation process (Freuder 1982; Dechter and Pearl 1989). Moreover, another factor increasing the number of backtracking points is the size of the value set of the variable. Putting a variable which has a large set of values in the first part of the order increases backtracking in the propagation process. The optimization model is a nonlinear optimization model. As in all these problems, we know that the higher the number of variables, the higher the number of iterations in the solution procedure. There are strong relations between CP and qualitative simulation at two points. These are to determine qualitative variable initial values and to filter out spurious behaviors that consist of inconsistent values according to qualitative constraints during simulation execution. Since value propagation determines consistent value assignments to qualitative variables, it allows filtering out spurious inconsistent behaviors by checking value assignments. Qual-Sim is a qualitative simulator developed using Prolog (Hocaoğlu 2000) that is extended by an optimization model generator. The generator generates the variable ordering optimization model and solves it using the Lingo 9.0 API (application programming interface). The main contributions are (1) an optimization model is developed to minimize qualitative variable propagation in a qualitative differential equation set for qualitative variables that have a discrete value set, (2) a sign algebraic activity analysis is applied to prune infeasible solution spaces, (3) the optimization model is represented in a general form so that it can be applied for the case that values of some of the variables are known and the case they are not known, and (4) it is possible to use the optimal variable order during qualitative simulation to check inconsistent variable value assignment.

The paper has been organized in the following way. The next section provides the necessary definitions. Section "Qualitative Constraints and Symbols" summarizes the qualitative constraints and symbols. Section "Case Study: U-Tube Problem Description" explains a case study. The optimization model that is the focus of this study is described in Section "Optimization Model". Finally, the paper ends with a conclusion part.

Conceptual Definitions

It is possible to describe a constraint-based problem (CSP) as an unfamiliar set of variables and a domain depending on constraints which are fulfilled by the variables. Within the concept of these problems, a domain could be not only a continuous range but also an integer range which is probably enumerated. A CSP is an NP-hard problem. In order to cope with this difficulty, several CP techniques that are based on local consistency algorithms have been proposed (Dechter 2003). There are some studies to determine the time complexity of arc consistency testing depending on variable ordering (Berkholz and Verbitsky 2018). All variables in a domain have their own discrete and finite value sets, and they are connected (not fully) to each other via constraint. A solution which meets all the constraints can be provided for a problem when a value is assigned to each variable. CP is related to propagating a known value of a variable through unknown variables via constraints. During propagation, for a variable there might be many alternative solutions placed on a search tree, depending on its value set (its domain). Although a different alternative search strategy might be applied, assigning values to variables so that all constraints are fulfilled is a must. The algorithm proceeds by diminishing each domain one by one until either a solution are obtained or a solution cannot be found. A value is eliminated from the domain each time. In this way, the constraints which are acting on the domain are checked to understand whether any constraints indicate that another value that is available in another domain is forbidden. If it comes to that, it is also eliminated, and the system keeps on repeating this process iteratively. In the process, consistency is checked for nodes and arcs that are formed by constraints between constrained variables (Kumar 1992; Mayoh et al. 1994). A comparison of consistency propagation approaches can be found in Zheng and Horsch (2003). CP is also used in optimization problems, where a numerical objective function is maximized under given constraints. In such usage, the solution is generalized from the numerical total order to a non-numerical partial order that can be interpreted in terms of information (Nait Abdallah and Van Emden 2013). In the study, a novel local similarity learning approach, which can exploit the supervisory information encapsulated in pairwise constraints, including must-link and cannot-link constraints, to learn better similarity measurements between the instances is proposed (Fu et al. 2015). Learning algorithms are used in CP problems, and some local learning algorithms attempt to exploit the available pairwise constraints to learn a new set of similarities, which are consistent with the supervisory information in the pairwise constraints, before propagating these initial constraints (Fu et al. 2015) that are developed for this purpose.

Domain elimination may take place in two ways; by choice or by consequence of propagation which is necessary for the fulfillment of some constraints. If a failure occurs, the algorithm backtracks until the last choice, to get the opposite decision and keep on trying. In the case of no solution being available, it backtracks only one step and analyzes the whole decisions by using the bottom-up method until there is no solution proved or one is found. When solving a CSP using a backtrack search algorithm, local consistency is often used before and during the search to reduce the size of the search space (Dechter 2003). In the literature, we see variable ordering-based CP problem solutions (Nait Abdallah and Van Emden 2013). In the study, a dependency tree depending on variable couples is created, and value assignment is done based on Pareto optimality by taking node consistencies into consideration. In a sequence of variables, the width of a variable is defined as the total number of connections that the variable has with previous variables in the sequence. In CP, discrete value sets are organized on a search tree, and a search process is done on the tree to find variable values so that constraints are satisfied. During a search of variables with unknown values, being uninitialized by propagation and having a high number of members of a value set to increase the backtracking points on the search tree. In a similar way, variable width increases the backtracking points. Constraint-based qualitative simulation models include qualitative variables which have discrete value sets with qualitative values in the set and qualitative constraints.

Qualitative Constraints and Symbols

Qualitative functions depict function families each keeping uncountable quantitative representations belonging to the family. Qualitative representation focuses on the relation type kept between variables rather than quantitative information in the function such as coefficients and numerical values (Kuipers 1994). In this study, six types of qualitative constraints are examined. These are monotonic increasing and monotonic decreasing functions, the derivation function, and functions of minus, summation, and multiplication. $M^+ = (P_1, P_2)$ and $M^- = (P_1, P_2)$ represent monotonic-increasing and monotonic-decreasing functions, respectively, and in both functions, any change one of the parameters causes an increase or decrease on the other parameter. The derivation function is symbolized as $Deriv = (P_1, P_2)$, and derivation of the first parameter yields the second parameter. Summation of first and second parameters gives the third parameter in $Add = (P_1, P_2, P_3)$, in other words, $P_3 = P_1 + P_2$, and in a similar way, $Minus = (P_1 a\, a, P_2)$ and $Mult = (P_1, P_2, P_3)$ are given by $P_1 = -1 \times P_2$ and $P_3 = P_1 \times P_2$, respectively.

Case Study: U-Tube Problem Description

The U-tube example, which is a well-known problem especially in the area of qualitative simulation, is quite simple but it is useful for modeling solution approaches to CP problems (Kuipers 1994). A U-tube is a system made by two tubes (named A and B) with different diameters connected to each other by a pipe. Any change made in the amount of liquid in the tubes causes the system to undergo some serial behaviors. The system behaviors are identified by a set of state variables and by constraints given below.

Deriv(amtA, flowBA); Flow from tube B to tube A (flowBA) is determined by derivation of the amount of liquid (amtA) in tube A
M+(amtB, pressureB); Pressure at the bottom of tube B (pressureB) changes monotonically with the amount of liquid (amtB) in tube B
M+(amtA, pressureA); Pressure at the bottom of tube A (pressureA)
M+(pAB, flowAB); Difference between pressure A and pressure B (pAB) changes monotonically with the amount of flow from tube A to tube B (flowAB)
Deriv(amtB, flowAB); Flow from tube A to tube B is determined by derivation of the amount of liquid in tube B
Add(amtA, amtB, total); Total amount of liquid in the system is equal to total
Minus(flowAB, flowBA); flowAB = −1 * flowBA
Add(pAB, pressureB, pressureA); pAB + pressureB = pressureA
Constant(total); Total is constant

A behavior is a state variable set trajectory ordered on a time axis, and it is generated by deducing the constraint set by the guidance of a set of rules describing what state variable takes what value with its direction of change. The knowledge used to discover the future of the system is defined as deep knowledge because of the constraints defining a structural information rather than shallow behavioral knowledge built by if-then-else rules such as expert systems do (Hocaoğlu 2000). The variables, value sets and the constraints that define the U-tube problem are shown (Table 1).

Table 1 The variable name and value set tuples are as follows in (varName, valueSet) form

Variable name	Explanation	Value set
amtA	The fluid amount in tube A	[0, amax, inf]
amtB	Fluid amount in tube B	[0, bmax, inf]
pressureA	Pressure on the bottom surface of tube A	[0, inf]
pressureB	Pressure on the bottom surface of tube B	[0, inf]
pAB	The pressure difference between tube A and tube B	[minf, 0, inf]
flowAB	Fluid flow from tube A to tube B	[minf, 0, inf]
flowBA	Fluid flow from tube B to tube A	[minf, 0, inf]
Total	The total amount of fluid in the U-tube system	[0, inf]

To be able to minimize backtracking points, the variables with low width values are located in the first part of the order. In a randomly ordered set of variables, the width of a variable is determined by the numbers of variables that are constrained by at least a constraint located before it. A randomly ordered variable sequence is given in Fig. 1. The dependencies between variables are determined by the constraints. Variable widths are computed depending on the number of preceding variables in the sequence, so that flowAB has zero width because there is no connection coming from preceding variables in the sequence, but the value for flowBA is equal to two because of the variables amtA and flowAB. The problem is to order the variables to propagate their values in a way that the variable sequence gives minimum width and backtracking points. Minimizing backtracking points is related to pushing the variables with smaller sets of values to first orders. In the example, the initial state information says that the variable flowAB has an interval value of $[0, \mathit{inf}]$ and it has decreasing direction $(\downarrow)$. Propagating this value through constraints gives the solution set; (pressureA = {0, inf, [0, inf]}, flowAB = {[0, inf]}, pAB = {0, [0, inf]}, amtA = {amax, inf, 0, [amax, inf], [0, amax]}, amtB = {bmax, inf, 0, [bmax, inf], [0, bmax]}, pressureB = {0, inf, [0, inf]}, flowBA = {[minf, 0]}, total = {0, inf, [0, inf]}).

Because of the *Minus(flowAB, flowBA)* constraint, the value of *flowBA* is computed as $[\mathit{minf}, 0]$ and it increases $(\uparrow)$. All other variable values are computed in a similar way (Hocaoğlu 2000). Because of the incomplete nature of the information that qualitative simulation deals with, for most of the variables, a solution set is found after propagation rather than computing a unique qualitative value. To minimize solution sets and force them to have a unique value, a search process is made on the solution set. In the process, all values are tried to find the ones satisfying all constraints. The number of members of the value set on the solution tree and the width of the variables arising from their order and dependency level with previous variables are the factors increasing the backtracking points in the search. The aim is to arrange variables in order so that backtracking on the solution tree is minimized.

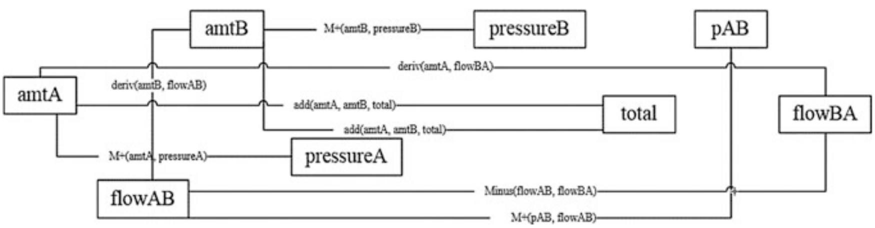

Fig. 1 A randomly ordered variable sequence

Optimization Model

The optimization model has been developed to minimize backtracking on the search tree so that the order of the variables gives minimum width for the network and a rigid distribution according to the variables' widths. Since a variable value set is an important factor, the optimization model aims to arrange the variables from the ones which have fewer members in their domain to the higher ones. The following subsections explain what decision-making variables the problem has, what the goal function is and how it is formulated, and what constraints the model has and how they are formulated. The decision variables used in the model are as follows:

O_i: The order of variable named as i in the sequence, N_i: Number of the value set members of variable i, and TR_i: Total relations coming to variable ***i*** from the variables in preceding orders. TR_i defines the width of variable i. The maximum width defines network width. $R_{i,j}^{sign}$: The relation between variable i and variable j. If *sign* is equal to p then variable i takes place in the order before variable j. if the sign is equal to m then variable j takes place in the order before variable i. Since only one of the sequences is possible, if $R_{i,j}^{p}$ is equal to 1 then $R_{i,j}^{m}$ is equal to 0.

Objective Function

The main goals are to minimize the total width of variables in the network, to ensure the constraint network is distributed rigidly with respect to width and to allow variables that have a value set with fewer members take places in the first part of the order. The optimization model has two parts. The first part (G1) is created to minimize value propagation backtracking points (The first item is to minimize multiplication of total relations (width) by variable order and number of variable value set. The aim of the first item is to put a variable in a sequence so that placement minimizes variable width). The second part (G2) is to minimize distances between neighboring variables in the resulting order in order to have a homogenous sequence (cns: Number of variable couples that are connected to each other by a constraint, n: Number of variables).

$$\boldsymbol{min}\, G1 = \sum_{i=1}^{n} TR_i * O_i * N_i \quad \text{and} \quad \boldsymbol{min}\, G2 = \sum_{i=1}^{cns} f_i \rightarrow \min \mathrm{Z} = \mathrm{G1} + \mathrm{G2}$$

Constraints

The model has seven constraint groups and they are given below.

C.I: Computing width of a variable; the group computes the width of each variable and assigns the results to a variable to minimize TR_i*Si. $\boldsymbol{TR_i} - \sum\left(\boldsymbol{R^m_{i,j}} + \boldsymbol{R^p_{j,i}}\right) = \mathbf{0}$. The computation is made between variables that have a connection to each other arising from sharing a constraint. For example, because of the constraint M+(*amtA, pressureA*), there is a dependency between *amtA* and *pressureA*. *RamtA_pressureA_p* represents *amtA* comes before *pressureA* in the sequence, and *RamtA_pressureA_m* does that for the opposite case. While we can mention that there is an *Rx_y_sign* variable for *amtA* and *pressureA*, we cannot do that for variables if there is no connection between them obtained by any constraint.

C.II: Ensuring two variables can be ordered only in one direction; two variables can be ordered just in one sequence so that one of them follows other. That means that if $\boldsymbol{R^m_{i,j}}$ is equal to **1**, then $\boldsymbol{R^p_{i,j}}$ must be equal to **0** or vice versa.

$$\mathrm{R^m_{i,j}} + \mathrm{R^p_{i,j}} = 1$$

C.III: Each variable can take one and only one place in a sequence; to be able to ensure that a variable takes only one place in a sequence and an order is reserved just for a variable, the following constraints are accommodated.

$\prod_{i=1}^{n} O_i = n!$ and $\sum_{i=0}^{n} O_i = n(n+1)/2$, where n is variable numbers.

C.IV: Putting the variables which have a minimum number of value set; $N_i = Val_i$.

C.V: Variables sharing the same constraint should be close to each other; $(O_i - O_{i+1})^2 = f_i$. The constraints are created between the variables that are parameters of the same constraints.

C.VI: Giving precedence to the known variables; each variable has a value assigned between L_0 and L_1. L_0 and L_1 are any possible order's bottom and top limit that a variable is allowed to be placed. The values are determined according to how many variables are known. The constraint aims to place the variables to the orders between the interval given by L_0 and L_1, and L_1 is greater or equal to the number of variables, which have value. The constraints are written in two alternative forms. The first form consists of two equations. The equations force variables to be ordered in the given order interval, in other words, they order the variables between L_0 and L_1. $\prod_{i=L_0}^{L_1} i = \prod_{i=L_0}^{L_1} O_i$ and $\sum_{i=L_0}^{L_1} i = \sum_{i=L_0}^{L_1} O_i$. The second form of constraints are created as inequalities, and they try to keep the variable order between L_0 and L_1 in the form of $L_1 \geq O_i \geq L_0$ for each variable with a value.

C.VII: The variables must be integers; $\boldsymbol{O_i}\,\boldsymbol{i} = \mathbf{1}, \ldots, \boldsymbol{n}$ *the optimization model constructed for the U-tube problem, and it results the sequence as [flowBA, flowAB, amtA, pAB, amtB, pressureA, pressureB, total].*

Qualitative Solution for Optimization Model

The qualitative analysis that is called the Activity Analysis technique can be applied to a wide range of linear, nonlinear and constrained optimization problems. Besides that, it can be integrated with so many diversified numerical problems effortlessly (Williams and Cagan 1996a, b). The activity analysis technique is able to combine two search styles which are conventionally known as completely different from each other. The first one deals with a strategic and conflict-based approach which is utilized in satisfying a search to remove finite and inconsistent subspaces, whereas the second style of search is much more related to tactical and numerical methods (Vanderplaats 1984) and is used in a continuous optimization search in order to find the optimal solution monotonously. In activity analysis, subspaces are cut out strategically with under favor of the power of perspective. Thereby, subspaces are excluded as suboptimal, and then the remaining subspaces are calculated by numerical methods. The main advantages of this technique are being able to remove the large suboptimal subspaces emerging from Qualitative Kuhn-Tucker (QKT) which can be defined as an abstraction of foundational Kuhn-Tucker (KT). The algorithm within the activity analysis technique provides simplicity and integrity by creating a linear assignment and qualitative vector equations. The leaving out of suboptimal subspaces reasonably results in conflict and prime implicant usage in order to meet the search. As a result, a model is developed which is capable of supplying economizer description, ensuring accuracy, and optimizing the filtration obtained from QKT. Lastly, activity analysis could be summarized as a technique that is able to automatize the embedded rules by using the simplex method in order to find a feasible linear space. In the next phase, these rules are generated and implemented for nonlinear problems. KT conditions (Kuhn and Tucker 1951) include a vector equation set which meets completely a feasible point $\boldsymbol{X}^*$ when the point is constant (Table 2). Due to KT being inadequate when the condition of a point is constant, Qualitative Kuhn-Tucker is derived from KT. Differently, from KT, a qualitative feature is included in QKT to check at each point $\boldsymbol{x}$ whether every constraint is efficient at $\boldsymbol{x}$ or not. Besides that, the quadrant of the coordinate axes of each gradient $\nabla \boldsymbol{f}$, $\nabla \boldsymbol{g}$ and $\nabla \boldsymbol{h}$ is inserted into QKT. It is also possible to develop these features easily, keep them for the large subset of the feasible space on an equal basis, and systematize it for all sorts of optimization problems. This mathematical approach behaves as it was expected when the sign algebra and traditional matrix algebra are considered (Williams and Cagan 1996b). QKT is an improved version of KT providing a feasible point $\boldsymbol{X}^*$ being stationary only if QKT conditions are satisfied. Objective function $(\boldsymbol{f})$, equality constraints (h_i) and inequality constraints $(\boldsymbol{g}_j)$ are the functions of $\boldsymbol{x}$, and $\boldsymbol{x}$ is the vector (all variables of the model)$^{\mathrm{T}}$. The steps of the solution are as follows: (1) Compute Jacobian matrixes $\nabla \boldsymbol{f}, \nabla \boldsymbol{h}$ and $\nabla \boldsymbol{g}$ by symbolic differentiation, (2) Compute signs of Jacobians, and (3) Enhance QKT1 by adding matrix sums and products.

Table 2 Quantitative and qualitative KT conditions

Quantitative KT conditions	Qualitative KT conditions
KT1 $\nabla f(X^*) + \lambda^T \nabla h(X^*) + \mu^T \nabla g(X^*) = 0^T$ Subject to KT2 $\mu^T g(X^*) = 0^T$ KT3 $\mu \geq 0$ Where $\boldsymbol{h}$ and $\boldsymbol{g}$ represent equality and convex inequality constraints, respectively	QKT1 $[\nabla f(X^*)] + [\lambda]^T [\nabla h(X^*)] + [\mu]^T [\nabla g(X^*)] \supseteq 0^T$ Subject to; QKT1 $[\mu]^T [g(X^*)] = 0^T$ QKT2 $[\mu_i] \neq \hat{-}$ Where the sign vector $[\boldsymbol{v}]$ symbolizes the sign of the elements of $\boldsymbol{v}$: These are $[\boldsymbol{v}_i] \in \{-, 0, +\}$

In activity analysis, we look for $[\mu_i] = +$ to turn a related $\boldsymbol{g_i}$ constraint inequality into an equality constraint. This makes the search space narrower and the process faster. In the U-tube example case, $h = (h_1, h_2, \ldots, h_n)^T, \quad g = (g_1)^T$. The resultant sign matrixes are;

- $f(Number\ of\ Variables) = 44$ (a vector)
- $h(Number\ of\ equality\ Constraints \times Number\ of\ Variables)$
- $g(Number\ of\ inequality\ Constraints \times Number\ of\ Variables)$

All members of the $[\nabla \boldsymbol{f}]$ vector is equal to $+$. In the U-tube example, the approach gives a superior advantage by saving computation effort even though the model has just one inequality constraint. Before turning the inequality constraint $\boldsymbol{g}_1$ into an equality constraint (without doing activity analysis) the optimization model is solved in 2421 iterations, but as a result of activity analysis turning $\boldsymbol{g}_1$ into an equality constraint, the same objective value is reached in 301 iterations ($\sim$12% effort). If the inequality type constraints used in constraint group VI are given as alternative constraints, instead of equalities, the optimal result is reached by 195,411 iterations, and it does not give a better result in the case of equalities used. Since the group VI constraint set consists of inequality type constraints, it determines the optimization performance. The solution performances based on number of iterations are given in Table 3. Since inequality type constraints are seen in the group VI constraint set, the performance is determined based on the set.

Table 3 Solution performance

Case#	Applied constraints	Performance (iterations)	Percentage
1	Equality type constraints are used (the first form)	674	0.34
2	Inequality type constraints are used	197,371	100
	Inequalities are turned into equalities		
3	One constraint is turned into equality	29,613	15.0
4	Two constraints are turned into equality	21,532	10.9
5	All constraints are turned into equality	4286	2.17
		Average	7.15

As seen in the table, Case #1 gives the best performance regarding the number of iterations. In Case #2, we have two inequalities for each variable. Because of the fact that it increases inequalities, the model gives the worst performance. After a qualitative analysis, the inequalities in Case #2 are turned into equalities using qualitative analysis and Case #3, Case #4, and Case #5 are obtained. It is obvious that fewer constraints and equality type constraints give better results, and that is why qualitative analysis tries to turn inequalities into equalities. The last column in the table shows the percentage of the iterations according to the worst solution. In our case, any constraint that is turned into an equality constraint from an inequality constraint gives a solution. Because of that, activity analysis results in a convex set and finds an optimal solution. Turning inequality constraints into equality constraints by setting a combination of the order automatically results in optimal orders and one of them is the best solution. Solving the model by keeping inequality constraints gives the best result directly, but it consumes the most processing time. Since the model is open to defining user-defined constraints, in the case of an increase in the number of inequality constraints defined by users or numbers of the variables with known values, qualitative activity analysis improves the processing time-saving more and more. The soft computation nature of the problem and the search process on the solution tree are the main reasons of the choice of Prolog. In the literature there are some soft CP approaches and software tools, such as fuzzy CP (Fuzzy Prolog) (Guadarrama et al. 2004), and in a part of this study, for both qualitative simulation and qualitative CP, that is why Prolog is chosen as a development language (Hocaoğlu 2000).

Conclusion

While the optimization model template represents quantitative optimization models to order variables in a way that the variable sequence gives minimum backtracking and consequently a fast solution for the CP process, the qualitative optimization model counterpart of the quantitative model is solved to make the quantitative model solution fast by eliminating suboptimal spaces. The numerical result shows that solving the optimization model with the guidance of the qualitative optimization model saves approximately 83% computation time for our example, and propagation on the ordered variable set saves up to 85% computation time. The model can be solved in two different ways. The first way is the case there is a set of variables with known values. In this case, the goal is to put the known variables in the first part of the order to be able to propagate their values to determine the rest of the variable values. The second way is the case there is no variable with a known value. This case gives the optimal propagation order, and it determines which variable(s) should be known to be able to have the fastest propagation order. It is possible to use the optimization model in any CP problem that has a set of variables with a set of discrete values. Because of its success in pruning mathematical spaces that do not consist of the extremum point, activity analysis has a general usage in nonlinear optimization problems. The analysis makes the solution faster because it turns the problem of searching extremum points in a set into searching them on a set of equations.

Finding a fast solution for CP problems is important, especially, for real-time systems. As an example, qualitative simulation is used for process control purposes (Vescovi et al. 1997). In this usage, the initial state is defined by the variables that their values have from the process to be controlled. Any snapshot situation of the process is accepted as an initial state, and possible behaviors for some time later of the process is attempted to predict. The difficulty in picking the variable values up at any time and in the impossibility of measuring some variables values directly make both the input set and even the information about the constraints describing the system behavior incomplete. CP procedures help modelers to find under these circumstances the initial state for qualitative simulation models.

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On Copula Based Serial Dependence in Statistical Process Control

Ozlen Erkal Sonmez and Alp Baray

Abstract Copula is a distribution function on the unit hypercube with uniform margins. The margin is directly related to the stochastic behaviour of one variable, while joint distribution function covers the holistic character of more. In multivariate (and particularly bivariate) analysis, using copulas is an elegant way to solve the missing information problem between joint distribution function and the total of the margins. Hereby, the intention of this paper is twofold. Firstly, the paper intends to emphasize the advantages of copulas in practice. In order to encourage potential researchers to diversify their subject of work with these functions, authors give the essential introductory details for a clear understanding of copulas associated with their basic mathematical and statistical preliminaries. Secondly, the study exemplifies the practical usage of copulas in statistical process control area. In this context, process parameters are estimated in order to calculate the control limits of a typical Shewhart type control chart. Parameter estimation is performed by Maximum Likelihood Estimation (MLE) for the bivariate Clayton copula in univariate AR (1) time series with several different levels of high dependence. Since monitoring autocorrelated data in control charts is known as being one of the main causes of producing tighter control limits than required, false alarm rate may be increased and accordingly, the performance of control charts may be dramatically decreased. This study shows that copulas may alternatively be used for getting the same or little wider acceptable region between upper and lower limits. This recognition of the properness of copulas may help to decrease some of the negative effects of dependent data being monitored on charts for further studies.

Keywords Autocorrelation · Control charts · Copulas · Dependence
Statistical process control (SPC)

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_11

Introduction

Normality and Independence are the prominent two assumptions in conventional quality control aspect (Psarakis and Papaleonida 2007). A dependency exists when two or more successive observations are dependent on the previous ones partially or serially. Dependency may cause some disruptive effects in the mechanisms of data monitoring systems. Typically, such tools may be also used for monitoring and the improvement of the processes mainly for a wide range of quality applications in the industry within statistical process control (SPC) context. More specifically, conventional control chart applications are generally performed under the assumption of 'no correlation exists' between the consecutive observations (Del Castillo 2002). Hence, the charts may negatively respond to the existence of autocorrelation in the data related to the quality characteristics observed. In fact, even small levels of autocorrelation may have some significant effects on the statistical properties of control charts (Psarakis and Papaleonida 2007).

When 'Independence' assumption is not satisfied, it is clear that some standard procedures should be changed or adapted somehow in order to handle the potential negative effects of autocorrelation or serial correlation. In fact, this is a well-known and continually emphasized problem in SPC literature. Notably, many researchers look for the urgent remedy for different cases of autocorrelation in many applications on control charts (Lu and Reynolds 2001; Shu et al. 2002; Knoth and Schmid 2004; Box and Narashiman 2010; Huang et al. 2013, 2016; Franco et al. 2014; Prajapati and Singh 2016; Lu 2017; Maleki et al. 2017a, b; Hussein et al. 2017; Albaraccin et al. 2017; Kao 2017; Triantafyllopoulos and Bersimis 2017; Chen et al. 2018).

Against all and more of these efforts, the correlation in data has still been a very frequent case in practice. Simply, the production type itself set a substructure up for autocorrelation to occur. Especially in continuous processes, dependency in data often exists inherently (Emura et al. 2016) Apart from these, without any other motivation, just the dynamics of processes may even cause the existence of autocorrelation (Psarakis and Papaleonida 2007). Moreover, some sampling techniques and technologies may also support the issue (Franco et al. 2014). It may also be nourished by the ever developing data collection tools which are generally capable of frequent sampling and consecutive data storing techniques nowadays. Therefore, in this era, it becomes more possible to store and analyze sequential industrial data which is mostly serially correlated. Since dependency has been regarded as a current problem for the control charts, autocorrelation should be meticulously considered in practice.

Generally, the aim of any control chart is to detect the changes in time (Verdier 2013). Therefore, accuracy is one of the key factors for the performance evaluation and comparison of control charts, as well as being also their design factor. Hence false alarms are not desired and false alarm rate (FAR) is tried to be decreased significantly. However, correlated data generally results in an increasing FAR of quality control charts, mainly because of the generation of tighter control limits than required (Psarakis and Papaleonida 2007). Hereby, tighter limits define a tighter acceptable region, while a wider area is generally needed. In that case, although the status is not ‘out of control’ in reality, an observation may give an out of control signal for that control chart. Moreover, control charts may also not be efficient or rapid enough to detect the return to ‘in control’ status than ‘out of control’ for the same reason. The accuracy and efficiency of charts may be damaged in this way. Finally, the performance and ability of the chart for detecting changes in time decrease substantially.

In general form, the core of copula theory was introduced by Sklar in 1959. His efforts were connected with the studies of Frechet, Hoeffding and others on joint distribution functions (Sklar 1973). Sklar mainly defines copulas from two different perspectives:

1. Copulas are the functions to merge multivariate (and so multidimensional) distribution functions to their 1-dimensional margins.
2. Copulas are the multivariate (or bivariate) functions whose margins (U[0,1]) are uniformly distributed on the [0,1] interval (Nelsen 2006). By this way, random variables over a common probability space may be defined as connected (Sklar 1973).

Copula functions are fundamental tools which may be used for dependence (correlation) modeling. They also inherently take part in describing the dependence between the extremes (Embrechts 2009). In this study, copula functions are used in order to estimate the process parameters when the series observed have an auto-correlation structure. Authors initially propose the general introductory information about copula functions in order to ensure a clear understanding of the theory. In this way, potential researchers from a very wide range of disciplines would be informed about the advantages and potential benefits of copulas. Afterwards, study inclines to a more specific area, statistical process control, in order to emphasize the advantages of the usage of copula functions for the generation of typical 3-sigma limits for a Shewhart type chart operating under copula based dependence.

Copulas

Copulas are mainly bivariate or multivariate functions with some specific properties. They enable to signalize the dependency structure apart from its marginal distributions (Emura et al. 2016).

Behind the copula theory, there are some significant preliminaries and conditions. These are defined both in the statistical and mathematical base. Copula functions are generally used as a linking tool for joining other functions and are closely related to the distributions with “given margins”. Hereby, a margin (or marginal distribution) represents the individual stochastic behaviour of one variable, while joint distribution function shows the holistic character of more variables.

In multivariate (and particularly bivariate) analysis, using copulas is an elegant way to resolve the missing information problem between joint distribution function and the total of the margins.

For the two dimensional (bivariate) case of a pair of random variables like X and Y, distribution functions are $F(x) = P[X \leq x]$ and $G(y) = P[Y \leq y]$ respectively. Then, their joint distribution function is $H(x, y) = P[X \leq x, Y \leq y]$. For any pair of random numbers $F(x)$, $G(y)$ and $H(x, y)$ values may be attained in that case. Because they are all probability distributions, these attained values are all in [0,1] interval. Then, each pair of $(x,\ y)$, random numbers indicates a point within the form of $(F(x), G(y))$ in $[0, 1] \times [0, 1]$ unit square. This ordered pair points out the value of $H(x, y)$ in [0,1]. The relation which assigns the value of joint distribution function to each ordered pair of individual distribution functions is also a function itself, called copula (Nelsen 2006).

Within the conditions of the theory, Sklar's Theorem indicates that copula is a function like C from an m dimensional m-cube (hypercube) to the $[0, 1]$ interval (Trivedi and Zimmer 2005). Therefore, copula may be defined as a distribution function on the unit hypercube with its uniform margins (Lee and Joe 2018). Although the original datasets have different types of marginal distributions initially, comparing the dependence structures may be possible by standardizing the margins into uniform distributions. This would be useful in order to detect the similarities of dependence structures (even visually) in some cases. Supportively, the ranks of the observations also do not change by transforming the margins with the increasing transformations. This gives the researchers flexibility in the adjustment of margins without changing the exact dependence structure (Embrechts and Hofert 2012). Researchers and decision-makers have then a flexibility while forming an initial point also for their simulation studies.

For the 2-dimensional (bivariate) case, the following conditions may be listed behind the copula theory:

1. H is a nondecreasing (2-increasing (quasi-monotone)) function.
2. H is a function whose domain Dom$H = S_1 \times S_2$ is a subset of $\bar{R}^2$ and whose range Ran$H$ is a subset of $\bar{R}$ in I^2. ($\bar{R}$ is the extended real line of $(-\infty,\ +\infty)$, $\bar{R}^2$ is the extended real plane, I^2 is unit square of $[0, 1] \times [0, 1]$, S_1 and S_2 are nonempty subsets of $\bar{R}$.)
3. H is a grounded function (H is grounded when $H(x, a_2) = 0 = H(a_1, y)$ for all (x, y) pairs while a_1 and a_2 shows the least elements of S_1 and S_2 respectively.) Grounded property indicates that if the margin of any outcome is zero, then the joint probability of all outcomes is zero (Trivedi and Zimmer 2005).
4. H has margins like F and G given by Dom$F = S_1$ and $F(x) = H(x, b_2)$ for all x in S_1 and Dom$G = S_2$ and $G(y) = H(b_1, y)$ for all y in S_2, while b_1 and b_2 shows the greatest elements of S_1 and S_2 respectively (Nelsen 2006).

Copulas in Statistical Process Control

Since they had been developed, copula functions are regarded to be very popular tools in statistics (Perrone and Müller 2016). These fundamental functions may be used in many areas from different disciplines, including to model the nonlinear relations, asymmetricality or tail dependency (Sukparungsee et al. 2018). Although the correlation coefficient is one of the prior alternative measures in order to define the dependency structure, it can not always be the proper measure for the data analyzed. Copulas operate a different kind of dependency measure, considering not only the linear correlations but also the nonlinear ones (Nelsen 2006). Therefore, inference for the dependency structure may potentially be enhanced by these functions.

Especially in comparison to some frequently preferred areas for copula based applications in the literature (such as risk management in financial applications), statistical process control still remains as a *relatively* demanding research area for copulas. In fact, in statistical process control, mainly a risk management effort is made within the statistical dynamics of charts. Actually, from an intuitional perspective, copulas and copula applications may be regarded as convenient also for statistical process control. Fortunately, the current (and relatively novel) literature supports this argument (Kuvattana et al. 2015a, b, c, 2016; Kuvattana and Sukparungsee 2017; Busababodhin and Amphanthong 2016; Fatahi et al. 2011, 2012; Dokouhaki and Noorossana 2013; Hryniewicz and Szediw 2010; Hryniewicz 2012; Verdier 2013; Emura et al. 2016). However, the necessity for more of emerging studies in SPC and control charts for copula applications can not be ignored.

Copula Based Parameter Estimation on a Shewhart Type Chart for Dependent Data

To monitor the stability of the mean of a process in simple classical case, $\bar{X}$ the chart may be used within Shewhart type charts. In Shewhart charts, n subsamples are taken from the process with a specific frequency. If the model is defined in the classical way (without any other assumptions), then the errors and averages for these n's are expected to be normally distributed. To monitor the process, averages are plotted in time order on $\bar{X}$ chart with its limits at $\mu \mp k\sigma_{\bar{X}}$. If μ and $\sigma_{\bar{X}}$ are unknown, then they are usually estimated with $\hat{\mu} = \overline{\overline{X}}$ and $\sigma_{\bar{X}} = \frac{\bar{R}}{d_2\sqrt{n}}$. $\overline{\overline{X}}$ shows the average of averages of samples and $\bar{R}$ shows the average range of samples. d_2 depends on the sample size and is a bias correction factor to estimate $\sigma_{\bar{X}}$. For $2 \leq n \leq 9$ interval $d_2 \approx \sqrt{n}$ is generally a good approximation. However, if no subgroups are defined and subgroup size is kept equal to 1 $(n = 1)$, then individual measurements are plotted on the chart with the limits at $\bar{X} \mp k\frac{\bar{R}}{d_2}$ where $\bar{R}$ is the average of moving ranges by artificial samples of size 2 and the constant d_2 is equal to 1.128 (Del Castillo 2002).

In the study, subgroup size n is assumed as 5 for the data which is randomly generated for 5 scenarios for different levels of high correlation. The concept of 'high correlation' is categorized into two sections as 'high' and 'very high' dependence. Hereby, high correlation includes 0.80 and 0.85 values for the Lag 1 correlation coefficient, while very high correlation includes 0.90, 0.95 and 0.98 values. Generation of normally distributed time series within these specific correlation levels is performed by Arima.sim function. All the random observations are positively preferred for the sample size N, which is selected as 500, for all the scenarios.

Parameter estimation is performed by Maximum Likelihood Estimation (MLE) for the bivariate Clayton copula in univariate AR(1) time series with a high level of autocorrelation. MLE is an applicable and suitable technique, especially for SPC applications. Its convenience is indicated by (Emura et al. 2016). In this study, Clayton is preferred mainly because of its popularity and tractability within other copula types. Clayton MLE is conducted on R via 'Copula.Markov' package introduced by (Emura et al. 2016).

The study mainly exemplifies the practical usage of copulas in statistical process control area in order to compare the known and estimated parameters for the calculation phase of $k = 3$ (typical 3-sigma) control limits for Shewhart type control charts under Clayton copula dependence.

An equation for one parameter Clayton copula is given below. Herein, $\propto \in (-1, \infty)\backslash\{0\}$ represents the dependence measure between first ordered successive random observations. I is the indicator functions for margins. u_1 and u_2 are the transformed random variables (Emura et al. 2016).

$$C(u_1, u_2; \propto) = (u_1^{-\propto} + u_2^{-\propto} - 1)^{-\frac{1}{\propto}} I(u_1^{-\propto} + u_2^{-\propto} - 1 > 0)$$

MLE maximizes a log-likelihood function for the current data for any chosen copula. This maximation is conducted automatically by Newton-Raphson Algorithm within the package. Lower control limit (LCL) and Upper control limit (UCL) are calculated via $LCL = \hat{\mu} - 3\hat{\sigma}$ and $LCL = \hat{\mu} + 3\hat{\sigma}$ equations respectively. When the likelihood function gives a proper solution, gradients are almost equal to zero. Moreover, negative definite Hessian matrix guarantees that MLE attains a local maximum of log-likelihood which may both be obtained within the routines of Copula.Markov.

Hereby, Table 1 shows the known and estimated parameters calculated via the package and related indicators for the accuracy of estimation. Copula.Markov package ensures a certain practical implementation ease, especially for the complex computations of (first and second) derivative expressions for Clayton the copula (Emura et al. 2016).

Table 1 Known and estimated parameters and indicators for the accuracy of estimation

	High dependence		Very high dependence		
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Correlation (Lag 1)	0.80	0.85	0.90	0.95	0.98
Known parameters					
Mean	2.509591	3.266208	4.902973	9.317552	23.914
Standard deviation	0.5142909	0.514411	0.6437819	0.7593598	1.473462
Upper control limit (UCL)	4.052464	4.809441	6.834319	11.59563	28.33438
Lower control limit (LCL)	0.9667181	1.722975	2.971627	7.039472	19.4936
Acceptable region between UCL and LCL	3.085746	3.086466	3.862692	4.556158	8.84077
Estimated parameters via Clayton MLE					
Mean	2.6222436	3.266208	4.9029733	9.3175515	23.913999
Standard deviation	0.5231647	0.514411	0.6437819	0.7593598	1.473462
Upper control limit (UCL)	4.1917378	4.809441	6.8343191	11.5956308	28.334384
Lower control limit (LCL)	1.0527494	1.722975	2.9716275	7.0394723	19.493614
Acceptable region between UCL and LCL	3.138988	3.086466	3.862692	4.556159	8.84077
Indicators for the accuracy of estimation					
Gradient	Almost equal to zero	Almost equal to zero	Almost equal to zero	Almost equal to zero	Almost equal to zero
Hessian matrix	Negative definite	Negative definite	Negative definite	Negative definite	Negative definite

Results

Discussion and Conclusion

The resulting table of the study (Table 1) reveals very close approximate values for the known and estimated parameters for all scenarios. As also compatible with the ideal case indicated in the literature, copula based approximation (estimation) values suggest an equal or little wider acceptable region between upper and lower control limits for each scenario of different levels of high correlation. This recognition may help to decrease some of the negative effects of dependent data being monitored on charts in further studies.

In fact, copulas have been very popular as fundamental dependence functions since they had been theorized by Sklar in 1959. They may be used as an alternative dependency modeling tool which may welcome the convenience of the studies in many different areas. They are the special linking functions which may be used for transforming the representation structure of dependence or correlation.

Although numerous applications of copulas are available so far, the complex mathematical and statistical background of the theory may also discourage researchers from specific disciplines especially in the preliminary phase. With this aim, this study initially renders the base for the copula theory.

Besides other disciplines, copula functions may also appropriately be used for dependence analysis on dependent data for SPC. Because serial dependency in data simply violates the 'Independence' assumption in standard applications of SPC, it is a widely investigated critical issue on statistical quality control area from past to nowadays. However, in comparison to other copula applications, copulas for SPC is *relatively* a novel and demanding research area.

This study emphasizes the necessity within the current literature and proposes a practical implementation in SPC.

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Analyzing Pipe Production Fault Rates by Association Rules and Classification According to Working Conditions and Employee Characteristics

Deniz Demircioglu Diren, Hussein Al-Sanabani and Tugcen Hatipoglu

Abstract In order to survive in a competitive environment, companies are required to increase the productivity by identifying the factors that affect the failure rates. In this study, fault rates of a pipe manufacturing company are investigated. Therefore, based on data attributes such as demographic characteristics of employees, employee training, physical working conditions, social facilities etc. were gathered. Briefly, data were analyzed by association rules, correlation, and various classification algorithms. The association rules, measurements, and correlations of attributes are examined to understand the current situation. Then, based on this information, various classification algorithms have been used for estimation. The higher accuracy of the prediction, the greater results will occur. Therefore, the accuracy of the classification algorithms is compared and the algorithm with the highest performance is achieved.

Keywords Association rule technique · Classification algorithm
Predictive model · Descriptive model

Introduction

Data mining techniques are disciplines that are used to obtain meaningful results through computer programs from data entry for the purpose determined by the experts. It defines data analysis as the process that produces information that raw

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_12

data cannot afford (Jacobs 1999). In this process, firstly the problem is defined and the data set is created. Then the model is established, monitored and analyzed for the solution of the problem (Shearer 2000). The field of application of data mining techniques is very broad and involves many different disciplines. There are lots of studies about data mining like as; quality control (He et al. 2013), medicine (Sona and Ariya 2014), education (Romero and Ventura 2013), financial analysis (Kovalerchuk and Vityaev 2005) and credit scoring.

Data mining techniques can be divided into two main model types like, predictive and descriptive. Predictive models try to understand the future and address the questions of "what could happen?" and descriptive models try to understand the past and address the questions of "what has happened?". Classification and regression models are predictive, clustering and association rules are descriptive models (Agyapong et al. 2016).

Classification and regression are supervised methods that provide models that predict future conditions by using current state data. Classification is a model that allows analyzing a set of classes by classifying them according to the attributes that used to achieve the specified target value. Classification is used to estimate categorical data and regression is used to estimate continuous data (Han and Kamber 2001).

The most commonly used classification techniques are (Dreiseitl et al. 2001; Wang 2008; Bhavsar and Ganatra 2012; Sathya and Abraham 2013);

- Artificial Neural Network
- Decision Trees
- K-Nearest Neigbor
- Navie Bayes
- Support Vector Machines etc.

Clustering and association rules are unsupervised methods, unlike classification and regression. This is the main difference between these two methods. In clustering technique, the data are grouped according to their similarities without pre-defined classes It is desired that the similarities within the cluster are high and the similarities between the clusters are low (Han and Kamber 2001). In addition to the importance of similarities in the data set, there is a great deal of interest in the relationships between attributes. Association-relationship rules are the technique used to obtain unrecognized relationships between attributes because of the large database (Sinthuja et al. 2017). There are many applications in various areas with the association rules (Rajak and Gupta 2003) and some studies show that using this relationship and rules is providing great benefit to the firm, such as low production mistakes, more accurate sales policies, and increased profits (Lau et al. 2009; Djatna and Alitu 2015).

In this study, it is aimed to investigate the effects of 19 attributes (such as demographical characteristics, working conditions, training, and social facilities) on the wastage rates in the production of a plastic pipe manufacturing company. Hence, first, the current condition of the process is described by using association rules and correlation analysis and the most effective attribute has been detected. Then, various classification algorithms are used to estimate the waste rates of future situations. It is proposed to use the most successful algorithm by comparing the performances of the algorithms.

Methodology

In this study, the proposed model consists of three step.

1. **Preparing of useable data set by data collection and reduction**: Reduce unnecessary data are obtained from collect by questionnaire.
2. **Identification of the current condition**: Association rules, weights, and correlations techniques are used for this step.
3. **Comparison of classification algorithms for predictive of future conditions**: Random forest, gradient boosted trees, naïve bayes, deep learning, decision tree algorithms were used for this step.

The architecture of the proposed model is shown in Fig. 1.

Association Rules Technique

The association rules are used to find interesting relationships or correlations between large data sets. The Association Rules identify frequent feature values within a given set of data. The mathematical model of the association rule was presented in 1993 (Agrawal et al. 1993). The most basic example of this technique is basket analysis. The aim of analysis is to find out the purchasing habits of customers by finding positive and negative correlations between products.

Two basic attributes of association rules are two fold, support, and confidence. The rules are generated to provide the user-specified min threshold for these attributes. Support is defined as the fraction of item set to the overall transaction in the database. Support account is shown in Eq. 1. Confidence is respect to

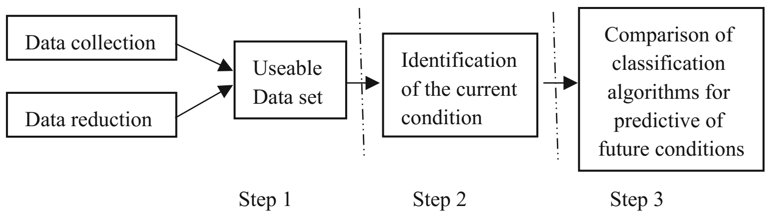

Fig. 1 The proposed model

transaction T that contains x which also contains y. Shown in Eq. 2 (Foguem et al. 2013).

$$\text{Support}(X \to Y) = \frac{\text{Count}(X, Y)}{n} \tag{1}$$

where n is the number of the transaction in the dataset

$$\text{Confidence}(X \to Y) = \frac{\text{Count}(X, Y)}{\text{Count}\, X} \tag{2}$$

When generating rules, it is important to choose the appropriate algorithm besides support and confidence attributes. The main algorithms are the Apriori (Agrawal et al. 1993), Eclat (Zaki 2000) and FP-Growth (Han et al. 2004) algorithms.

In this study, the FP-Growth is used. The major advantage of the FP-Growth over the Apriori is the capability of scanning large datasets which uses only 2 data scans (https://docs.rapidminer.com).

Predictive Algorithms

In this study, classification algorithms are used to predict future conditions. According to the observed characteristics of a sample, a predetermined class assignment is called classification. Many classification algorithms have been applied and the most suitable ones have been compared with random forests, gradient boosted trees, naïve bays, deep learning and decision trees, and the accuracy of these algorithms have been compared.

Results

Preparing for Training Data Set

The dataset includes the demographic characteristics of the employees in a pipe manufacturing company, the social-physical environment and management satisfaction from the firm, the product group and types produced in the firm, and the faulty rates and related information. There are 82 lines and 19 attributes. Data reduction and preprocessing were used for managing missing values and clearing the noisy. Examples of these are presented in Table 1.

The fault_rate attribute is the target attribute for this study. This attribute was discretizing by frequency into three range (range 1 [0.02–0.085], range 2 [0.085–0.145], range 3 [0.145–0.4]).

Table 1 Type and range of attribute

Attribute	Type	Range
Fault_rate	Real	[0.02–4]
Sexuality	Boolean	{0 = female, 1 = Male}
Age	Integer	{1 = 18–28, 2 = 29–39, 3 = 40–50, 4 = 51 and older}
Educational_level	Integer	{1 = primary school graduate, 2 = general high school, 3 = technical high school}
Work_experience	Integer	{0 = 0, 1 = 1–3 years, 2 = 4–6 years, 3 = 7 years and over}
Physical_conditions	Integer	{0 = bad, 1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Cooperation	Integer	{0 = bad, 1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Social_facilities	Integer	{0 = bad, 1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Health_care	Integer	{0 = bad, 1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Rewarding	Integer	{0 = bad, 1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Teamwork	Integer	{0 = bad,1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Suggestion_support	Integer	{0 = bad, 1 = not (so) bad, 2 = good, 3 = very good, 4 = perfect, 5 = no idea}
Participation_in_management	Integer	{0 = limited, 1 = average, 2 = high}
Number_of_education	Integer	{0–9}
Warning	Boolean	{0 = there is, 1 = there is not}
Warning_after_education	Boolean	{0 = there is, 1 = there is not}
Product_group	Boolean	{0 = pvc, 1 = pprc}
Product_type	Boolean	{0 = pipe, 1 = rider}

Identification of the Current Conditions

For identification association rules, network chart, weights values, and correlations were used with Rapidminer 8.1.001. These software platforms include data preparation techniques, statistical and prediction methods and machine learning techniques was used to obtain the results of this study. For the operation of the algorithm and to control the number of rules, it is necessary to determine the minimum support and minimum confidence values of the user. Support and confidence values were determined through trial and error in this study.

We implemented FP-Growth algorithm with (min support = 0.19, min Confidence = 0.6). The network chart of rules is shown in Fig. 2.

The association rules of the data set created using the FP-Growth algorithm. The algorithm's result gives us the rule that passes the thresholds of the min support and

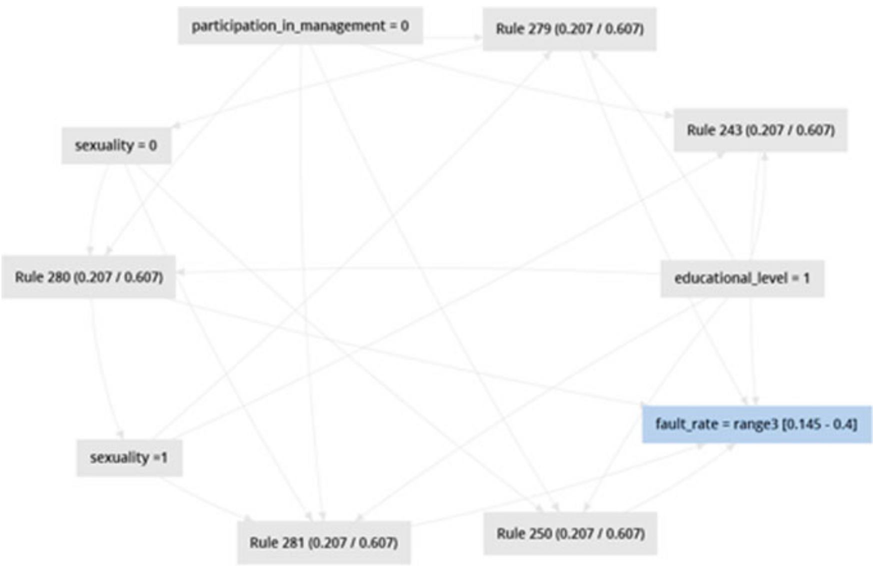

Fig. 2 Network chart of rules

min Confidence. By these results, the rules that have our target attribute (fault_rate) in its conclusion have been selected. However, because the range 2 [0.085–0.145] represents the natural state, it is excluded from the results only the result of range 1 [0.02–0.085] and range 3 [0.145–0.4] was showed.

The fault_rate attribute is the target attribute for this study. This attribute was discretize by frequency into three range (range 1 [0.02–0.085], range 2 [0.085–0.145], range 3 [0.145–0.4]).

This discretization is performed by equal frequency (Equal-depth) binning. It divides the range of continuous variable into *N* intervals, each containing an approximately same number of samples. Numerical values are assigned to the bin (interval) representing the range segment covering the numerical value. The Table 2 shows that the association rules of range 1.

The association rules that have range 1 [0.02–0.085] in its conclusion are presented in Table 3.

The first rule in Table 1 can be explained as flows:

If educational_level = 3. Then fault_rate = range 1 [0.02–0.085].

Table 2 The association rules of range 1

No.	Nomial value	Absolute	Fraction
1	Range 1 [0.02–0.085]	31	0.38095238095238093
2	Range 2 [0.085–0.145]	26	0.30952380952380953
3	Range 3 [0.145–0.4]	25	0.30952380952380953

It means that the fault rate is as low as possible when the level of education is a technical high school. The second rule in the table means that the fault rate is low when the participation in management is grater as possible.

The association rules that have range 3 [0.145–0.4] in its conclusion are presented in Table 4.

Table 4 shows that fault rate is maximum when the level of educational is primary school graduate and/or when there is not participation in management. It also shows that the sex does not affect the fault rate. Figure 2 shows these results.

The association rules result show that the most affected attributes of the fault_rate are the educational_level followed by participation_in_management.

The weights which determined via correlation are shown in Table 5, means the global importance of each attribute for the value of the target attribute (fault_rate).

The most important attribute with the highest weight is the educational_level which is followed by participation_in_management. The submitted table confirms the results of the association rules.

To provide a better understanding of the data set, the matrix that shows the correlations between attributes is shown in Table 6.

As seen in Table 6, the most affected attributes that reducing the fault_ rate are educational_level, participation_in_management, work_experience, number_of_education, age, and product_type. The strong relationship between fault_rate, educational_level, participation_in_management is highlighted.

Table 3 The association rules of range 1

No.	Premises	Conclusion	Support	Confidence
1	Educational_level = 3	Fault_rate = range 1 [0.02–0.085]	0.207317	0.772727
2	Participation_in_management = 2	Fault_rate = range 1 [0.02–0.085]	0.195121	0.695652

Table 4 The association rules of range 2

No.	Premises	Conclusion	Support	Confidence
1	Sexuality = 1, participation_in_management = 0, educational_level = 1	Fault_rate = range 3 [0.145–0.4]	0.207317	0.607142
2	Sexuality = 0, participation_in_management = 0, educational_level = 1	Fault_rate = range 3 [0.145–0.4]	0.207317	0.607142

Table 5 The weights of attribute

Attributes	Weight
Educational_level	1.0
Participation_in_management	0.8322658286645787
Work_experience	0.7281868730240564
Number_of_education	0.7239727678635314
Age	0.5987201558664222
Product_type = 1	0.36160265099182304
Product_type = 0	0.36160265099182304
Warning = 1	0.2567164371592949
Warning = 0	0.2567164371592949
Product_group = 1	0.19477307023878498
Product_group = 0	0.19477307023878498
Health_care	0.1814345003762254
Cooperation	0.12013211485018485
Sexuality = 1	0.08657447356154577
Sexuality = 0	0.08657447356154577
Teamwork	0.06973058770982261
Rewarding	0.04375370939770539
Safety	0.032222145302034086
Social_facilities	0.02348631416774351
Suggestion_support	0.015075071578880491
Warning_after_education = 1	7.376427231872175E−4
Warning_after_education = 0	7.376427231872175E−4
Physical_conditions	0.0

Identification of the Future Conditions

Comparison of classification algorithms to develop the best scenario is applied by testing the dataset with random forest, gradient boosted trees, naïve bayes, deep learning, and decision tree predictive algorithms. The performance from the perspective of accuracy and execution time shows in Table 7 and graphical demonstration in Fig. 3.

The result shows that the random forest algorithm is greater. The model, developing by random forest algorithm, should be useful in making decisions on hiring new workers or changing existed workers' positions. Hence, the firm will be able to act proactively with the analysis.

Table 6 Correlations between attributes

Attributes	Fault_rate = range 1 [0.02–0.085]	Educational_level	Participation_in_management	Work_experience	Number_of_education	Age	Product_type
Fault_rate = range 1 [0.02–0.085]	1.000	0.609	0.471	0.445	0.434	0.365	0.263
Educational_level	0.609	1.000	0.652	0.070	0.235	0.071	0.154
Participation_in_management	0.471	0.652	1.000	0.416	0.629	0.220	0.264
Work_experience	0.445	0.070	0.416	1.000	0.821	0.669	0.299
Number_of_education	0.434	0.235	0.629	0.821	1.000	0.593	0.354
Age	0.365	0.071	0.220	0.669	0.593	1.000	0.167
Product_type	0.263	0.154	0.264	0.299	0.354	0.167	1.000
Product_group	0.152	0.116	0.036	0.184	0.169	0.285	0.281
Warning	0.144	0.203	0.075	−0.005	−0.069	−0.072	0.245
Social_facilities	0.053	0.234	0.226	0.142	0.194	0.088	0.184
Teamwork	0.013	−0.043	0.077	0.005	0.021	0.073	0.058
Warning_after_education	−0.011	0.056	0.026	0.036	0.048	−0.046	0.124
Physical_conditions	−0.013	0.121	0.042	−0.064	−0.044	−0.055	−0.140
Sexuality	−0.036	0.030	−0.040	−0.023	−0.042	−0.050	0.003
Suggestion_support	−0.040	−0.026	−0.074	−0.073	−0.147	−0.052	−0.125
Safety	−0.049	0.104	0.100	−0.091	−0.021	0.027	−0.029
Health_care	−0.111	0.067	−0.007	−0.158	−0.092	−0.224	−0.091
Rewarding	−0.146	−0.038	0.002	0.017	0.026	−0.049	0.002
cooperation	−0.189	−0.278	−0.155	0.051	0.013	0.105	0.088
fault_rate = range 2 [0.085–0.145]	−0.531	−0.206	−0.092	−0.146	−0.127	−0.114	−0.148

Table 7 Accuracy and run time of algorithms

Model	Accuracy (%)	Run time
Random forest	68.75	6.252 s
Generalized linear model	62.50	860 ms
Deep learning	62.50	951 ms
Naive bayes	56.25	85 ms
Gradient boosted trees	56.25	61.455 s
Decision tree	31.25	252 ms

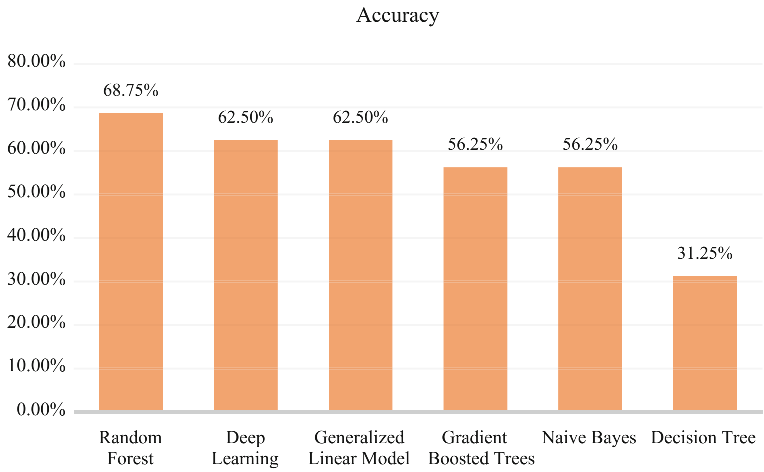

Fig. 3 Accuracy of algorithms

Discussion and Conclusion

The main purpose of this study is to be able to determine the future situation of the firm against the indefinite environment. Our second aim is to analyze the current situation. Thus, the firm will be able to act proactively with the analysis. The study consists of 2 stages. Firstly, analysis of the condition in the firm is applied to the rules of association, correlations, and weights. In the second stage, it is aimed to predict the future conditions and lead the firm by using various classification algorithms. The accuracy of the prediction has significant importance in terms of decision making. For this reason, the classification algorithms used in the study are compared in terms of prediction accuracy. The algorithm with the highest accuracy is determined as a random forest. In future studies, larger and more complex data sets and different classification algorithms should be used.

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Air Cargo Facility Layout Planning and Meta-Heuristic Solution Approach

Elif Karakaya and Fahrettin Eldemir

Abstract In recent years, with the increase of world trade size, the importance of the Air Cargo operations has increased even more. The rapid progression of air cargo transportation has caused development of intralogistics systems, the establishment of new facilities, the installation of new material handling equipment and facilities layout design issues. Although it is possible to reduce the system costs and increase the total cargo handling capacity with the facility layout planning (FLP) algorithms; it has been observed that the FLP algorithms have not been used in the airway cargo facilities designs. In this study, the air cargo facility design issue has been tackled as layout problem. Firstly, the existing layout algorithms in the literature have been addressed and then, FLPs have been taken into the consideration with the BlocPlan layout construction that is integrated with the Ant Colony Optimization (ACO) algorithm. In the application part of the study, the data of a major air cargo operator in Istanbul Airport data have been used and the transportation costs have been decreased with the proposed integrated FLP algorithm.

Keywords Facility layout algorithms · Air cargo · Ant colony optimization

Introduction

Air Cargo industry is developing rapidly. Demand for air cargo worldwide is increasing tremendously. In Istanbul, a new airport and cargo facilities are being constructed which should be designed such a way that the facility should respond to

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*, Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_13

the increasing demand and also should be competitive with the world from the decreased costs perspective.

For cargo terminals and facilities built at the airports, both physical structures and technology investments are critical. It is important that not only the operations in these facilities are properly planned and but also the technology is used correctly. While using the most contemporary technologies, the layout and the operations should be planned in the most correct way in line with the needs of the air cargo firms. By doing so, the maximum benefit should be obtained from the technology investments. The aim of this study is to optimize the layout and use of storage spaces in the cargo terminal and to enhance the use of material handling systems.

Within the scope of this study, four hypotheses have been tested which are listed below;

1. Air cargo facilities can be accepted as a case of facility layout problems and designed using various analytical model to minimize operational costs and maximize system capacity.
2. The Flexible Aisle Facility Layout Algorithms could be applicable for the air cargo facility layout problems.
3. The Ant-Colony Metaheuristics will generate efficient results in sequencing of departments in the facility. Therefore, the Ant-Colony Metaheuristics can be employed in Flexible Aisle Facility Layout Algorithms.
4. The usage of Ant-Colony Metaheuristics improvement for facility layout problems will decrease the operational costs in air cargo facilities.

Literature Review

The airline cargo industry becomes more important and a key facilitator of world trade with increasing need of transportation, which is understood by doubling in volume every 10 years since 1970 (Chang et al. 2007). In a similar way, Wong et al. noticed the growth rate of worldwide air cargo transport is 50% more than passenger transport growth rate between 1995 and 2004 (Wong et al. 2009). This growth has holdout in recent years. IATA data endorses the findings of airline cargo that 36% of commodities traded worldwide transported by air (IATA 2006). Airfreight forwarding is becoming an important source of revenue for airlines (Han et al. 2010; Nobert and Roy 1998). While the profitability rate in the sector was only 5% in 2000, it increased to 40% in 2009. According to the forecasts made by the Boeing Company in 2013 (Boeing 2014), the air cargo market will continue to grow at 4.7% per annum and the annual revenue of US$207.8 billion per kilometer (RTK) will reach 521.8 billion. It is estimated that it will rise to nearly three times the sector’s volume (Fig. 1). Rapidly growing global trade, fast and timely delivery requests and companies’ low inventory retention efforts; this can be illustrated as an example of various factors that affect striking growth (Ou et al. 2010).

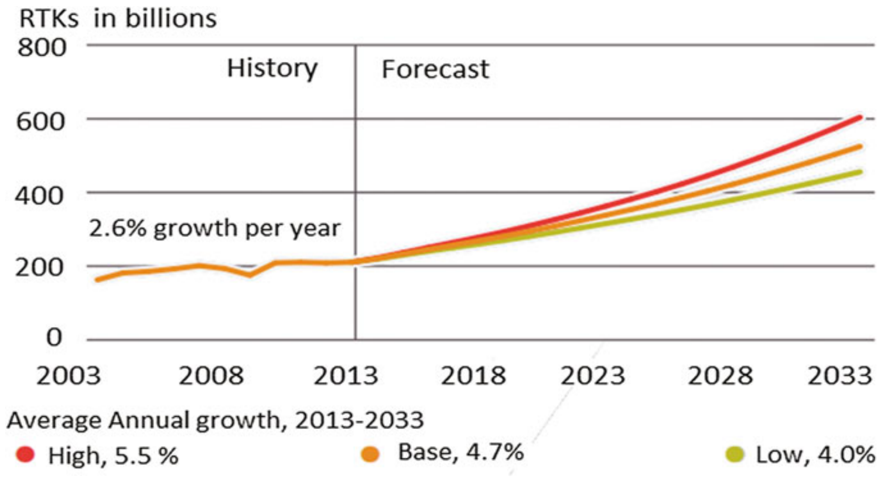

Fig. 1 Growth forecast of world air cargo transport

Methodology

The specific stages of this study could be summarized under three headings; (1) Constructing an efficient layout planning and design, (2) Development of Flexible Aisle Algorithms and (3) Integrating of BlocPlan with a nature inspired metaheuristic model.

In order to complete above stages, six basic steps are determined which are listed below comprehensively.

1. Data Collection and Analysis
2. Determination of the Departments and Space Requirements
3. Flow/Cost Analysis between departments
4. Facility Layout Problem and matching it with Air-Cargo operations
5. Flexible Aisle Construction Algorithm i.e. BlocPlan
6. Ant Colony Metaheuristic Model

In this section, firstly a general point of view of facility layout algorithms will be drawn and then BlocPlan method (as an example of layout construction algorithm for unequal department area problems) is defined under the headings of flexible aisle construction algorithms.

Facility Layout Algorithm

Facility Layout Problem (FLP) is accepted as a fundamental issue within the context of facility planning. Bozer et al. (1994) explained the scope of FLP as an arrangement of field of departments in terms of flows or relationships between each other by taking some requirements and constraints into the consideration.

The flow between departments is considered with the aspect of reducing the distance between departments with high flows. An efficient and effective design of a facility can reduce the time and effort that a system has to spend and it creates great advantages on material handling.

FLP has been studied by researchers for many years. Several methodologies have been tested in order to find the most efficient algorithm. There are two common facility layout algorithms; construction algorithms and the improvement algorithms. It can be said that improvement algorithms are more frequently encountered. since they have potential to utilize different heuristics. In this study, steepest-descent type improvement algorithms and meta-heuristics will have the focus on.

There is a large volume of published research on FLP. Singh & Sharma (2006) have been reviewed the literature in attempt to compare many facility layout approaches. Ahmadi & Jokar (2016) investigated the efficiency of mathematical programming for both single and multi-floor facilities. Besides, facility layout problems have been handled by using mix integer programming technique by Konak et al. (2006). Eldemir et al. (2003, 2004) studied on automated storage/retrieval systems by taking material handling issue into consideration accepted as an important part of FLP subject. Koopmans & Beckman (1957) were the first to model the problem of designing plants with material flow in equal area by using Quadratic Assignment Problem (QAP). QAP is used in a wide field of application including urban planning, control panel layout and wiring designs. The aim of the QAP is minimizing the transportation distances in the facility assuming that all departments have equal spaces, and all the priorities of layout, are known (Meller & Gau 2007).

Flexible Aisle Construction Algorithms

For Facility Layout Problems (FLPs) with unequal department areas, the QAP is inappropriate. For the unequal areas FLPs, the construction algorithms are used then they are improved by the steepest decent algorithm or metaheuristics. The most common construction algorithm for the unequal area FLPs is BlocPlan. BlocPlan generates a layout that has pre-determined number of aisles within a facility. Depending on the area requirements of departments within an aisle, the width of the aisle has flexibility. Therefore, these type of algorithms is called as Flexible Aisle Construction Algorithms.

BlocPlan was developed by Donaghey and Pire in 1991 and generates placements on the block type. The algorithm uses both the relationship chart and data to flow from-to chart as input. The cost of the layout can be calculated using the distance-based objective function calculated or adjacency-based objective function.

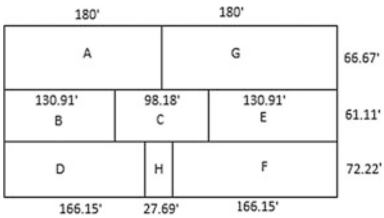

Fig. 2 As an example of flexible aisle layout design (Tompkins et al. 2010)

BlocPlan starts with pre-determined number of bands (aisles) but has the flexibility of placing departments in any band and in any sequence. Moreover, it is allowed to change the bandwidth (Tompkins et al. 2010).

Algorithms inputs are:

1. Number of departments
2. Area of each department
3. Flow between chart or relationship chart
4. Length and width values of the facility floor
5. Department sequence (Optional)
6. Fixed points of any department if it is available

The output of BlocPlan (Fig. 2) is proposed a layout and points of the layout shown with a graphically corresponding score. It is a very impressive layout design algorithm. It is used as a construction and improvement algorithm, providing great flexibility to the user. It can be used for both single-storey and multi-storey residential layouts (Diaz and Smith 2007).

BlocPlan type of construction algorithms needs improvement procedures. The Pairwise Exchange method is often preferred the improvement heuristic method. Sometimes it is referred as steepest decent algorithm. This method is not guaranteed to find the optimal layout. The final layout solution depends on the initial layout and this method does not consider the size and shape of departments. For finding the final layout, additional work has to be done by rearranging the departments if size and shape are not suitable.

This method can be used with both the adjacency-based and distance-based objectives. The purpose of this technique is to find the minimum material transportation cost between different departments. Usually, practitioners and scientist consider the distance between specific departments is rectilinear which is calculated by taking centroids points of equal predetermined department locations.

The pairwise exchange method defines iterations which include all feasible change combination of department pairs and then total costs are evaluated after each iteration and the pair that ensures the largest reduction in total cost is chosen for pair exchange before next iteration. If the lowest total cost of next iteration is greater than the total cost of the previous iteration, the iterations are terminated. Thus, final layout is determined.

Ant Colony Meta-Heuristic Approach

Metaheuristic are methods based on the realization of the deep search of the most favorable regions of the solution space. The solution quality of metaheuristic methods is higher than those obtained by conventional heuristic approaches.

In recent years, there has been an increasing amount of literature on meta-heuristics methods in the field of facility layout problems since the first study of Armour & Elwood (1962). These studies could be exemplified by the following papers; Gonçalves & Resende (2015), Kulturel-Konak (2012), Kulturel-Konak & Konak (2011). Laporte & Osman (1996), Mazinani et al. (2013) and Ripon et al. (2013).

The metaheuristic approach has four components: initial space of solution, search engine, learning and guideline strategies, and management of information structures; as well as four separated classifications: guided construction search process, guided local search process, population search process, and hybrids of the processes (Osman 2001).

Ant Colony Optimization (ACO) was first introduced by Dorigo et al. in 1992 while making a study based on the teamwork behavior of ants. Ants are able to find the shortest way to food source using the special chemical pheromone path left by other ants foraging for food. Goss et al. (1989) in an experiment shown in Fig. 3 that the simple behaviors of the ants perform a complex task. In the experiment each ant tries different route to reach the food. On the path, each ant leaves some scent called pheromone. The ants those found shorter route completes more trips in a certain time period therefore these ants leave more pheromone. The pheromones guide the behavior of the ants.

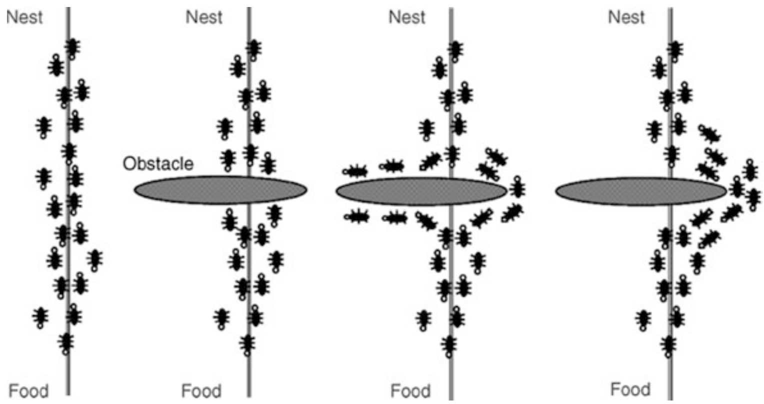

Fig. 3 Ant colony food search pattern (Talbi 2009)

The same rule was applied for solving optimization problems. Ants while moving around for food keep the excretion of pheromones on their path. As the ants that took the shortest path to find food start returning, followers of the pheromone path on the trail increase. Ants who move later, foraging for food, follow the trail. So, the concentration of pheromones increases. This can show the shortest path to all ants. The same principle is applied in the optimization problem to get the best solution (Gogna and Tayal 2013). In the literature, some studies used the ACO algorithm to solve the similar problems. Merz and Freisleben (1997) did a QAP study and comparison of heuristics; Gambardella et al. (1999) are running a ACO algorithm for Vehicle Routing Problem.

The ACO has been found useful in combinatorial optimization problems such as; production scheduling, assignment and vehicle routing. It has been observed by ACO which is proposed by Dorigo (1992) will applied to Air-cargo facility layout problem. At this point, for the detail information about air freight industry, Petersen (2007) could be offered, while for air cargo facility design Van Oudheusden & Boey (1994) can be acceptable as a beneficial source. The ACO for the best solution or a set of good solutions is given below:

- Determine stopping criteria (e.g. Stop if no improvement)
- Define pheromone matrix
- Initialize the pheromone matrix
- Give directives to the ants to construct solutions using the pheromone matrix
- Find the ant with the best solution
- Reinforce the pheromone values with the information from the best ant.
- Evaporate the pheromone values that are not used in best solution
- Check if the stopping criteria are met.

Case Study

For this study, one of the largest air cargo operator facilities of Turkey is determined as a case study. In this facility, products are stored within the two groups which are general cargo and special cargo. Also, special cargo includes several sub-groups; cool-chain equipment, live animals, valuables, perishable goods, pharmaceuticals, funeral transportation, dangerous goods, fragile goods etc. Especially, the zone of special cargos should be defined in terms of volumes and some environment requirements such as temperature or hazard ratio. The representative sample of air cargo facility is given in Fig. 4.

In order to apply ACO algorithm to find the best layout construction within the concept of air cargo facility, several steps are taken as follows:

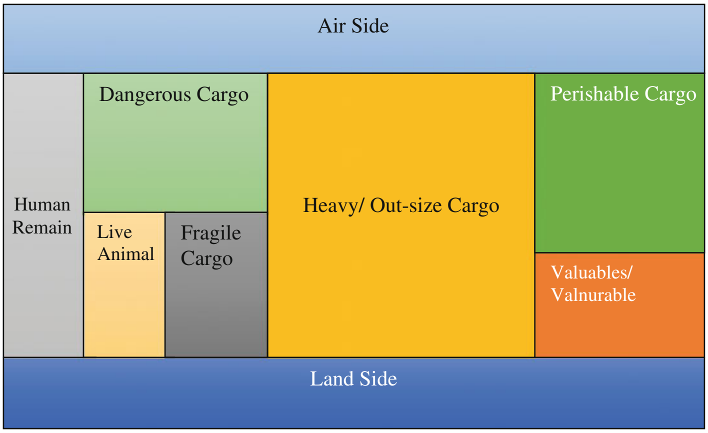

Fig. 4 An example layout plan for air cargo facilities

Step 1: Define facility design parameters; facility length, width, number of departments, and space requirements for each department
Step 2: Set the number of aisles (bands)for BlocPlan
Step 3: Select the parameters for ACO; number of ants to use, maximum iteration, evaporation rate, and pheromone release rate
Step 4: Initialize pheromone matrix
For each iteration **do**
 Step 5: Set number of departments to include in each aisle (randomly or predetermined)
 For each ant **do**:
  Based on pheromone matrix sequence the departments
  Place departments in to the layout
  Calculate the cost
  If the best solution for the elements of pheromone matrix**:**
   Release more pheromone if in the best solution
   Evaporate pheromone if not in the best solution
   Record Best solution
  end if
 end ant **loop**
end iteration **loop** (Termination criteria: Max iteration reached or no significant improvement for a while)

ACO algorithm has been constructed by using MATLAB software package. After running algorithm without taking any constraints into consideration the following total cost graph in Fig. 5 and layout design in Fig. 6 has obtained.

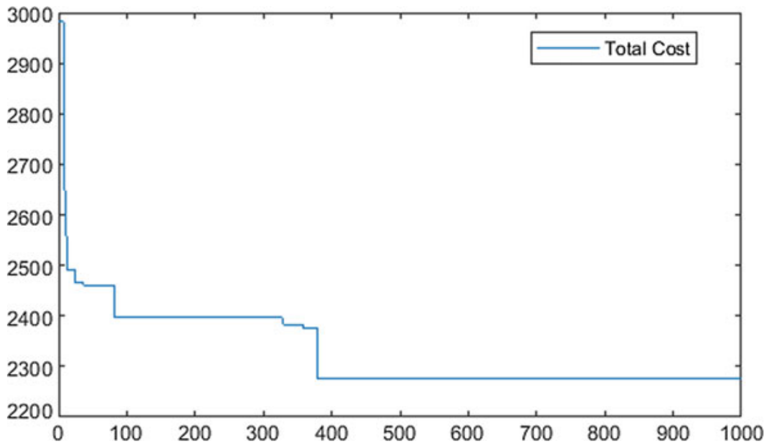

Fig. 5 Total cost behavior during 1000 iterations

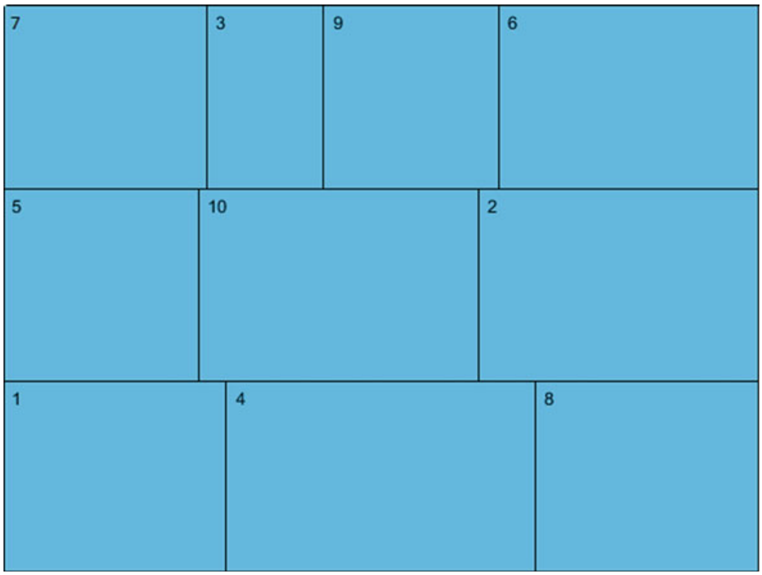

Fig. 6 Facility layout with pre-determined number of cut

In the first scenario, the number of departments to include in each aisle (cuts/cut parameters) is determined by the user as mentioned above in step 5 of pseudocode. After running algorithm by taking predetermined number of cuts into account, departments' dimensions are almost same and the ratio of department length and width is more or less one. However, it is so obvious that the obtained layout plan is not enough suitable for air cargo facilities in terms of its structural features such as land and airside should be located opposite one another. In this case, the number of cuts (departments within aisles or bands) is also inserted into the model as a decision variable to find the best cut combination. As it can be shown in Fig. 7,

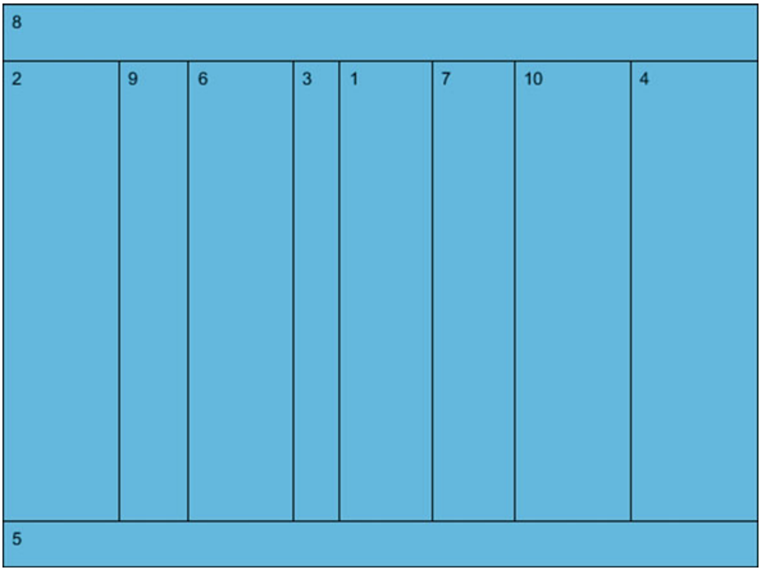

Fig. 7 Facility layout with optimum number of cuts

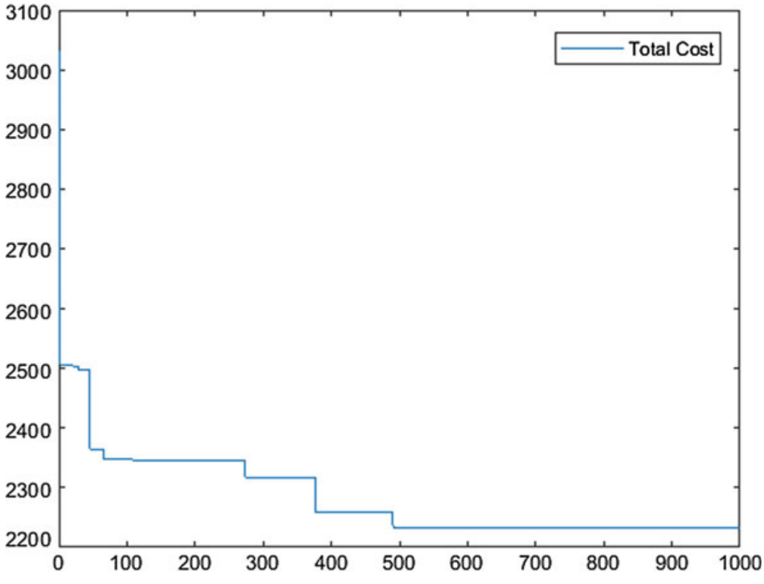

Fig. 8 Total cost behavior after inserting cut parameter

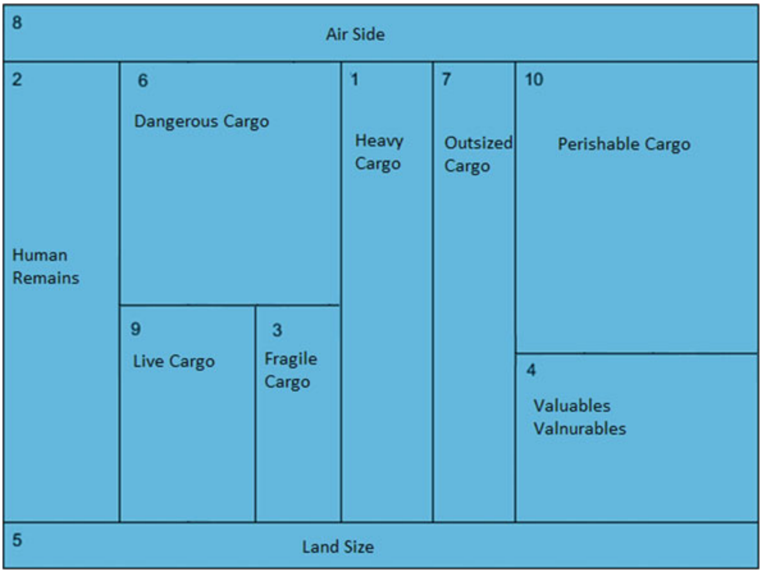

Fig. 9 Air cargo facility design after final touch

obtained facility design is considerably appropriate. At the same time, a noticeable difference in total cost after embedded cut parameters inside the developed algorithm can be seen in Fig. 8.

Even though facility layout design is rather cost effective for the air cargo concept, however, some departments such as 9, 3 and 1 are not suitable when the length/width ratio of these departments are considered. That is why, a final touch with human judgement is required. Hence some department arrangements are performed and the last version of layout are attained which is represented in Fig. 9.

Discussion and Conclusion

At the end of this study, the following tasks are fulfilled. **Development of New Algorithm for Air Cargo Facility Layout**—Flexible Aisle Algorithm is constructed in terms of Air cargo specifications and requirements. **Improved Layout Algorithms**—Available BlocPlan Algorithm is better utilized by ant colony metaheuristics. The fine-tuning of metaheuristics parameters for air-cargo facilities is achieved so that the new approach is much faster than the algorithms in the literature. **Cost Minimization**—Construction of the Layout that will provide the minimum cost for a typical Air Cargo Facility and it will ensure a decrease in the operational costs.

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Root Cause Detection with an Ensemble Machine Learning Approach in the Multivariate Manufacturing Process

Deniz Demircioglu Diren, Semra Boran, Ihsan Hakan Selvi and Tugcen Hatipoglu

Abstract Quality control in multivariate manufacturing processes should be applied with multi variate control charts. Although this method is sufficient, it doesn't include the causes of uncontrolled situations. It only shows samples that are out of control. A variety of methods are required to determine the root cause(s) of the uncontrolled situations. In this study, a classification model, based on the ensemble approach of machine learning classification algorithms, is proposed for determining the root cause(s). Algorithms are compared according to predictive accuracy, kappa value and root square mean error rates as performance criteria. Results show that Neural Network ensemble techniques are more efficient and successful than individual Neural Network learning algorithms.

Keywords Multivariate process · Multivariate quality control charts
Mason young tracy decomposition · Machine learning

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_14

Introduction

Recently, quality control in companies has become significantly important. In order to improve the quality of the product or service, it is necessary to monitor and analyze the existing quality correctly. High competitive power is achieved through high accuracy analysis. Statistical process control techniques such as quality control diagrams are used to determine the quality status. In general, the number of quality characteristics that are effective in production processes is high. Conventional univariate quality control charts are not sufficient for such processes. For this reason, multivariate control charts should be used instead of univariate quality control chart. First the multivariate variable quality control diagram Hotelling T^2 was developed in 1947 (Hotelling 1947). Then, different multivariate quality control diagrams were developed according to the magnitude of the shift in the process.

The multivariate control charts are sufficient in monitoring and detecting the quality conditions of the process. However, it is not possible to detect which quality characteristic(s) are the root cause of out of signal. Due to the fact that, all the quality characteristics are shown in a statistically single point on the chart. Statistical and machine learning techniques should be used for detecting the root cause. The most commonly used statistical technique is the Mason Young Tracy Decomposition (MYT) developed for Hotelling T^2 (Mason et al. 1995). This technique has proven sufficient in root-cause detection (Parra and Loaiza 2003; Çetin and Birgören 2007). However, this technique is not able to predictive the root cause of the new sample fault by learning the current situation. This is one of the limitations of this method. For this reason, machine learning algorithms are frequently used to determine the root causes of uncontrolled situations (Chen and Wang 2004; Aparasi and Sanz 2010; Du et al. 2012; He et al. 2013).

For the root cause(s) detection, first, the quality conditions of the samples in the production data must be determined. In this study, multivariate Hotelling T^2 control chart is used for monitoring and diagnosing the process. Then the root cause(s) of uncontrolled conditions are identified by MYT. In order to analyze the current situation and to predict the new situation, machine learning algorithms have been applied with MYT method. A training data set for machine learning are prepared by using Hotelling T^2 and MYT. Network (NN) and ensemble Neural Network (by boosting and bagging) algorithms are used to predict the root cause(s) of the new sample fault. The algorithms are compared according to kappa, root mean squared error and accuracy performance criteria. As a result of the study, the algorithm with the highest performance had been determined.

The rest of the paper is organized as follows. The proposed methodology has been given in Section "Methodology". In Section "Results", the approaches used in the study are explained in detail. Finally, the study has been concluded with results and suggestions in Section "Discussion and Conclusion".

Methodology

This study consists of 5 step. The methodology starts with collecting the process data, the second phase is preparing of training data set for machine learning algorithm, the third step is applying the individual and ensemble NN with cross validation, fourth is Comparison performance of classifying algorithms and the last step is choosing the classification algorithm to be used. The model of the study is presented in Fig. 1.

Hotelling T^2

Primary multivariate control chart Hotelling T^2 was provided for monitoring p-variate simultaneously by using T^2 statistic (Hotelling 1947). The parameters for this chart would be as follows:

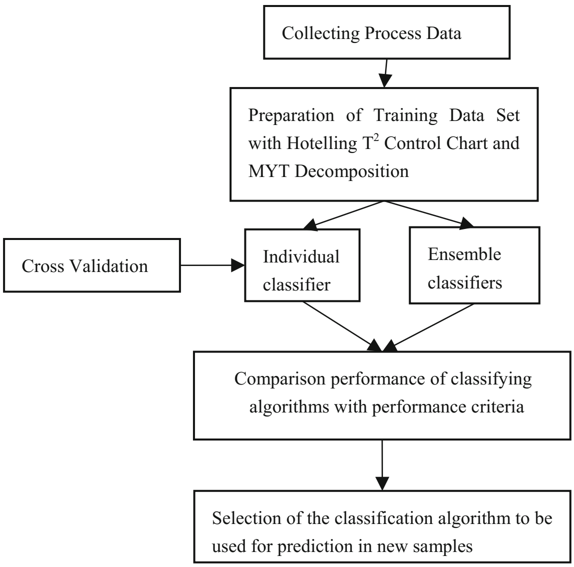
$$T^2 = n(X - \bar{X})' S^{-1} (X - \bar{X}) \tag{1}$$

Where $\bar{X}$ is the mean vector of the sample and S is the covariance matrix.

$$UCL = \frac{(m-1)^2}{m} \beta_{\alpha, p/2, (m-p-1)/2} \tag{2}$$

$$LCL = 0 \tag{3}$$

Fig. 1 The architecture of the proposed model



where $\beta_{\alpha,\ p/2,\ (m\text{-}p\text{-}1)/2}$ is the upper α-th percentile of the beta distribution with parameters p/2 and (m − p − 1)/2.

If all points are between UCL and LCL, then it can be said that the process is in control otherwise the process is statistically out of control.

MYT Decomposition

MYT decomposition method detect the root cause of out of control condition by decomposing of T^2 statistic into independent components as conditional and unconditional (Mason et al. 1995, 1997).

If the individual variable is handled, then it's called unconditional part otherwise more than one variable is handled it's called conditional part. The calculation of conditional and unconditional parts respectively is as follows:

$$T^2 = T^2_{p-1} + T^2_{p.1}, \ldots, p-1 \tag{4}$$

$$T^2_{p-1} = (X_i^{(p-1)} - \bar{X}^{(p-1)})' S_{XX}^{-1}\left(X_i^{(p-1)} - \bar{X}^{(p-1)}\right) \tag{5}$$

$$T_{p.1,p-1} = \frac{x_{ip} - \bar{x}_{p.1,..,p-1}}{s_{p.1,\ldots,p-1}} \tag{6}$$

There are threshold values defined for conditional and unconditioned parts. If these thresholds are exceeded, it can be said that there is an out of control condition caused by that variable or variable group (Mason et al. 1995, 1997).

Machine Learning Algorithm

Machine learning is a statistical model that investigates how computers automatically learn from data. Machine learning divided two main class. Classification is a supervised learning that learns from the labeled examples in the training data. Clustering is an unsupervised learning that the input examples not labeled (Han et al. 2012). Classification algorithms are usually used to detect the root cause(s) of the out of control condition. These algorithms that implementation to detect root cause include Decision Tree (Guh and Shiue 2008; He et al. 2013), Support Vector Machine (Du et al. 2012), k-Nearest Neigborhood (He et al. 2007), Bayesian Networks (Verron et al. 2006) and hybrid methods (Cheng and Cheng 2008; Salehi et al. 2011). Furthermore, Neural Network (NN) is a very successful and preferable classification technique for many years (Nikai and Abbasi 2005; Aparisi and Sanz 2010; Masood and Hassan 2013; Karimi and Rad 2014).

– ***Neural Network:***
The neural network is a technique that models the ability to process nerves in the human brain. A single layer feed-forward network has one or more input and output. These input and output neurons are connected with a weighting factor. A multi-layer network has a layered structure. Each layer consists of input hidden and output neurons (Kröse and Smagt 1996). These networks are seen in Fig. 2a, b.

Inputs in the neural network that train about fault diagnosis are the variables that affect the outputs. The number of inputs and outputs is determined according to the problem. For the number of hidden layer nodes, the appropriate transfer function (such as sigmoid, tangent-sigmoid, and logarithmic-sigmoid) is applied. To train the neural network, data set are divided into test and train data.

The high accuracy performance of the algorithm depends on determining the parameters optimally and training the network correctly. When all these conditions are responded, sometimes the desired accuracy cannot be achieved. In these situations, ensemble learning methods can be used to increase the individual use of classification methods that shown in Fig. 3 (Han et al. 2012). In the literature, there are different ensemble techniques in machine learning methods.

In the ensemble methods known classification algorithms are preferred as the basic learning algorithm. In our study, Neural Network is used as the basic learning algorithm while Boosting and Bagging techniques are used as the ensemble methods.

– ***Boosting:***
In terms of classification, prediction speed is an important criterion as well as prediction accuracy rates. The prediction speed depends on the boosting method (Freund 1999). The Boosting method focuses on incorrect decisions rather than

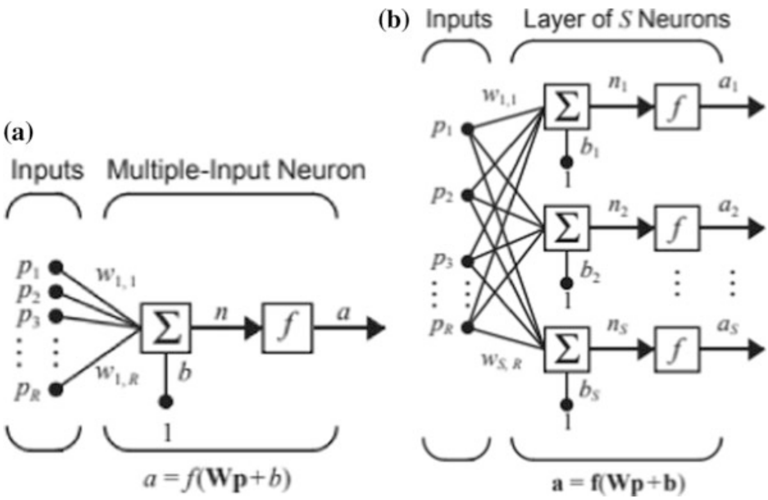


Fig. 2 **a** Single layer network, **b** Multi-layer network

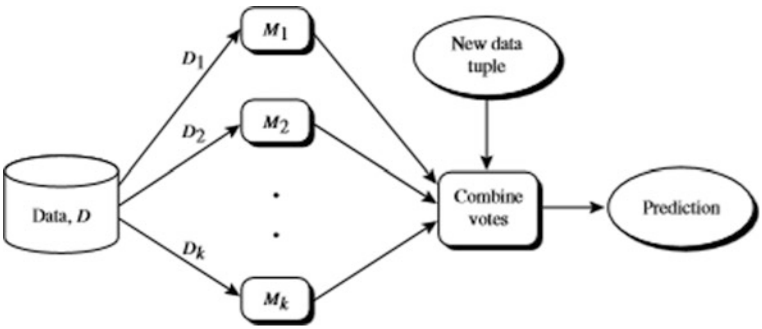


Fig. 3 Increasing classifier accuracy

correct decisions and uses the incorrect data that the previous classifier cannot correctly determine. This algorithm aims to make a more accurate prediction by adding the incorrect data back into the training set to be used later. The success of the algorithm increases due to the detection of weak classifiers and updates of weights (Breiman 1996a, b). Adaboost is the most commonly used boosting algorithm. The procedure of the adaboost method is as Fig. 4 (Han et al. 2012):

– ***Bagging:***
Bagging ensemble method generates new training sets with random selections from an existing training set and aims to retrain the base learning algorithm. Due to the random selections, some training samples are not included in the new training set and also some may occur several. By creating different data sets, the total classification success is increased (Breiman 1996a, b). The procedure of the bagging method is presented in Fig. 5 (Han et al. 2012):

Performance criteria

– ***Kappa***
Kappa value is a statistical calculation that measures the compliance of diagnoses. The formula of Kappa is shown below (Cohen 1960):

$$K = \frac{P(a) - P(x)}{1 - P(x)} \tag{7}$$

where P(a) is the probability of the classifier's accuracy and P(x) is the weighted average of the probability of estimates.

Kappa ranges between 0 and 1. '1' expresses perfect fit while '0' means weak fit.

– ***Root Mean Squared Error (RMSE)***
The RMSE is often used as a measure of the difference between the estimates made by the estimator and the actual values obtained from the estimator. The error squares average is one of the most commonly used successful measures for numerical predictions. The RMSE formula is explained as follows (Lehmann and Casella 2003):

Algorithm: AdaBoost. A boosting algorithm—create an ensemble of classifiers. Each one gives a weighted vote.

Input:

D, a set of d class-labeled training tuples;
k, the number of rounds (one classifier is generated per round);
a classification learning scheme.

Output: A composite model.

Method:

(1) initialize the weight of each tuple in D to 1/d;
(2) **for** i=1 to k **do** // for each round:
(3) sample D with replacement according to the tuple weights to obtain D_i;
(4) use training set Di to derive a model, M_i;
(5) compute error(M_i), the error rate of M_i
(6) **if** error(M_i) > 0.5 **then**
(7) go back to step 3 and try again;
(8) **end if**
(9) **for** each tuple in Di that was correctly classified **do**
(10) multiply the weight of the tuple by error(M_i)/(1−error(M_i)); // update weights
(11) normalize the weight of each tuple;
(12) **end for**

To use the ensemble to classify tuple ,X:

(1) initialize weight of each class to 0;
(2) **for** i=1 to k **do** // for each classifier:
(3) $\mathbf{w}_i$ =log 1−error(M_i) error(M_i) ; // weight of the classifier's vote
(4) c=M_i(X); // get class prediction for X from M_i
(5) add w_i to weight for class c
(6) **end for**
(7)return the class with the largest weight:

Fig. 4 Procedure of boosting

$$RMSE = \sqrt{\frac{(p_1 - a_1)^2 + \ldots + (p_n - a_n)^2}{n}} \tag{8}$$

where p is the estimated value and a is a real value

– ***Accuracy Rate***

Accuracy rate is defined as the number of correctly classified samples from all samples. Accuracy is the most popular method and uses a very simple formula as shown below.

Algorithm: Bagging . The bagging algorithm — create an ensemble of classification models for a learning scheme where each model gives an equally weighted prediction.

Input:

D, a set of d training tuples;

k, the number of models in the ensemble;

a classification learning scheme (decision tree algorithm, na¨ıve Bayesian, etc.).

Output: The ensemble—a composite model, M∗.

Method:

(1) **for** i=1 to k do // create k models:

(2) create a bootstrap sample, Di, by sampling D with replacement;

(3) use D_i and the learning scheme to derive a model, M_i;

(4) **end for**

To use the ensemble to classify a tuple, X:

let each of the k models classify X and return the majority vote;

Fig. 5 Procedure for bagging

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} 100\% \tag{9}$$

TP: number of true positive samples in the test set,
TN: number of true negative samples in the test set,
FP: number of false positive samples in the test,
FN: number of false negative sample in the test set.

Results

Preparing for Training Data Set

The data of the paint fixing process are used in the study. The process includes 3 parameters such as temperature, humidity, and pressure. Hotelling T^2 control diagram was applied to 497 sample data which collected from the process and 130 samples were found to be out of control. The result of the Hotelling T^2 control chart should be seen in Fig. 6.

The out of control conditions which diagnosis by the control diagram are interpreted by (4–6) formulas according to the MYT method. Based on the equations, the root causes were determined. In the dataset, there are 5 root causes and faultless products. These root causes are; temperature, pressure-humidity, temperature-humidity, temperature-pressure, temperature-pressure-humidity and faultless.

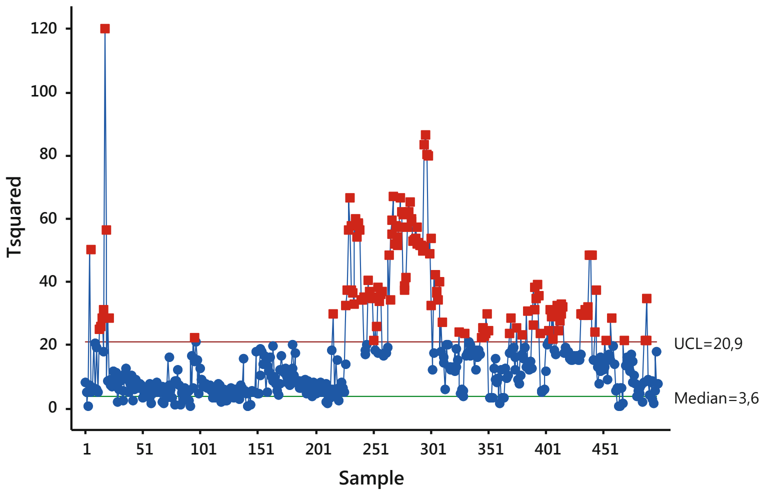


Fig. 6 Hotelling T^2 control chart

Since this method is not very practical and does not have the ability to make predictions, the use of prediction classification algorithms is considered appropriate. Individual NN and ensemble NN are evaluated according to various performance criteria.

Analysis of Predictive Performance of Individual and Ensemble Algorithms

Individual and ensemble neural net classifier are used by Rapidminer Studio 7.6 program for predictive the new sample root cause. The structure of the neural network consists of 3 inputs and 5 outputs. The outputs occur the root cause of the out of control condition in the process. The outputs are listed as; temperature, pressure-humidity, temperature-humidity, temperature-pressure, temperate-pressure-humidity and faultless. The hidden layer node number is determined as 5 by trial. Levenberg - marquardt training function, the sigmoid transfer function is used and the network type is fed forward back propagation. The best learning rate is achieved with 150 training.

The performance values of algorithms according to kappa criteria are shown in Table 1.

According to kappa criteria its seen that the most successful method is boosting-neural net.

The performance values of algorithms according to accuracy criteria are shown in Table 2.

According to accuracy criteria its seen that the most successful method is boosting-neural net.

Table 1 Kappa values

Algorithm	Kappa
Neural net	0.804 ± 0.1
Boosting-neural net	0.922 ± 0.054
Bagging-neural net	0.811 ± 0.097

Table 2 Accuracy values

Algorithm	Accuracy
Neural net	92.13% ± 3.69%
Boosting-neural net	96.58% ± 2.40%
Bagging-neural net	92.35% ± 3.69%

Table 3 RMSE values

Algorithm	RMSE
Neural net	0.244 ± 0.059
Boosting-neural net	0.152 ± 0.07
Bagging-neural net	0.256 ± 0.065

Also, the performance values of algorithms according to RMSE criteria are shown in Table 3.

According to RMSE criteria its seen that the most successful method is boosting-neural net.

Discussion and Conclusion

The company, the study is conducted, performs in the automotive sector. Seat, door panel, and bumper modules are produced in the firm. The examined part in terms of quality is processed in the paint department. The problem of surface quality and fluidity obtained at the end of fixing the paint on the product is evaluated. In the study 497 sample data is analyzed according to three variables that affect the process quality. 130 sample is determined faulty. Five different root causes have been identified in the process. Then the root causes of the data and examples are classified by individual and ensemble learning algorithms. Classifications according to used algorithms have been compared. Our attention has been called to the fact that, boosting ensemble method is chosen as the best algorithm with 0.922 kappa value, 96.58 accuracy value, and 0.152 RMSE value. When all the performance criterion conclusion is evaluated, it is seen that the ensemble methods increase the accuracy and decrease the incorrect predictions according to the single algorithms. Among the algorithms used in the study, it is pointed that the most appropriate and successful algorithm is the boosting-neural network. The process of estimating with the algorithm in this study is determined as sufficient. Several different machine learning algorithms such as Decision Tree, Naïve Bayes, Support Vector Machine and ensemble methods should be applied in the same process in the future studies.

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Inventory Control Through ABC/XYZ Analysis

Esra Agca Aktunc, Meltem Basaran, Gozde Ari, Mumin Irican and Sahna Gungor

Abstract In this study, inventory and production control of a group of products from a major manufacturer of domestic and industrial gas meters is examined. ABC and XYZ analyses are carried out for the inventory items to determine the production strategy of each item class and the Economic Order Quantity (EOQ). After this examination, one of the end products of the company is chosen to develop the Materials Requirement Plan (MRP) for. The Bill of Materials (BOM) for the chosen product is created and MRP is developed according to the BOM levels. The monthly demand data for the final product is obtained based on the annual demand and the required quantities for all sub materials of the final product are calculated with MRP. Finally, after the ABC/XYZ analysis, BOM structuring, and MRP calculations, a user interface is developed in Excel using Visual Basic for Applications (VBA) to access, edit, and add the desired information easily.

Keywords Inventory control · ABC/XYZ analysis · Item classification Materials Requirement Planning (MRP)

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_15

Introduction

The industrial revolutions of the last century resulted in an immense variety of products and increased the complexity of manufacturing systems. As the supply chains become more challenging to manage, the inbound and outbound logistics processes, material management and physical distribution, respectively, require more attention than ever (Min and Zhou 2002). The majority of manufacturing companies have complicated material management requirements for a wide variety of products each with several parts and they often rely heavily on Materials Requirement Planning (MRP) to achieve their cost and quality goals. The Manufacturing Planning and Control (MPC) system manages the efficient flow of materials, the utilization of resources including human workforce and equipment, and the timely fulfillment of customer requirements (Vollmann et al. 2005). MPC systems mainly consist of a Master Production Schedule (MPS) that is determined based on demand forecasts and production capacity, detailed material plans developed by MRP, detailed capacity plans developed based on the material plans, and finally the execution of these plans on the shop floor using production schedules and through the suppliers for outsourced materials. As part of the MPC system, MRP is of primary importance to the operations of companies especially if they assemble their final products from various components.

In this study, we focus on the inventory and production control of a product group from a major manufacturer of domestic and industrial gas meters. The company has been manufacturing cutting moulds, plastic injections, and fixtures for civil and defense industries since 1969 and it recently established the gas equipment department. This company produces various types of products with hundreds of components. Due to the difficulty of maintaining accurate inventory levels, the company often faces an overstocking problem that incurs significant costs. In order to reduce overstocking of items, production planning must be done for all levels of production in advance. This requires the use of MRP where production quantities for each level are determined based on demand forecasts.

MRP was first developed in IBM by Joseph Orlicky and his colleagues in the 1960s and it gained popularity in manufacturing management after the 1972 “MRP Crusade” of the American Production and Inventory Control Society (APICS) (Hopp and Spearman 2008). Orlicky estimated that 150 firms were using MRP systems by 1970s and that there would be 700 firms by 1975 as a result of the APICS efforts (Orlicky 1975). Despite the prevalence of MRP systems by end of the 1970s, the experience made it clear that MRP was not compatible with certain manufacturing environments in which assembly lines were not dedicated and reliable or the product models are rapidly changing (McKay 2011).

MRP is an example of push systems in which the products are pushed to the next level upon completion as opposed to the pull system in which the products are pulled by the next level only when they are requested (Nahmias 2005). The demand for components, which is the dependent demand, is a function of the demand for final products, an independent demand. Therefore, MRP requires an MPS that provides when and how many of a product must be produced, a Bill of Materials (BOM) that shows the required number of components for a part or product, and the inventory levels of related items.

For the majority of manufacturers, products differ in terms of their cost, consumption rate, or demand variability and these differences must be reflected in MRP for effective planning. The necessity to distinguish products resulted in a Stock Keeping Unit (SKU) classification techniques. Two prevalent SKU classification techniques are the ABC analysis, where products are grouped based on mostly demand volume or demand value (value of sales), and the fast, normal, slow moving (FNS) technique, where products are grouped based on demand rate or demand frequency (van Kampen et al. 2012). A combination of these two techniques is the ABC/XYZ analysis, where the XYZ analysis is essentially the FNS technique as it groups products based on their consumption rate (Scholz-Reiter et al. 2012). In this study, ABC/XYZ analysis is used to obtain a better idea about product groups of the manufacturer and to enable the manufacturer to make more accurate inventory management decisions.

Literature Review

In any production and inventory system that utilizes MRP, one should consider the differences among products in terms of characteristics such as cost, sales value, consumption rate, and demand variability. The same production and inventory rules may not apply to all products and it would be impractical and inefficient to determine inventory control policies for each product individually. Therefore, each product should be examined in comparison with the other products and a suitable strategy should be determined for different groups of products. van Kampen et al. (2012) provide a detailed review of SKU classification literature in the field of production and operations management and distinguish between techniques that are based on judgmental and statistical knowledge. The analytic hierarchy process (AHP), the technique for order preference by similarity to ideal solution (TOPSIS), and distance modeling are based on expert judgment. ABC or Pareto analysis, FNS, decision tree, cluster analysis, optimization, neural networks, and genetic algorithm are statistical techniques based on SKU characteristics data.

One of the widely used SKU classification techniques is the ABC analysis that determines the estimated importance of items by dividing the inventory into three classes (Vollmann et al. 2005). Class A items constitute a low proportion of items in terms of quantity, but a high proportion of the monetary value of all items. Class C items, on the contrary, constitute a high proportion of items in quantity, but a low proportion of the overall value. This approach is similar to using the Pareto principle, which states that 80% of effects are due to 20% of the causes. However, in the ABC analysis, the percentage values are not fixed and one can determine the threshold percentages based on the objective, such as 70, 20, and 10%.

The literature is divided on which class of items should receive the highest service level as some authors argue that class A items should get the highest service level to avoid frequent backlogs and others argue that class C items should get the highest service level to avoid dealing with stockouts of these items (Teunter et al. 2010). In this study, we assume that class A items are very valuable and must be monitored closely, class B items are of average importance but must still be monitored frequently, whereas class C items are trivial and can be monitored with little effort. Products in different classes would require different management and controls since the impact of decisions regarding class A items would have a greater effect on the overall inventory cost performance than that regarding class C items.

Several studies have proposed improvements in the traditional ABC analysis. Teunter et al. (2010) introduce a new cost criterion that accounts for the criticality of an SKU, measured by shortage cost, in comparison with the inventory holding cost. Millstein et al. (2014) propose a mixed-integer linear program that optimizes the number of groups, their service levels, and assignment of SKUs to groups subject to a limited budget. In order to consider other important criteria than demand volume or demand value, the importance of multiple criteria ABC classification was first highlighted by Flores and Whybark (1986). Embarking on the search for better multi-criteria classifications, Partovi and Burton (1993) apply the AHP technique including criticality, lead time, the unit price of the part, and demand as the key criteria. Yu (2011) compares three artificial-intelligence (AI)-based classification techniques with benchmark techniques and suggest that AI-based techniques that are more accurate than the traditional analysis can improve the efficiency of inventory management. For the multiple criteria ABC analysis, Liu et al. (2016) develop a classification approach based on the outranking model such that an inventory item that scores badly on one or more key criteria is not placed in good classes at all.

Another way to classify items is XYZ analysis based on the variability of demand for items. Demand for X items has very little variation, which results in reliable forecasts of future demand. Demand for Y items has some fluctuations that can be predicted, such as seasonality, trend, or economic factors; therefore, future demand forecasts are less reliable for these items. Demand for Z items is highly variable and it is extremely difficult to make reliable forecasts for these items.

The combination of ABC and XYZ analyses enables the inventory manager to identify items based on both their value and demand frequency, so that appropriate inventory control measures can be taken to manage each item effectively (Silver et al. 1998). The ABC/XYZ analysis results in nine classes (AX, AY, AZ, BX, BY, BZ, CX, CY, CZ) and the properties of the extreme combinations can be summarized as follows:

- AX: Very valuable items, demand forecast is easy due to low variability
- CX: Trivial items that are relatively easy to forecast
- AZ: Very valuable items that are difficult to forecast
- CZ: Trivial items that are difficult to forecast

ABC/XYZ analysis can be used for strategic supply and inventory control for various industries such as the food industry and mechanical engineering industry (Reiner and Trcka 2004; Scholz-Reiter et al. 2012).

Next, the item classification and MRP application for the manufacturing company are described.

Methodology

As two prevalent SKU classification techniques, ABC and XYZ analyses are used to classify items in the presence of single criterion or single item characteristics (van Kampen et al. 2012). Based on the data gathered from the manufacturing company studied, the most important criteria to consider were determined to be the annual cost of items and the frequency of demand for the items. The frequency of demand can be represented in terms of the inter-demand interval, which is a scarcely used characteristic in the product classification literature with the aim of forecasting (Johnston and Boylan 1996). Other criteria such as lead time or criticality were not available for use for all the products in question; therefore, ABC analysis is performed based on the single criterion of annual cost and XYZ analysis is performed based on the single criterion of demand frequency. Finally, these two analyses are combined to group the items into nine classes that provide more specific guidelines about effective inventory management procedures for each class.

Item Classification with ABC Analysis

For the manufacturing company studied, in the ABC analysis, the following classification rule is implemented:

- A-items: 0–70% of the cumulative annual cost
- B-items: 70–90% of the cumulative annual cost
- C-items: 90–100% of the cumulative annual cost

The classification of 130 products as ABC-items and the cost associated with each class are presented in Table 1. There are 26 A-items (20% of inventory items) with 69.91% share in the cost, 44 B-items (33.85% of inventory items) with 19.87% share in the cost, and 60 C-items (46.15% of inventory items) with 10.23% share in the cost. The relationship between the percent of inventory items in each class and the accumulated cost is shown in Fig. 1.

Table 1 ABC analysis results

Item number	Item	Units	Quantity	Annual cost (TL)	Cumulative % of cost	ABC	Share in cost	Percent of SKUs
1	TES-900300	KG	810.00	18,579.56	10.85%	A	69.91%	20.00%
2	INS-ODO501	Quantity	674.00	12,246.50	18.00%	A		
3	FKF-V28000	Quantity	13.00	7,352.97	22.29%	A		
26	INS-AP1000	Quantity	5.00	1,281.58	69.91%	A		
27	43120110022	Quantity	4,726.00	1,160.16	70.58%	B	19.87%	33.85%
28	TAS-400352	Quantity	11.00	1,133.67	71.24%	B		
29	XKM-320800	Quantity	11.00	1,105.93	71.89%	B		
70	11343012010	Quantity	15.00	469.95	89.77%	B		
71	RMH-008000	Quantity	2.00	465.00	90.04%	C	10.23%	46.15%
72	KMH-012003	Quantity	3.00	436.64	90.30%	C		
73	INS-GR1700	Quantity	1.00	427.10	90.55%	C		
130	XSK-161200	Quantity	2.00	155.60	100.00%	C		
Total				171,300.79			100.00%	100.00%

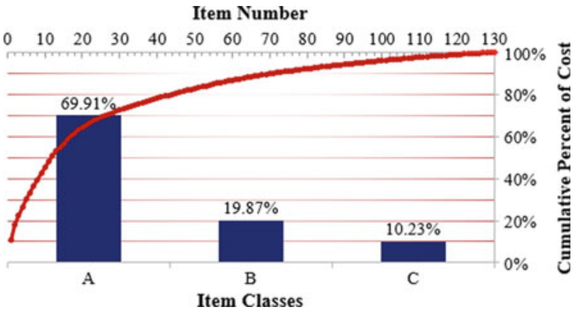

Fig. 1 ABC analysis chart

Item Classification with XYZ Analysis

Based on the demand data obtained from the company, in the XYZ analysis, the following classification rule is implemented:

- X-items: items with demand frequency of at least 16
- Y-items: items with demand frequency between 10 and 16
- Z-items: items with demand frequency of less than 10

The classification of 130 products as XYZ-items is presented in Table 2. There are 12 X-items, 17 Y-items, and 101 Z-items.

Table 2 XYZ analysis results

Item Number	Item	Units	Frequency of use	XYZ	Percent of SKUs
1	ZMP-300600	KG	48	X	9.23
2	YED-940002	Quantity	29	X	
3	XSK-161600	Quantity	26	X	
12	TUT-020076	Quantity	16	X	
13	TES-900300	Quantity	12	Y	13.08
14	TES-001300	Quantity	12	Y	
15	TAS-909002	Quantity	12	Y	
29	PAR-060001	Quantity	10	Y	
30	PAR-030005	Quantity	9	Z	77.69
31	PAR-021100	Quantity	9	Z	
32	MTK-219800	Quantity	9	Z	
130	TAS-501500	Quantity	1	Z	

ABC/XYZ Analysis

The number of items of the company classified according to ABC/XYZ analysis is shown in Table 3. The majority of the items are in CZ and BZ classes, which are not very valuable, but difficult to forecast. Therefore, keeping high safety stock is recommended. For the few AX and BX class items of the company, no safety stock is necessary and Just In Time (JIT) supply can be used since demand for these items has little variability.

Economic Order Quantity (EOQ) and Safety Stock

After the classification of items, the EOQ and safety stock levels are determined for each product based on the following notation and formulas.

A: fixed ordering cost
D: annual demand
h: inventory holding cost per unit per year

$$EOQ = \sqrt{\frac{2AD}{h}}$$

SS: safety stock
b: annual backorder cost per unit
R: reorder point (R^* is the optimal value)
D_L: demand during lead time

$$P(R \leq R^*) = \frac{b}{b+h}, \quad SS = R^* - E[D_L]$$

The EOQ and safety stock levels for a sample of items from different classes are shown in Table 4. For instance, since AX, BX, and BY items have considerably

Table 3 Number of items in each class based on ABC/XYZ analysis

	X	Y	Z	Total
A	1	5	20	26
B	1	4	39	44
C	10	8	42	60
Total	12	17	101	130

Table 4 Sample EOQ and safety stock results

Item	Total quantity	Total cost	ABC/ XYZ	Daily consumption	EOQ	Safety stock
TES-900300	810.00	18,579.56	A Y	3.12	47	32
INS-OD0501	674.00	12,246.50	A Z	2.59	39	39
FKF-V28000	13.00	7,352.97	A Z	0.05	1	1
YED-940002	37.00	4,894.37	A X	0.14	5	0
43120110022	4,726.00	1,160.16	B Y	18.18	546	0
TAS-400352	11.00	1,133.67	B Y	0.04	2	0
XKM-320800	11.00	1,105.93	B X	0.04	2	0
MTK-211500	26.00	480.00	B Z	0.10	2	3
RMH-008000	2.00	465.00	C Y	0.01	1	1
KMH-012000	500.00	287.31	C Z	1.92	29	116
FOK-SO6001	20.00	285.72	C Z	0.08	2	5
XKM-321800	70.00	265.05	C X	0.27	49	13
TUT-210000	4.00	231.47	C X	0.02	3	1
XSK-161200	2.00	155.60	C Z	0.01	1	1

low demand variability, no safety stock is required. However, for the CZ items, safety stock is fairly high in order to be prepared for unexpected demand levels. These results are compatible with the item classification technique.

The MRP Procedure

The MRP procedure for the company is developed using MS Excel with VBA. Here, a natural gas meter product from the BY class is selected to demonstrate the process. The BOM of the natural gas meter consists of six levels below the end item level as shown in Fig. 2. There are 12, 15, 28, 34, 28, and 13 components at Level 1–6, respectively. These numbers can give an idea about the complexity of the MRP system for even this single product. Since the BY items require no safety stock, the Lot-for-Lot (LFL) method is used for lot sizing in this example, i.e., the net requirements of a period are produced in that period.

Based on MPS that dictates the demanded quantity of the product and the BOM explosion, the following MRP notation and formulations are used for projection of item requirements.

D_t: gross requirements for month t
S_t: scheduled receipt in month t
I_t: projected on-hand inventory for the end of month t (I_0 is the initial on-hand inventory)

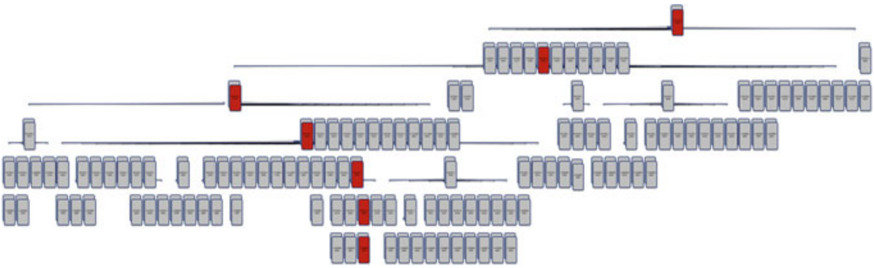

Fig. 2 BOM of selected gas meter product

Table 5 Sample MRP results

ITEM: 43120110022		Level 0								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	0	0	0	0	0	796	785	790	786	780	789
Scheduled Receipts													
Projected On Hand Inv	800	800	800	800	800	800	800	800	4	0	0	0	0
Net Requirements		0	0	0	0	0	0	0	781	790	786	780	789
Planned Receipts		0	0	0	0	0	0	0	781	790	786	780	789
Planned Release	0	0	0	0	0	0	0	781	790	786	780	789	0
ITEM: 33120110980		Level 1								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	0	0	0	0	0	781	790	786	780	789	0
Scheduled Receipts													
Projected On Hand Inv	200	200	200	200	200	200	200	200	0	0	0	0	0
Net Requirements		0	0	0	0	0	0	581	790	786	780	789	0
Planned Receipts		0	0	0	0	0	0	581	790	786	780	789	0
Planned Release		0	0	0	0	0	581	790	786	780	789	0	0
ITEM: 33120110976		Level 2								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	0	0	0	0	581	790	786	780	789	0	0
Scheduled Receipts													
Projected On Hand Inv	36	36	36	36	36	36	36	0	0	0	0	0	0
Net Requirements		0	0	0	0	0	545	790	786	780	789	0	0
Planned Receipts		0	0	0	0	0	545	790	786	780	789	0	0
Planned Release		0	0	0	0	545	790	786	780	789	0	0	0
ITEM: 33120110962		Level 3								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	0	0	0	545	790	786	780	789	0	0	0
Scheduled Receipts													
Projected On Hand Inv	13	13	13	13	13	13	0	0	0	0	0	0	0
Net Requirements						532	790	786	780	789	0	0	0
Planned Receipts		0	0	0	0	532	790	786	780	789	0	0	0
Planned Release		0	0	0	532	790	786	780	789	0	0	0	0
ITEM: 33120110987		Level 4								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	0	0	532	790	786	780	789	0	0	0	0
Scheduled Receipts													
Projected On Hand Inv						0	0	0	0	0	0	0	0
Net Requirements		0	0	0	532	790	786	780	789	0	0	0	0
Planned Receipts		0	0	0	532	790	786	780	789	0	0	0	0
Planned Release		0	0	532	790	786	780	789	0	0	0	0	0
ITEM: 23120110408		Level 5								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	0	1064	1580	1572	1560	1578	0	0	0	0	0
Scheduled Receipts													
Projected On Hand Inv					0	0	0	0	0	0	0	0	0
Net Requirements		0	0	1064	1580	1572	1560	1578	0	0	0	0	0
Planned Receipts		0	0	1064	1580	1572	1560	1578	0	0	0	0	0
Planned Release		0	1064	1580	1572	1560	1578	0	0	0	0	0	0
ITEM: 11000007055	Multiple Parts	Level 6								LEAD TIME:			1
										LOT SIZE:			1
										SAFETY STK:			0
	PAST DUE	1	2	3	4	5	6	7	8	9	10	11	12
Gross Requirements		0	89908	140699,26	167841	185430,6	188331	57972,9	47268	6312	0	0	0
Scheduled Receipts													
Projected On Hand Inv						0	0	0	0	0	0	0	0
Net Requirements		0	89908	140699,26	167841	185430,6	188331	57972,9	47268	6312	0	0	0
Planned Receipts		0	89908	140699,26	167841	185430,6	188331	57972,9	47268	6312	0	0	0
Planned Release		89908	140699,26	167841	185430,6	188331	57972,9	47268	6312	0	0	0	0

N_t: net requirements for month t (demands other than on-hand inventory and scheduled receipts)

$$I_t = I_{t-1} - D_t + S_t$$

$$N_t = \min\{\max(-I_t, 0), D_t\}$$

The planned receipt is the amount required at the beginning of a month so that the I_t level does not drop below zero. The planned release is equal to the planned receipt offset by the lead time. The results of MRP for the selected natural gas meter product is shown in Table 5. It is worth noting that some components appear in multiple levels of the BOM, which is considered in the MRP procedure in calculating the gross requirements.

Results

The classification of 130 items according to the ABC/XYZ analysis enabled us to determine more suitable inventory strategies specific to each product class. The AZ and BZ class items are identified as problematic items because their demand is impossible to forecast accurately and they are valuable items for the company. Unfortunately, 15.38% of items are AZ items and 30% of items are BZ items, which requires the company to develop inventory management strategies designed to reduce the cost of these items while avoiding shortages (causing bottlenecks in production) or overstocking (causing unnecessary cost). One solution proposed for these items is determining reasonable safety stock levels and using these as inputs of the MRP procedure.

To demonstrate the MRP procedure, the natural gas meter product was selected as a BY class item. For this type of products, little or no safety stock is suggested, which enables the use of the LFL method for lot sizing. The MRP procedure produces the monthly plans regarding all the components in the BOM of the selected product.

Finally, all the applications in a single MS Excel workbook are connected via the use of VBA macros in order to present the company with a user-friendly interface for this decision support tool. The main menu of the inventory control decision support tool is shown in Fig. 3 where the user can access and edit product information, conduct the item classification analyses with the click of related buttons, or perform MRP procedure for a selected product easily.

Fig. 3 The main menu of the inventory control decision support tool

Conclusion

In this study, ABC/XYZ Analysis is used for better classification of inventory items in materials management of a manufacturer of gas meters. It is usually not enough to classify stock items according to just the ABC analysis, because it only gives information about the monetary value. In order to integrate the frequency of use, XYZ analysis is combined with the ABC analysis. As a result of the ABC/XYZ classification of 130 products, class-based inventory control strategies were determined. High-value and highly demanded items need to have low average stock levels but high safety stock, whereas low-value and lowly demanded items can have low stock levels and little or no safety stock. The MRP system is demonstrated using a natural gas meter product from BY class and a user-interface is developed in MS Excel via VBA macros so that the company can utilize these methods in inventory and production management.

The proposed classification of their products is valuable information for the manufacturing company studied because it can easily lead to improvements in their inventory performance by eliminating shortages and overstocking. The integration of ABC/XYZ item classification with MRP results in more reliable decisions regarding the size and timing of orders for each item to reduce inventory costs while meeting production goals.

This study can be extended by incorporating other characteristics of products such as lead time, criticality of products in terms of their customers, or profit margin into the classification technique. Another interesting future research direction would be the application of a decision tree approach to this product classification problem where each characteristic is used one by one to determine the appropriate inventory management procedures.

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Evaluating Service Quality of an Airline Maintenance Company by Applying Fuzzy-AHP

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Abstract Quality greatly affects both customer satisfaction and the performance of a product or service. Therefore, due to competitive market conditions, the importance of quality measurement has increased. In reality, measuring quality is not an easy task, especially in the service sector, due to the heterogeneous, inseparable and incomprehensible characteristics of service products. Most service sector products are intangible. In the field of aviation, the quality of care directly affects aviation safety. This increases the importance of measuring and improving service quality in aviation. In this study, fuzzy analytical hierarchy process approach was used for measurements. In the hierarchical structure, 3 main criteria, 6 first level sub-criteria and 17 s level sub-criteria were used for quality measurement in airline maintenance service. The surveys were answered by experts working for maintenance companies. The final maintenance quality results were converted to a letter scale and used for service quality improvement.

Keywords Service quality measurement · Multi-criteria decision making
Fuzzy analytical hierarchy process · System selection

Introduction

Quality measurement has a big role in achieving organizational effectiveness (Aydin 2017). Service quality is critical for judging the success or failure of organizations (Estrada and Romero 2016). Quality is a term that is considered indicative of high level customer satisfaction and refers to factors that characterize a product or service. Service quality is an elusive and abstract construct that is

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*, Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_16

difficult to define and measure. Therefore, to measure the quality of service, traditional measurements make use of cardinal or ordinal scales (Akdag et al. 2014).

One of the methods of measuring service quality is the Analytic Hierarchy Process (AHP), which is a multi-criteria decision making method (Akdag et al. 2014). The AHP method is widely used to solve many complicated decision making problems. AHP is used in various sectors such as government, business, industry, healthcare, and education. AHP generates a weight for each evaluation criterion according to the decision maker's pairwise comparisons of the criteria. Higher weights represent higher importance levels. AHP assigns a score to each option according to the decision maker's pairwise comparisons of the options based on that criterion.

Fuzzy AHP is an even more popular methodology for measuring uncertainty (Zheng et al. 2012). In the fuzzy AHP methodology, entries of the pairwise comparison matrices are expressed with fuzzy numbers. This is an approach that deals with uncertain data and imperious knowledge. When decision makers need to make a decision in circumstances of uncertainty, they can use fuzzy AHP (Kahraman and Öztayşi 2013). The most common applications of AHP and fuzzy AHP are given below.

- Location selection
- Project and portfolio selection
- Supplier selection
- Planning and budgeting
- Product selection
- Market research
- Performance and risk measurement
- Personnel selection
- Vehicle selection.

There is a huge literature about service quality measurement. Cronin et al. indicated that the quality of customer service can be evaluated by the customer's predetermined expectation of important service elements and the customer's perception of after service transaction satisfaction (Cronin and Taylor 1992). Kahraman et al. used fuzzy AHP for comparing catering firms in Turkey. Triangular fuzzy numbers are produced by customers and experts (Kahraman et al. 2004). Taking into account the risk factors, Chan et al. proposed a model to provide a framework for an organization to select global suppliers. They used extended fuzzy AHP in the selection of global suppliers (Chan and Kumar 2007). Tolga et al. used AHP in the selection of operating systems. The economic part of the decision making process was improved with fuzzy backup analysis. Non-economic factors and the financial figures were combined by using fuzzy AHP (Tolga et al. 2005). Akdağ et al. evaluated the service quality of various hospitals in Turkey and used Fuzzy AHP and the TOPSIS method (Akdag et al. 2014). In a study, conducted by Stfano et al., fuzzy AHP was used to measure performance quality. Quality is a factor that affects customer satisfaction. It is important for organizations serving the perception of customer satisfaction (Stefano et al. 2015).

Maintenance services and quality satisfaction are important indicators. To satisfy the different needs of their clients, every aircraft maintenance and repair company must concentrate on improving their marketing strategies and the way in which they operate. Aircraft maintenance and repair companies must place importance on the services they provide such as engine, landing gear, component maintenance. The objective of this paper is to evaluate the service quality of an airline company by using fuzzy AHP.

Methodology

AHP

AHP, developed by Thomas L. Saaty in the 1980s, is a technique used to organize and analyze complex decisions, based on mathematics and psychology (Saaty 1980). AHP provides objective mathematics for manipulating the subjective and personal preferences of an individual or a group inevitably when a decision is made. Basically, AHP works by developing criteria for evaluating priorities and alternatives for alternatives. AHP can be described as a decision making and forecasting method that gives the percentage distributions of decision points in terms of factors affecting the decision, which can be used when defining the decision hierarchy. AHP relies on individual benchmarks on a decision hierarchy, using a predefined comparison scale, containing the factors that influence decision making and, if necessary, the significance of the decision points in terms of these factors. As a result, differences in significance are transformed into percentages on decision points.

The steps to be taken in order to resolve a decision-making problem with AHP are described below. The formulation and the related explanations have been made for each stage.

Step 1: Defining the Decision-Making Problem

The definition of the problem of decision making occurs in two stages. In the first stage, decision points are determined. In other words, the number of results that are going to be evaluated is determined. In the second stage, the factors affecting the decision points are identified. In this study, the number of decision points is symbolized by m, and the number of factors affecting the decision points is symbolized by n. In particular, it is important that the number of factors that will impact the endpoint is accurately determined and that detailed descriptions of each factor are made, so that binary comparisons can be made consistent and logical.

Step 2: Creating Factor Comparison Matrices

The interfacial comparison matrix is a dimensional square matrix. The matrix components on the diagonal of this matrix take the value one. The comparison matrix is given in Eq. 1.

Step 3: Determining the Percentage Distribution for Factors

The comparison matrix shows the significance levels of the factors according to each other within a certain logic. However, to determine the weights of all of these factors, in other words, to determine the percentage significance distributions, the column vectors forming the comparison matrix are used and n column b vector of n components are formed.

Step 4: Measuring the Consistency of the Benchmark Factors

Although AHP has a coherent system in itself, the veracity of the results will naturally depend on the consistency of the decision maker's comparison between the factors. AHP suggests a process for measuring the consistency of these comparisons. The resulting Consistency Ratio (CR) provides the possibility to test the consistency of the comparison of the priorities found as well as the individual comparisons between the factors. AHP is based on a comparison of the coefficient of the CR calculation with a factor called Factor Value (λ). For the calculation of λ, the initial matrix is compared with the matrix of the priority vector to obtain the column vector. The Randomness Indicators (RI) are given in Table 1.

Step 5: Finding the Percentage Distribution of the m Decision Point for each Factor

This step is as described in Step 4, with the difference that, the percentage distribution of the decision points is determined for each factor. In other words, individual comparisons and matrix operations are repeated as many times as the number of factors (n times). However, here the size of the comparison matrices to be used at the decision points for each factor will be $m * m$. After each comparison operation, column vectors are obtained which represent the percent distributions of the dimension and the evaluated factor according to the decision points.

Step 6: Finding the Distribution of Results at Decision Points

In this stage, first, a $m * n$ dimensional decision matrix is formed, which is formed from n $m^{*}1$ dimensional S column vector described in Step 5.

Table 1 Randomness indicators (RI)

1	2	3	4	5	6	7	8	9	10
0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Fuzzy AHP

The definition of “fuzzy” emerged as a result of the complexity in decision making problems encountered in real life. This fuzziness is scientifically defined as uncertainty, and in situations where uncertainty is the case, the decision maker’s preference is to make more general judgments rather than definite one. Therefore, in order to express the uncertainties in the methods used for decision making, “fuzzy logic” which is very similar to human thinking, is added to the methods. In classical approaches, there is a binary logic, which means something is either right or wrong. In fuzzy logic, on the other hand, there are many situations between right and wrong. Many decision making and problem solving methods are very complex. The decision making models and the success of decision makers depend on uncertainty. Decision makers prefer to express their comparisons as a range rather than fixed values, due to the fuzzy nature of the process. Since the AHP method does not sufficiently consider humanitarian factors, an alternative method to this multi criteria decision making method was developed. In order to solve hierarchical fuzzy problems, the fuzzy AHP was designed.

There is a very large literature that shows situations in which the comparison rates are inattentive judgments. For many real world problems, some decision data can be precisely assessed while others cannot. In practice, although humans are unsuccessful in making quantitative approximations, they are comparatively efficient in qualitative forecasting. Essentially, the uncertainty in preference judgments gives rise to uncertainty in the ranking of alternatives as well as difficulty in defining the consistency of preferences. The applications are performed using many different perspectives and fuzzy AHP methods (Özdağoğlu 2010).

In this study, Buckley’s fuzzy AHP was used for the quality evaluation problem. The steps used for the Buckley’s fuzzy AHP algorithm can be summarized as follows (Buckley 1985).

Step 1: Create a decision-making team.
Step 2: Determine the factors, sub factors, and alternatives used in the selection process of the AHP model.
Step 3: Construct pairwise fuzzy comparison matrices among all the criteria in the hierarchical structure. The pairwise matrices are shown in Eq. 1. Where $\widetilde{d_{ij}^k}$ indicates the kth decision maker’s preference of ith criterion over jth criterion.

$$\tilde{A}^k = \begin{pmatrix} 1 & \tilde{d}_{12}^k & \cdots & \tilde{d}_{1n}^k \\ \tilde{d}_{21}^k & 1 & \ddots & \tilde{d}_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{d}_{n1}^k & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} \quad (1)$$

The triangular fuzzy numbers are given in Table 2, based on the values between 1 and 9 defined in the Saaty scale.

Step 4: If there is more than one decision maker, the preferences of decision makers and calculated as in Eq. 2.

$$\tilde{d}_{ij} = \sqrt[K]{\prod_{k=1}^{K} \tilde{d}_{ij}^{k}} \tag{2}$$

where all $\tilde{d}_{ij}^{k}$ is a fuzzy number.

Step 5: Pairwise contribution matrix is updated as shown in Eq. 3.

$$\tilde{A} = \begin{pmatrix} \tilde{d}_{11} & \cdots & \tilde{d}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \cdots & \tilde{d}_{nn} \end{pmatrix} \tag{3}$$

Step 6: The Buckley's fuzzy AHP is calculated as shown in Eq. 5. $\tilde{r}_i$ represents the triangular values. The total sum of the geometric mean of each row is calculated as in Eq. 4.

$$\tilde{r}_i = \left(\prod_{j=1}^{n} \tilde{d}_{ij} \right)^{1/n} \quad \text{where} \quad i = 1, 2, \ldots, \text{n} \tag{4}$$

Step 7: The local weights are calculated as shown in Eq. 5.

$$\tilde{r}_i = \frac{\tilde{r}_i}{\sum_{r=1}^{n} \tilde{r}_n} \tag{5}$$

Table 2 Fuzzy numbers for criteria comparison

Explanation	Importance level	Inverse
Equally important	(1, 1, 1)	(1, 1, 1)
Much less important	(2, 3, 4)	(1/4, 1/3, 1/2)
Important	(3, 4, 5)	(1/5, 1/4, 1/3)
Very important	(6, 7, 8)	(1/8, 1/7, 1/6)
Absolute important	(8, 9, 9)	(1/9, 1/9, 1/8)

Step 8: Calculation of the global weights which is obtained from the local weights. After that, global weights are defuzzified.
Step 9: In the last step quality performance was calculated using the weights from the surveys.

Identifying the Main Criteria and Sub-criteria

In this paper, a hierarchical structure constructed with, 3 main criteria, 6 first level sub criteria and 17 s level sub criteria were used. These criteria were determined by a group of experts consisting of 2 academic experts and 2 airline service company workers. The proposed criteria are explained below.

Delivery operations:

- Delivery on time: Delivery of parts and materials on time.
- Receiving of the airplane from a customer: Receiving of aircraft and other controls.
- Insurance operations: The insurance for the aircraft maintained.

Customer relations:

- Customization: Customer satisfaction regarding services received outside.
- Customer satisfaction: Customer satisfaction regarding the work done.

Equipment and certification:

- Certificate of competence: Nationally and internationally recognized certificate.
- Calibration of devices: Calibration range of the devices.
- Availability: Availability of place, workers, and materials.

Employee information and safety:

- Competence of workers: Knowledge and skills of employees.
- Job security: The physical safety of the employees and the dangers and risks of the job.
- Task analysis: Analyzing the certification process.

Financial sources:

- The existence of necessary equipment: The equipment required to do maintenance.
- Work place and physical condition: Sufficiency of operating conditions.
- Man-hours' amount: A man-hour is the amount of work performed by the average worker in one hour.

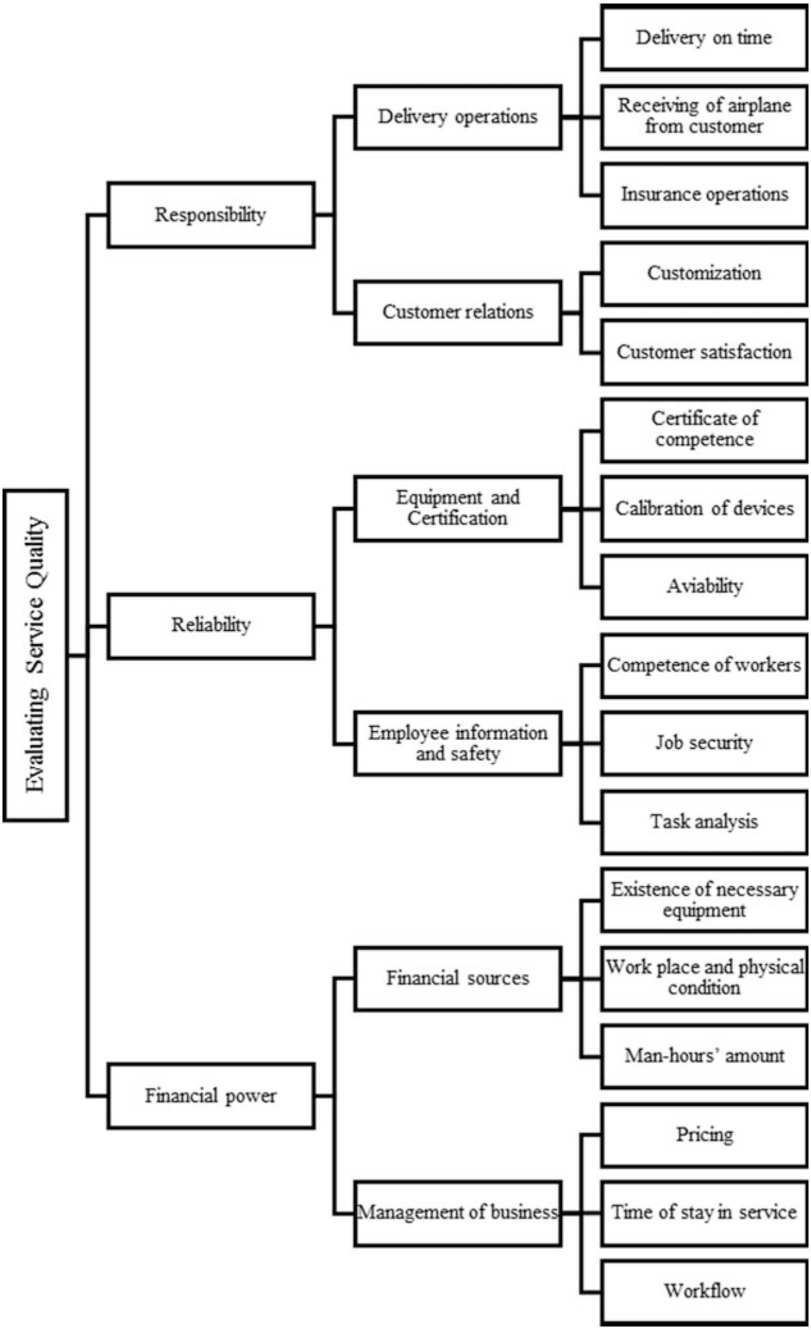

Fig. 1 Hieratical structure of the proposed model

Management of business:

- Pricing: Investment to improve the quality.
- Time of stay in service: Duration of maintenance for aircraft.
- Workflow: The sequential steps that comprise a work process in the business environment.

The proposed hieratical structure is given in Fig. 1. Here, related criteria are grouped with together and pairwise comparisons are made according to the structure.

Application and Results

In this part of the study, two surveys were applied. The first survey was to determine the weights of the criteria. The fuzzy AHP survey was applied to a group consisting of 2 airline service quality experts and 2 academics. Comparisons matrices were created and the group's decisions were calculated. The second survey was applied to 20 airline service company employees. The main criteria weights, according to the fuzzy AHP survey calculations, are given in Table 3.

The responsibility and reliability criteria are the most important criteria in Table 3. The financial power criterion has only a small amount of importance. After the main criteria weights, the first level sub-criteria global weights were calculated and given in Table 4.

The values in the application comparison matrix were obtained with the surveys conducted with the company. The geometric means were found for each row. Each local weight was found by dividing the geometric mean of each row by the total geometric mean. The global weights of second level sub-criteria are given in Table 5. Lastly, the quality score results are given in Table 6.

Table 3 Main criteria weights

Criteria	Weight
Responsibility	0.454824701
Reliability	0.447050721
Financial power	0.098124578

Table 4 First level sub criteria global weights

Criteria	Global weight
Delivery operations	0.188653687
Customer relations	0.266171013
Equipment and certification	0.107628877
Employee information and safety	0.339421844
Financial sources	0.073230495
Management of business	0.024894083

Table 5 Second level sub criteria global weights

Criteria	Global weight
Delivery on time	0.066844026
Receiving of airplane from customer	0.042255121
Insurance operations	0.07955454
Customization	0.073190768
Customer satisfaction	0.192980245
Certificate of competence	0.023907447
Calibration of devices	0.035958675
Availability	0.047762755
Competence of workers	0.133850446
Job security	0.173066119
Task analysis	0.032505279
Existence of necessary equipment	0.03484111
Work place and physical condition	0.023088759
Man-hours' amount	0.015300626
Pricing	0.009674902
Time of stay in service	0.007099261
Workflow	0.00811992

Table 6 Quality score calculation results

	Averages of survey	Weighted scores
Delivery on time	5.266	0.352
Receiving of airplane from customer	5.533	0.233
Insurance operations	5.933	0.472
Customization	4.600	0.336
Customer satisfaction	5.000	0.964
Certificate of competence	4.866	0.116
Calibration of devices	5.800	0.208
Availability	4.647	0.221
Competence of workers	5.200	0.696
Job security	5.200	0.899
Task analysis	4.800	0.156
Existence of necessary equipment	5.666	0.197
Work place and physical condition	5.466	0.126
Man-hours' amount	5.466	0.083
Pricing	4.666	0.045
Time of stay in service	4.933	0.035
Workflow	4.933	0.040
Sum		5.185

Table 7 Letter grade conversion scale

Score	Letter grade
6.30–7.00	AA
5.95–6.29	BA
5.60–5.94	BB
5.25–5.59	CB
4.90–5.24	CC
4.20–4.89	DC
3.50–4.19	DD
1.00–3.49	FF

To find the company's quality score, weighed score method was applied. The global weights were multiplied with the average of each criterion from the survey value. The values obtained were collected and the airline service company's quality score result was 5.185 out of 7.

Discussion and Conclusion

Measuring service quality is one of the most important challenges of our time. Service quality directly affects customer satisfaction and customer loyalty. In this study, a model was proposed to measure the service quality of an airline maintenance company. Indicators used in the model were created in consultation with company officials. These indicators and the coefficients of size were integrated with each other within a specific hierarchical structure using fuzzy AHP. The performance values were examined on a scale of 1–7, with 7 being the best performance. The performance of the airline maintenance company that was analyzed within the scope of the study was determined as 5.185. These results correspond to the CC letter grade. The letter grade conversion scale is given in Table 7.

In future studies, each company can implement the method of evaluating the service quality by choosing the appropriate criteria and calculating weights of these criteria. The criteria used may be different according to the characteristics of the companies. The results obtained can be compared with the results of previous years. A target can be created to improve service quality.

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A Fuzzy Based Risk Evaluation Model for Industry 4.0 Transition Process

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Abstract The concept of industry 4.0 is a critical topic that has been addressed by many studies recently as well as the business community. However, there are not many studies on the risk assessment of industry 4.0 transition process. In this paper, it is aimed to identify the risks that companies may face in the industry 4.0 transition process and to suggest a methodology for prioritization of these risks. We applied to expert opinions to address all numerical and verbal factors and used a fuzzy multicriteria decision-making (MCDM) methodology in order to determine the most and the least critical risks. For this aim, hesitant fuzzy sets (HFSs) and interval type-2 fuzzy sets (IT2FSs) have been utilized together to obtain the best results that are closer to the reality. Finally, risks have been prioritized for companies in the transition process to Industry 4.0.

Keywords Hesitant fuzzy sets · Industry 4.0 · Multi-criteria decision-making
Risk management · Type-2 fuzzy

Introduction

One of the most important developments in the last days in the industry is the concept of industry 4.0. Industry 4.0 can be also referred by the term "internet of things (IoT)". It means the entry of "Internet of things" into the production environment is starting a fourth industrial revolution: Industry 4.0 (Veza et al. 2015). These two terms refer to

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_17

the ingenious cooperation of devices in a factory that communicates with each other (Papa et al. 2017). Via Industry 4.0, high-performance computers through effective information exchange, powerful internet, and intelligent products and machines can revolutionize partially inflexible processes (Sommer 2015). Industry 4.0 focuses on developing methods to make production processes more flexible and to convert fixed production lines into self-configured assembly lines (Niesen et al. 2016). This concept projects a digital transformation that combines the cyber-physical world and the real world of manufacturing to deliver network-connected production with an improved process transparency (Preuveneers et al. 2017). Industry 4.0 revolution will exceed the current limits of production activities to provide a next generation intelligent, interoperable and interconnected production systems that can monitor system performance in real time to control costs, reduce downtime and prevent failures (Giannetti and Ransing 2016). In the first three industrial revolutions, mechanization has evolved through the proper management of electricity and information technology. With industry 4.0, global networks will be established machines, storage systems, and production facilities will be incorporated as cyber physical systems compatible with the Internet (Pereira et al. 2017). Besides all these, the effects of the rapidly developing technology of the Fourth Industrial Revolution put great difficulties for society and policy makers (Rajnai and Kocsis 2017). It means the fourth industrial revolution faces some challenges in the current manufacturing industry. The high levels of risk and uncertainty associated with companies' strategic planning activities are driven by the need to react to the rapidly increasing innovation pressure applied to manufacturing companies (Riel and Flatscher 2017). New approaches, modified frameworks, more complex IT infrastructures, etc. cause new risk types in the field of risk management because of links between people, systems, and objects have become more complex (Tupa et al. 2017). Production systems, intelligent products, analytical data, and business processes in the cloud interact directly with the customer to perform single individualized production ambitious goals and as result of this change, the risk of cyber security breaches increases (Preuveneers et al. 2017). That is, these new technological solutions always introduce security vulnerabilities and often reveal unexpected risks. So with increased confidence in technology to gain competitive advantage, security issues become one of the most critical and compelling requirements for a successful business (Pereira et al. 2017). However, it is not enough to examine these risks only in the field of information technology. Along with the inevitable changes caused by the transformation of the industrial age, there is a high probability that new risks will arise and there are many negative impacts on many companies in general. Considering all these risks and assessing them all in the same frame and determining the most critical risks is also of great importance in the industry 4.0 transformation. However, it may not be possible to quantify all of these risks. In this paper, we have identified the risks that companies may face in this industry 4.0 transformation and we have conducted a prioritization study among these risks. We applied to expert opinions to address all numerical and verbal factors and utilized a MCDM model so as to prioritize risks. We also applied HFSs and IT2FSs to get closer results to the truth and to incorporate expert opinions into the decision process. HFSs are effectively utilized when decision makers have hesitancy related to membership degree of an element in different decision-making problems. IT2FSs also have fuzzy membership functions and provide more pragmatic results in the decision-making process. The rest of the paper has been organized as follows: Section "Literature Review" includes a literature review of the study. Section "Hesitant Fuzzy Sets and Interval Type-2 Fuzzy Sets" presents a brief introduction related to hesitant fuzzy sets and interval type-2 fuzzy sets. The proposed fuzzy based methodology has been detailed in Section "The Proposed Fuzzy Based Methodology". Section "Application" presents a case study for risk assessment of Industry 4.0 transition process. Finally, Section "Conclusions and Future Suggestions" discusses the obtained results and future research suggestions.

Literature Review

In this section, the recently published papers about the Industry 4.0 and risk management have been analyzed. Riel and Flatscher (2017) proposed a structured methodological approach to strategic production planning in order to establish an actionable and living integrated manufacturing driven innovation road mapping process for Industry 4.0. Tupa et al. (2017) developed a research on Industry 4.0 related to key aspects and presentation of a design of a framework to implement risk management for the Industry 4.0 concept. Papa et al. (2017) presented how to design and implement mobile robot systems capable to work safety into complex industrial 4.0 environment. Saturno et al. (2017) proposed an analytic hierarchy process (AHP) method in evaluation for improving the diagnosis of automation systems in an existing production system towards alignment with Industry 4.0. Švingerová and Melichar (2017) reviewed Industry 4.0 from the perspective of benefits and risks that are not related to societal aspects but exclusively to serial production data from the automotive industry. Rajnai and Kocsis (2017) investigated the effect of Industry 4.0 on the digital transformation of manufacturing changes. Long et al. (2017) used extended coloured stochastic Petri nets for modelling the flexibility of production system in Industry 4.0. Pereira et al. (2017) presented some reflections regarding the challenges of Industry 4.0 emphasizing the security issues, towards raising awareness for security good practices within Industry 4.0. Preuveneers et al. (2017) evaluated the performance and scalability of an identity management solution for data flow-oriented processes to guarantee the authenticity and trustworthy access of users, machines, products, and business processes in Industry 4.0. Macurová et al. (2017) dealt with the questions of which features of today's business environment may become the driving factors in the implementation of Industry 4.0, and what risks and barriers are emerging on this way. Niesen et al. (2016) examined for assessing risks and security threats should be based on objective and transparent metrics that build on integrated real-time data in Industry 4.0 scenarios. Giannetti and Ransing (2016) proposed a novel algorithm to embed risk based thinking in quantifying uncertainty in manufacturing operations during the tolerance synthesis process. In this paper, an integrated fuzzy

MCDM methodology which consists of the Delphi method, hesitant and type-2 fuzzy sets have been proposed for the prioritization of possible risks in the industry 4.0 transition process. After determination of criteria and alternatives via literature review and Delphi approach, interval type-2 fuzzy AHP and hesitant fuzzy TOPSIS methods have been applied, respectively. The weights of evaluation criteria have been calculated through interval type-2 fuzzy AHP method, and the risks have been prioritized by using hesitant fuzzy TOPSIS method.

Hesitant Fuzzy Sets and Interval Type-2 Fuzzy Sets

Several different extensions of ordinary fuzzy sets such as type-2 fuzzy sets (T2FSs), intuitionistic fuzzy sets (IFSs), and hesitant fuzzy sets (HFSs) have been developed in the literature. Type-2 fuzzy sets whose membership functions are also fuzzy provide to cope with vagueness in the decision making process. Intuitionistic fuzzy sets developed by Atanassov (1986) use three different concepts as membership function, non-membership function, and hesitancy function in order to handle multi-criteria decision problems. HFSs which allow using different membership values between 0 and 1 for membership of an element is also an extension of regular fuzzy sets and developed by Torra (2010). Some basic concepts related to hesitant fuzzy sets are presented as follows:

Definition 1 (*Torra* 2010) Let X be a reference set, a hesitant fuzzy set on X is in terms of a function indicated as h that when applied to X returns a subset of [0, 1] and it is possible to indicate HFSs by using a mathematical expression given as follows: $E = \{\langle x, h_E(x)\rangle | x \in X\}$.

In this expression, $h_E(x)$ is a group of values in [0, 1] interval which denotes suitable membership degrees of the element $x \in X$ to the set E and $h_E(x)$ is called as a hesitant fuzzy element (HFE) (Xu and Xia 2011).

Definition 2 (*Torra* 2010; *Liao and Xu* 2013) Some basic operations (union, intersection, and complement) for three HFEs h, h_1 and h_2 are defined as follows:

$$\text{Lower bound}: h^-(x) = \min h(x) \quad \text{Upper bound}: h^+(x) = \max h(x)$$

$$h^c = \bigcup_{\gamma \in h} \{1-\gamma\}, \qquad h_1 \cup h_2 = \left\{h \in h_1 \cup h_2 \middle| h \geq \max(h_1^-, h_2^-)\right\}$$

$$h_1 \cap h_2 = \left\{h \in h_1 \cup h_2 \middle| h \leq \min(h_1^+, h_2^+)\right\}$$

Definition 3 (*Xia and Xu* 2011) Let h, h_1 and h_2 be three HFEs and λ be a positive number, some new operations are presented for three HFEs as follows:

$$h^\lambda = \bigcup_{\gamma \in h} \{\gamma^h\}, \quad \lambda h = \bigcup_{\gamma \in h} \left\{1 - (1-\gamma)^\lambda\right\}$$

$$\mathrm{h_1 \oplus h_2} = \bigcup_{\gamma_1 \in \mathrm{h_1}, \gamma_2 \in \mathrm{h_2}} \{\gamma_1 + \gamma_2 - \gamma_1\gamma_2\}, \ \mathrm{h_1 \otimes h_2} = \bigcup_{\gamma_1 \in \mathrm{h_1}, \gamma_2 \in \mathrm{h_2}} \{\gamma_1\gamma_2\}$$

Definition 4 (*Xu and Xia* 2011) Let $\mathrm{h_1}$ and $\mathrm{h_2}$ be two HFSs on $\mathrm{X} = \{x_1, x_2, \ldots, x_n\}$, the distance measure between $\mathrm{h_1}$ and $\mathrm{h_2}$ is represented by $\mathrm{d(h_1, h_2)}$ and it satisfies the following rules:

$$\begin{aligned} &0 \le \mathrm{d(h_1, h_2)} \le 1, \quad \mathrm{d(h_1, h_2)} = 0 \text{ if and only if } \mathrm{h_1 = h_2} \\ &\mathrm{d(h_1, h_2) = d(h_2, h_1)} \end{aligned}$$

Definition 5 (*Xu and Xia* 2011) Let $\mathrm{h_1}$ and $\mathrm{h_2}$ be two HFSs on $\mathrm{X} = \{x_1, x_2, \ldots, x_n\}$, the similarity measure between $\mathrm{h_1}$ and $\mathrm{h_2}$ is represented by $\mathrm{s(h_1, h_2)}$ and it satisfies the following rules:

$$0 \le \mathrm{s(h_1, h_2)} \le 1, \ \mathrm{s(h_1, h_2)} = 0 \text{ if and only if } \mathrm{h_1 = h_2}, \ \mathrm{s(h_1, h_2) = s(h_2, h_1)}.$$

Hesitant normalized Hamming and Euclidean distances are given in the following equations (Xu and Xia 2011) respectively.

$$\mathrm{d(h_1, h_2)} = \frac{1}{1}\sum_{\mathrm{j}=1}^{l} \left|\mathrm{h}_{1\sigma(\mathrm{j})} - \mathrm{h}_{2\sigma(\mathrm{j})}\right|, \quad \mathrm{d(h_1, h_2)} = \sqrt{\frac{1}{1}\sum_{\mathrm{j}=1}^{l} \left|\mathrm{h}_{1\sigma(\mathrm{j})} - \mathrm{h}_{2\sigma(\mathrm{j})}\right|^2}$$

where l(h) indicates the number of elements in the h and it is defined as the length of HFE. Generally, $l_{h_1} \neq l_{h_2}$, and the length of both HFEs is determined through l = max $\{l(h_1), l(h_2)\}$ equation.

Some basic definitions and operations for interval type-2 fuzzy sets are given in the following:

Definition 6 (*Mendel et al.* 2006*; Chen and Lee* 2010) A type-2 fuzzy set $\overset{\approx}{\mathrm{A}}$ in the universe of discourse X can be represented by a type-2 membership function $\mu_{\overset{\approx}{\mathrm{A}}}$, given in the following:

$\overset{\approx}{\mathrm{A}} = \left\{((\mathrm{x}, \mathrm{u}), \mu_{\overset{\approx}{\mathrm{A}}}(\mathrm{x}, \mathrm{u}))\middle| \forall \mathrm{x} \in \mathrm{X}, \forall \mathrm{u} \in \mathrm{J_x} \subseteq [0, 1], 0 \le \mu_{\overset{\approx}{\mathrm{A}}}(\mathrm{x}, \mathrm{u}) \le 1\right\}$, where $\mathrm{J_x}$ denotes an interval in [0, 1]. Moreover, the type-2 fuzzy set $\overset{\approx}{\mathrm{A}}$ also can be represented in the following:

$\overset{\approx}{\mathrm{A}} = \int_{\mathrm{x} \in \mathrm{X}} \int_{\mathrm{u} \in \mathrm{J_x}} \mu_{\overset{\approx}{A}}(\mathrm{x}, \mathrm{u})/(\mathrm{x}, \mathrm{u})$, where $\mathrm{J_x} \subseteq [0, 1]$ and $\iint$ denotes union over all admissible x and u.

Definition 7 (*Mendel et al.* 2006*; Chen and Lee* 2010) Let $\overset{\approx}{\mathrm{A}}$ be a type-2 fuzzy set in the universe of discourse X represented by a type-2 membership function $\mu_{\overset{\approx}{\mathrm{A}}}$. If all $\mu_{\overset{\approx}{\mathrm{A}}}(\mathrm{x}, \mathrm{u}) = 1$, then $\overset{\approx}{\mathrm{A}}$ is called as an interval type-2 fuzzy set. An interval type-2 fuzzy set $\tilde{\tilde{A}}$ can be considered as a special case of a type-2 fuzzy set, represented in the following:

$$\tilde{\tilde{A}} = \int_{x \in X} \int_{u \in J_x} \frac{1}{(x,u)} \quad \text{where} \quad J_x \subseteq [0,1].$$

Definition 8 (*Mendel et al.* 2006*; Chen and Lee* 2010) The upper and lower membership functions of an interval type-2 fuzzy set are type-1 fuzzy sets as shown in below, respectively.

$$\begin{aligned}\tilde{\tilde{A}}_1 = (\tilde{A}_1^U, \tilde{A}_1^L) = ((a_{11}^U, a_{12}^U, a_{13}^U, a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U))\\ (a_{11}^L, a_{12}^L, a_{13}^L, a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)))\end{aligned}$$

$$\begin{aligned}\tilde{\tilde{A}}_2 = (\tilde{A}_2^U, \tilde{A}_2^L) = ((a_{21}^U, a_{22}^U, a_{23}^U, a_{24}^U; H_1(\tilde{A}_2^U), H_2(\tilde{A}_2^U))\\ (a_{21}^L, a_{22}^L, a_{23}^L, a_{24}^L; H_1(\tilde{A}_2^L), H_2(\tilde{A}_2^L)))\end{aligned}$$

Definition 9 (*Chen and Lee* 2010*; Kılıç and Kaya* 2015) Let $\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ are two interval type-2 fuzzy sets. The basic operations such as addition and multiplication between these two trapezoidal interval type-2 fuzzy sets are defined as follows:

$$\begin{aligned}&\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2\\ &= (\tilde{A}_1^U, \tilde{A}_1^L) \oplus (\tilde{A}_2^U, \tilde{A}_2^L)\\ &= ((((a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U;\\ &\quad \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U))),\\ &\quad (a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L;\\ &\quad \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^{L}))).\end{aligned} \tag{1}$$

$$\begin{aligned}&\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2\\ &= (\tilde{A}_1^U, \tilde{A}_1^L) \otimes (\tilde{A}_2^U, \tilde{A}_1^L)\\ &= ((((a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U;\\ &\quad \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U))),\\ &\quad (a_{11}^L \otimes a_{21}^L, a_{12}^L \otimes a_{22}^L, a_{13}^L \otimes a_{23}^L, a_{14}^L \otimes a_{24}^L;\\ &\quad \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L))).\end{aligned} \tag{2}$$

$$k \times \tilde{\tilde{A}}_1 = ((k \times a_{11}^U, k \times a_{12}^U, k \times a_{13}^U, k \times a_{14}^U; H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U)), \\ (k \times a_{11}^L, k \times a_{12}^L, k \times a_{13}^L, k \times a_{14}^L; H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L)) \quad (3)$$

The Proposed Fuzzy Based Methodology

In this paper, an integrated fuzzy MCDM model which consists of interval type-2 fuzzy sets and hesitant fuzzy sets has been suggested to prioritize risks for industry 4.0 transition process. The details of these methods are briefly summarized as follows:

Interval Type-2 Fuzzy AHP

The steps of interval type-2 fuzzy AHP method are presented as follows (Kahraman et al. 2014; Kılıç and Kaya 2015; Erdoğan and Kaya 2016; Çevik Onar et al. 2014; Çolak and Kaya 2017):

Step 1 Decision problem is defined as a hierarchical structure consisting of objective, evaluation criteria, and alternatives.

Step 2 Type-2 fuzzy pairwise comparison matrix (PCM) is created by using expert evaluations. Each element of the PCM is an interval type-2 fuzzy set and obtained by using geometric mean of expert evaluations. The linguistic terms and corresponding interval type-2 fuzzy numbers utilized in this study are given in Table 1. Besides, the fuzzy PCM is shown as follows:

$$\tilde{\tilde{A}} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n} \\ \tilde{\tilde{a}}_{21} & 1 & \cdots & \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\tilde{a}}_{n1} & \tilde{\tilde{a}}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n} \\ \frac{1}{\tilde{\tilde{a}}_{12}} & 1 & \cdots & \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{\tilde{\tilde{a}}_{1n}} & \frac{1}{\tilde{\tilde{a}}_{2n}} & \cdots & 1 \end{bmatrix} \quad (4)$$

Table 1 Linguistic terms and corresponding interval type-2 fuzzy numbers (Erdoğan and Kaya 2016)

Linguistic terms	Corresponding interval type-2 fuzzy numbers
Absolutely Important (AI)	(7, 8, 9, 9; 1, 1) (7.1, 8.1, 8.9, 8.9; 0.85, 0.85)
Strongly Important (SI)	(5, 6, 8, 9; 1, 1) (5.1, 6.1, 7.9, 8.9; 0.85, 0.85)
Very Important (VI)	(3, 4, 6, 7; 1, 1) (3.1, 4.1, 5.9, 6.9; 0.85, 0.85)
More Important(MI)	(1, 2, 4, 5; 1, 1) (1.1, 2.1, 3.9, 4.9; 0.85, 0.85)
Equal (E)	(1, 1, 1, 1; 1, 1) (1, 1, 1, 1; 1, 1)

The geometric mean is utilized to aggregate expert evaluations. The geometric mean of n interval type-2 fuzzy numbers are calculated in the following:

$$\tilde{\tilde{a}}_{ij} = \sqrt[n]{\tilde{\tilde{a}}_{ij}^{1} \otimes \tilde{\tilde{a}}_{ij}^{2} \otimes \ldots \otimes \tilde{\tilde{a}}_{ij}^{n}} = \left[\tilde{\tilde{a}}_{ij}^{1} \otimes \tilde{\tilde{a}}_{ij}^{2} \otimes \ldots \otimes \tilde{\tilde{a}}_{ij}^{n}\right]^{\frac{1}{n}} \tag{5}$$

$$\begin{aligned} \sqrt[n]{\tilde{\tilde{a}}_{ij}} = &\left(\left(\sqrt[n]{a_{ij1}^{U}}, \sqrt[n]{a_{ij2}^{U}}, \sqrt[n]{a_{ij3}^{U}}, \sqrt[n]{a_{ij4}^{U}}; H_1^U(a_{ij}), H_2^U(a_{ij})\right)\right. \\ &\left.\left(\sqrt[n]{a_{ij1}^{L}}, \sqrt[n]{a_{ij2}^{L}}, \sqrt[n]{a_{ij3}^{L}}, \sqrt[n]{a_{ij4}^{L}}; H_1^L(a_{ij}), H_2^L(a_{ij})\right)\right. \end{aligned} \tag{6}$$

Step 3 The fuzzy PCMs are checked for consistency. The defuzzified values of interval type-2 fuzzy numbers are utilized to calculate consistency rates for PCMs. If the consistency rate is smaller than 0.1 matrix is consistent.

Step 4 Fuzzy geometric mean is computed for each criterion. The fuzzy geometric mean for each row is computed in the following:

$$\tilde{\tilde{r}}_i = [\tilde{\tilde{a}}_{i1} \otimes \tilde{\tilde{a}}_{i2} \otimes \ldots \otimes \tilde{\tilde{a}}_{in}]^{1/n} \tag{7}$$

Step 5 The interval type-2 fuzzy weights are computed for each criterion. The fuzzy weight of the ith criterion is computed in the following:

$$w_i = \tilde{\tilde{r}}_i \otimes [\tilde{\tilde{r}}_1 \oplus \ldots \oplus \tilde{\tilde{r}}_i \oplus \ldots \oplus \tilde{\tilde{r}}_n]^{-1} \tag{8}$$

Step 6 Interval type-2 fuzzy weights are defuzzified by using a suitable method in order to obtain crisp weights for each criterion.

Hesitant Fuzzy TOPSIS

The steps of hesitant fuzzy TOPSIS method are presented as follows (Zhang and Wei 2013; Çevik Onar et al. 2014; Çolak and Kaya 2017):

Step 1 The positive and negative ideal solutions are determined in the following:

$$A^* = \{h_1^*, h_2^*, h_3^*, \ldots, h_n^*\} \text{ where}$$

$$h_j^* = \bigcup_{i=1}^{m} h_{ij} = \bigcup_{\gamma_{1j} \in h_{1j}, \ldots, \gamma_{mj} \in h_{mj}}, \max\{\gamma_{1j}, \ldots, \gamma_{mj}\} \quad j = 1, 2, \ldots, n \tag{9}$$

$$A^- = \{h_1^-, h_2^-, h_3^-, \ldots, h_n^-\} \text{ where}$$

$$h_j^- = \bigcap_{i=1}^{m} h_{ij} = \bigcap_{\gamma_{1j}\in h_{1j},\ldots,\gamma_{mj}\in h_{mj}}, \min\{\gamma_{1j}, \ldots, \gamma_{mj}\} \quad j = 1, 2, \ldots, n \quad (10)$$

Step 2 The distance of each alternative from positive and negative ideal solutions are determined by using weighted hesitant normalized Euclidean distance as follows:

$$D_i^+ = \sum_{j=1}^{n} w_j \left\| h_{ij} - h_j^* \right\|, \text{ and } D_i^- = \sum_{j=1}^{n} w_j \left\| h_{ij} - h_j^- \right\| \quad (11)$$

where w_j indicates the crisp weight of the jth criterion determined by using interval type-2 fuzzy AHP method.

Step 3 The relative closeness index for each alternative is calculated through the following equation.

$$C_i = \frac{D_i^-}{(D_i^- + D_i^+)} \quad (12)$$

Step 4 Alternatives are ranked according to their relative closeness index values. The alternative which has the highest closeness index value is determined as the best alternative.

Application

In this study, an integrated fuzzy based MCDM methodology has been proposed for risk assessment of industry 4.0 transition process. Firstly, evaluation criteria and alternatives are determined through literature review and Delphi approach. The hierarchical structure for criteria and alternatives is presented in Fig. 1. Besides, a flowchart for the proposed methodology is also given in Fig. 2. As seen in Fig. 2, interval type-2 fuzzy AHP method has been applied in order to determine weights of evaluation criteria. In this method, linguistic evaluations obtained from 4 decision makers have been utilized to create pairwise comparison matrices. After checking consistency, interval type-2 fuzzy criteria weights have been calculated. Finally, the fuzzy criteria weights have been defuzzified by using the Center of Area (COA) method used by Kılıç and Kaya (2015).

The criteria utilized for evaluating the risk alternatives can be briefly explained as follows. Performance is an important criterion for measurement and defines the gaps between present and desired systems. Information security is mainly about privacy, which means that information should be accessible only by authorized

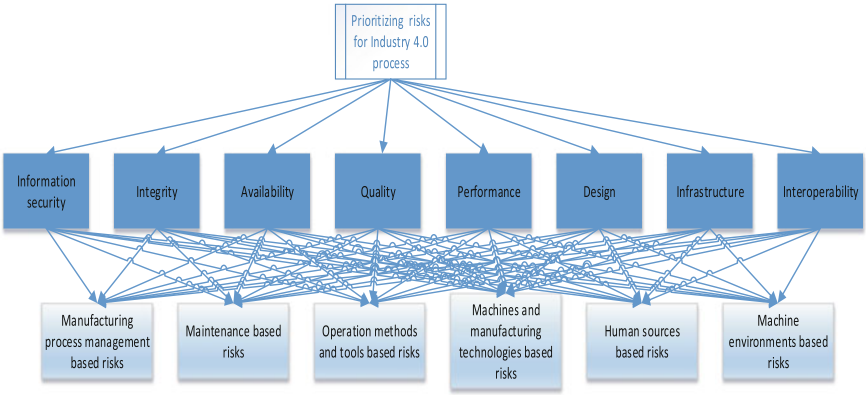

Fig. 1 The hierarchical framework for criteria and alternatives

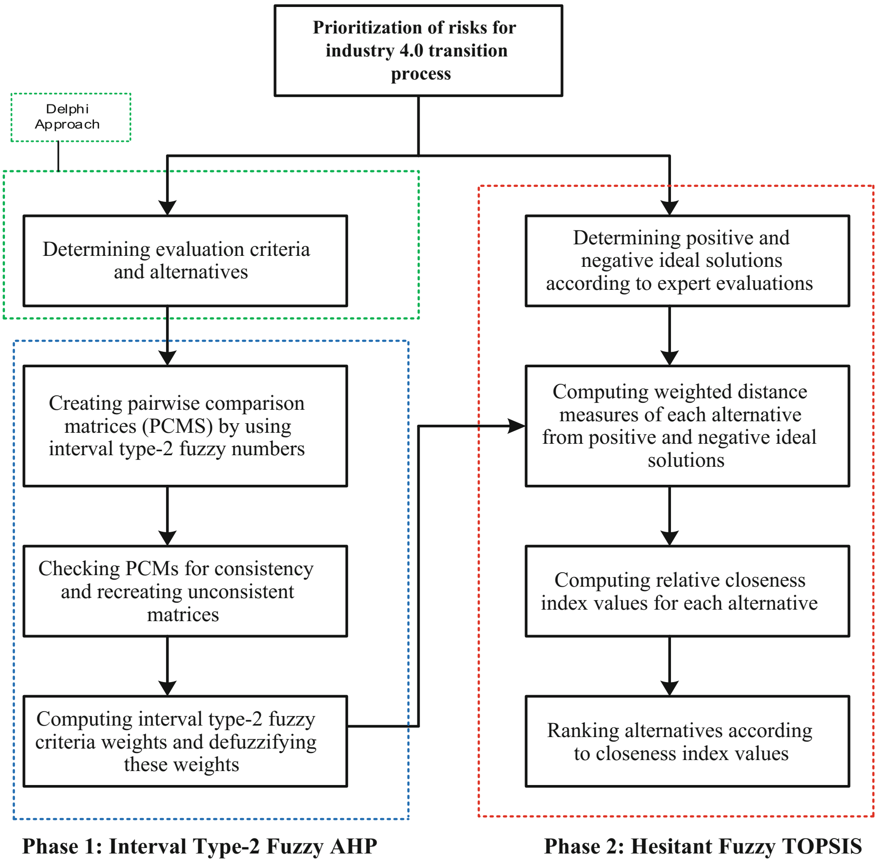

Fig. 2 The flowchart for the proposed methodology

people. Integrity means to preserve certainty and accuracy of information and transaction methods. Availability indicates to allow authorized users to access information and related entities when needed. Quality is an essential criterion and manufacturing companies must adopt a quality standard in the Industry 4.0 transition process. The design is also an important factor for handling risks in companies (Tupa et al. 2017). The infrastructure defines a single standard for networks and communication protocols between interoperable systems that facilitate communication between different suppliers for the same solution. Interoperability is the capacity of a system or product to work with other systems or products without any special effort by the customer (Saturno et al. 2017).

The interval type-2 fuzzy, the defuzzified and the normalized criteria weights have been obtained by means of interval type-2 fuzzy AHP calculations and presented in Table 2.

As seen in Table 2, the information security criterion has been determined as the most important criterion with the weight of 0.3321 among all criteria. Besides, the design has been determined as the least important criterion with the weight of 0.0333. These defuzzified criteria weights have been used in hesitant fuzzy TOPSIS method to compute weighted distance measures. Hesitant fuzzy decision matrix for risk assessment has been presented as shown in Table 3.

Positive and negative ideal solutions which indicate maximum and minimum values for each criterion are given as follows:

$$\begin{aligned} A^* &= \left\{h_1^*, h_2^*, h_3^*, \ldots, h_8^*\right\} = \{1, 1, 1, 1, 1, 1, 1, 1\} \\ A^- &= \left\{h_1^-, h_2^-, h_3^-, \ldots, h_8^-\right\} = \{0.4, 0.3, 0.4, 0.5, 0.5, 0.4, 0.4, 0.4\} \end{aligned}$$

In this study, hesitant Euclidean distance measure has been used in order to calculate the distance between two hesitant fuzzy sets. Euclidean distance between two hesitant fuzzy sets is calculated as follows:

$$\|\{0.7, 0.8, 0.9\} - \{1\}\| = \sqrt{\frac{1}{3}\left[|0.7-1|^2 + |0.8-1|^2 + |0.9-1|^2\right]} = 0.216$$

In the second step of the hesitant fuzzy TOPSIS method, distances from positive and negative ideal solutions for each alternative are determined as follows:

$$\begin{aligned} D_1^+ &= 0.3321 \times \|\{0.9, 1\} - \{1\}\| + 0.0462 \times \|\{0.7, 0.8, 0.9, 1\} - \{1\}\| + \ldots \\ &\quad + 0.1562 \times \|\{0.7, 0.8, 0.9\} - \{1\}\| + 0.0673 \times \|\{0.8, 0.9, 1\} - \{1\}\| = 0.134 \end{aligned}$$

$$\begin{aligned} D_1^- &= 0.3321 \times \|\{0.9, 1\} - \{0.4\}\| + 0.0462 \times \|\{0.7, 0.8, 0.9, 1\} - \{0.3\}\| + \ldots \\ &\quad + 0.1562 \times \|\{0.7, 0.8, 0.9\} - \{0.4\}\| + 0.0673 \times \|\{0.8, 0.9, 1\} - \{0.4\}\| = 0.480 \end{aligned}$$

The closeness index values for each alternative have been determined by using D^- and D^+ values as shown in the following:

Table 2 The weights of evaluation criteria

Criteria	Interval type-2 fuzzy weights	Defuzzified weights	Normalized weights
C1: Information security	(0.15, 0.24, 0.48, 0.69; 1, 1) (0.16, 0.25, 0.47, 0.67; 0.85, 0.85)	0.394	0.3321
C2: Integrity	(0.02, 0.03, 0.06, 0.10; 1, 1) (0.02, 0.03, 0.06, 0.10; 0.85, 0.85)	0.055	0.0462
C3: Availability	(0.09, 0.15, 0.29, 0.42; 1, 1) (0.10, 0.15, 0.28, 0.40; 0.85, 0.85)	0.238	0.2003
C4: Quality	(0.02, 0.03, 0.06, 0.10; 1, 1) (0.02, 0.03, 0.06, 0.10; 0.85, 0.85)	0.054	0.0456
C5: Performance	(0.05, 0.08, 0.17, 0.26; 1, 1) (0.06, 0.09, 0.16, 0.25; 0.85, 0.85)	0.141	0.1190
C6: Design	(0.02, 0.02, 0.04, 0.07; 1, 1) (0.02, 0.02, 0.04, 0.07; 0.85, 0.85)	0.039	0.0333
C7: Infrastructure	(0.07, 0.11, 0.22, 0.35; 1, 1) (0.07, 0.11, 0.21, 0.33; 0.85, 0.85)	0.185	0.1562
C8: Interoperability	(0.03, 0.05, 0.09, 0.15; 1, 1) (0.03, 0.05, 0.09, 0.14; 0.85, 0.85)	0.080	0.0673

Table 3 Hesitant fuzzy decision matrix

Alternatives	C1	C2	C3	C4
A1	{0.9, 1}	{0.7, 0.8, 0.9, 1}	{0.9, 1}	{0.8, 0.9}
A2	{0.7, 0.8, 0.9}	{0.7, 0.8, 1}	{0.8, 0.9, 1}	{0.8, 0.9}
A3	{0.7, 0.8, 0.9}	{0.6, 0.7, 0.8}	{0.8, 0.9, 1}	{0.8, 1}
A4	{0.8, 1}	{0.5, 0.7, 0.9}	{0.8, 0.9}	{0.7, 0.8}
A5	{0.4, 0.5, 0.6, 0.7}	{0.3, 0.4, 0.5}	{0.4, 0.5, 0.6}	{0.5, 0.7, 0.8}
A6	{0.7, 0.8, 0.9}	{0.6, 0.7, 0.8}	{0.7, 0.8}	{0.7, 0.8, 1}
Alternatives	C5	C6	C7	C8
A1	{0.7, 0.8, 0.9}	{0.5, 0.6, 0.7, 0.8}	{0.7, 0.8, 0.9}	{0.8, 0.9, 1}
A2	{0.7, 0.8}	{0.5, 0.6, 0.7}	{0.7, 0.8, 0.9}	{0.5, 0.7, 0.8}
A3	{0.8, 0.9, 1}	{0.7, 0.8, 0.9}	{0.8, 0.9, 1}	{0.6, 0.8, 0.9}
A4	{0.7, 0.9}	{0.8, 0.9}	{0.7, 0.8, 0.9}	{0.7, 0.8}
A5	{0.5}	{0.4, 0.5}	{0.4, 0.5}	{0.4, 0.6, 0.7}
A6	{0.7, 0.8, 0.9}	{0.8, 1}	{0.8, 0.9, 1}	{0.9, 1}

$$C_1 = \frac{D_1^-}{D_1^- + D_1^+} = \frac{0.480}{0.480 + 0.134} = 0.782$$

Finally, alternatives have been ranked through closeness index values. Weighted hesitant Euclidean distance measures, closeness index values for each alternative and related ranking have been presented in Table 4.

Table 4 The closeness index values for alternatives

Risks	D+	D−	Ci	Rank
A1: The risks based on manufacturing process management	0.134	0.480	0.782	1
A3: The risks based on operations methods and tools	0.179	0.442	0.712	2
A4: The risks based on machines and manufacturing technologies	0.189	0.432	0.696	3
A6: The risks based on machine environments	0.202	0.412	0.671	4
A2: The risks based on maintenance	0.216	0.400	0.649	5
A5: The risks based on human sources	0.494	0.131	0.209	6

As seen in Table 4, the risks based on manufacturing process management have been determined as the most critical risk. The risk alternatives have been ranked as operations methods and tools, machines and manufacturing technologies, machine environments, maintenance, and human sources based risks after manufacturing process management based risks respectively.

Conclusions and Future Suggestions

In this paper, an integrated fuzzy MCDM model based on the Delphi method, interval type-2 fuzzy sets and hesitant fuzzy sets has been suggested to prioritize risks for industry 4.0 transition process. By the way, we aimed to provide a useful study regarding potential risks of industry 4.0 for manufacturing companies. For this purpose, interval type-2 fuzzy AHP and hesitant fuzzy TOPSIS methods have been applied in order to prioritize risks. Firstly, the weights of the evaluation criteria have been successfully calculated by using interval type-2 fuzzy AHP method. Then alternative risks have been successfully ranked via hesitant fuzzy TOPSIS method. As one of the results, information security and design criteria have been determined as the most and the least important criterion respectively. By the way, the risks based on manufacturing process management are determined as the most critical risks for industry 4.0 transition process. Besides, the risk based on human sources are also evaluated as the least critical risks as a result of the proposed model.

We can say that this study can be beneficial for manufacturing companies while making a decision related to industry 4.0 transition. As a future suggestion, different MCDM methods can be applied together to this problem. Besides, different extensions of fuzzy sets such as intuitionistic fuzzy sets can be applied with MCDM methods for risk assessment in industry 4.0 process.

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Analysis of Frequent Visitor Patterns in a Shopping Mall

Onur Dogan, Omer Faruk Gurcan, Basar Oztaysi and Ugur Gokdere

Abstract Recent technological advances enabled companies to collect, store and process a large amount of data. Automated collection of human behavior is one of the recent developments in data collection field. Companies can analyze the behaviors of their customers and get insight into their needs by using automated collection technology. In this study, we analyze location-based services data collected from a major shopping mall in İstanbul. The data is composed of 293 locations and 12070 unique visitors. The results show the most frequent routes that users follow during different periods.

Keywords Data mining · Location based services · Bluetooth
Market basket analysis

Introduction

Current technological developments provide companies to collect, store and process a huge amount of data. One of the emerging study areas is human behavior analysis based on automatically collected data. Companies try to generate customer-oriented solutions via analyzing their interests and desires. For online companies, it is easier

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_18

because of simplicity of data collection. Each click or cursor movement can be collected and stored easily. On the other hand, physical retailers have a limitation about the collection of customer data. Infosys Company reports that 78% of consumers would be customers again if a retailer offers customer-oriented solutions (Infosys 2013). In the light of this study, the understanding customer is a critical factor for not only online companies but also physical retailers to survive in a competitive environment.

RetailNext (2017) declares that 84% of customers expect that retailers should integrate the online and offline channels. Therefore, physical stores need to provide customers-based service that they received from the Internet by establishing relationship digital channels (Wu et al. 2015). Tracking customers in the stores using different technologies such as Bluetooth facilitates integrating online and offline channels (Oosterlinck et al. 2017; Merad et al. 2016; Wu et al. 2015; Hurjui et al. 2008). The increase in mobile device usage of customers brings an opportunity for retailers to develop customer experience in-store shopping (Li et al. 2017). Bluetooth technology may be used to track customers' digital footprints. These digital footprints can be used to detect the customers' movement in-store and common routes. The results of such analysis can be used for in-store marketing purposes.

In this study, we use data collected via Beacon devices. The iBeacon devices (hereafter Beacons) broadcast low energy radio signals, interact with the smart devices in their coverage zone, and exchange information with them. The coverage zone of a Beacon device is 50 m, and their interaction distance can be fine-tuned within this range. This interaction, which is extremely power-efficient, is based on Bluetooth's innovative network technology Bluetooth Low Energy (BLE), or the trademarked name, Bluetooth® Smart. When a mobile device encounters a Beacon device in a venue, the mobile device automatically refers to a software program (SDK) embedded into a mobile application running on the mobile device. Consequently, it consults to the beacon's server. According to the command from the server, the mobile device performs any action, such as displaying a message or serving as a micro-location sensor. The beacon device, the embedded SDK in the application, and the server, together form the sensor-management platform of Blesh that realizes the Beacon communication. The data used in this study is collected by Blesh, a Turkish start-up company which offers enterprises the whole platform along with the assisting service to manage, focusing on refining the opportunities that come along with this platform, and how this new communication method can produce business solutions. As Blesh beacons, mobile application partners and the enterprise network grow, the beacon management platform turns gradually into an advertising platform for marketing agencies to get involved in. Exceeding 100.000 beacons in over 50 cities in Turkey, amounting to roughly 15.000 points of interest, Blesh beacons are placed in more than 200 shopping malls, prominent airports, leading banks, top retail shops, subway stations, cafés and restaurants and among many other venues.

The rest of the paper is as follows. In Sect. "Literature Review", a literature review of data collection in-store shopping. In Sect. "Methodology", the methodology is introduced with data collection and preparation details. Section "Application" involves the results of the application. Finally, the discussion and conclusion are given in Sect. "Discussion and Conclusion".

Literature Review

In the literature and industry, various ways are used to collect the data for customer behavior analysis. In a traditional way, the questionnaire is the most commonly preferred method to collect data from others such as observation and interview. Das and Varshneya (2017) and Kesari and Atulkar (2016) used a structured questionnaire to understand consumers' emotions and satisfaction, respectively, in a shopping mall. Some researches use both questionnaire and review methods to enhance the significance. For example, Kirchberg and Tröndle (2012) used interview method to research the similarities and differences between their experiences. The collected data are grouped into three categories: visitors' expectations refer to the motivations before the visit, experiences indicate social interactions during the visit and contributions point out what customers learned after the visit. Yiu and Ng (2010) also used both customer surveys and interview methods to measure buyers-to-shoppers ratio. Merad et al. (2016) used observation method in their study. Operators have directly observed customers' behaviors in the store.

As an alternative to data collection to analyze customer behavior, some technologies gather much more data in a non-invasive way. Traditional data collection methods, questionnaire, interview, observation or surveys, have some limitations. For instance, the real time of customers' activities, generally, cannot be saved. This results in deviations from actual results. For that reason, Willeims et al. (2017) used WiFi technology to compile an inventory of retail technologies, which are classified based on shopping value types and shopping cycle stage. Carrera et al. (2018) used WiFi technology for real-time tracking. Fukuzaki et al. (2015) tried to estimate the actual number of people in the area by comparing the number of acknowledged devices in the shopping mall by using WiFi. Oosterlinck et al. (2017) demonstrated the applicability of Bluetooth tracking in a shopping mall. They used Bluetooth scanners in their study. They obtained high data quality and low cost of data collection. Yewatkar et al. (2016) proposed a smart shopping cart system that will keep track of purchased products and online transaction for billing using RFID and ZigBee. Although Zigbee and Bluetooth technologies collect data in a similar way, the difference between them is the data exchange scale. Zigbee gathers data on a small scale.

The camera is another data collection technology. Camera technologies use sophisticated image processing algorithms that are complex to describe the object to be tracked (Oosterlinck et al. 2017). Wu et al. (2015) used the camera to record customers in the store to understand their behavior. They showed the trajectories of the customer in a heat map. Arroyo et al. (2015) used the in-store camera to detect

Table 1 Some data collection technologies and studies

Technology	Study	Technology	Study
Bluetooth	Yoshimura et al. (2014)	Zigbee	Stępień et al. (2016)
	Yoshimura et al. (2017)		Salim et al. (2014)
	Oosterlinck et al. (2017)		Pan et al. (2014)
	Frisby et al. (2017)	Camera	Liu et al. (2015)
	Castillo-Cara et al. (2016)		Yim et al. (2010)
	Delafontaine et al. (2012)		Esterle et al. (2014)
RFID	Catarinucci et al. (2014)		Arroyo et al. (2015)
	Jones et al. (2004)		Wu et al. (2015)
	Cao et al. (2014)	Infrared	Jovanovic et al. (2014)
	Seol et al. (2017)		Asha and Narasimhadhan (2017)
	Yewatkar et al. (2016)	Ultrasound	Jaramillo and Linnartz (2015)
Wi-Fi	Liu et al. (2014)		Bihler et al. (2011)
	Hernández et al. (2014)		
	Yuanfeng et al. (2016)		
	Fukuzaki et al. (2015)		
	Carrera et al. (2018)		
	Willeims et al. (2017)		

real-time detection of suspicious customer behaviors in a shopping mall. They benefited from advanced processing algorithms in their study.

Table 1 shows some studies used data collection technologies.

Methodology

Association Rule Mining (ARM) is one of the data mining methods that used to discover interesting dependencies between datasets (Feng et al. 2016). Many business enterprises collect a huge amount of data from various sources. Table 2 shows an example of data related to customer routes in a shopping mall. Each location in the shopping mall has a beacon ID that collects data from customers' mobile phone via Bluetooth.

Agrawal et al. (1993) first introduced ARM as an effective way to find relationships between hidden large datasets that satisfy a certain support and confidence values. Interesting relations or correlations are helpful in many businesses for making useful decisions (Han and Kamber 2006). Therefore, many industrial applications try to find dependencies between variables.

Support and confidence values are two critical parameters in the ARM. If the support value is very low, then generated rule may occur by chance. Also, very low support threshold may cause to generate uninteresting rules (Tan et al. 2005). Frequent item set generation is a result of the support threshold. On the other hand,

Table 2 An example of customer routes

Customer ID	Routes
4633698	{121600, 121633, 121565}
26066031	{121372, 121600, 121307, 121507}
29235005	{121289, 123937, 121388, 121372}
37711500	{121372, 121289, 121600, 121388}
35272768	{121372, 121289}

confidence check reliability of the inference made by rule. Minimum confidence value affects the generated rules. Equations 1 and 2 show the calculation of the support and confidence ratios, respectively.

$$Support, s\,(X \rightarrow Y) = \frac{n(X \cup Y)}{N} \tag{1}$$

$$Confidence, c\,(X \rightarrow Y) = \frac{n(X \cup Y)}{n(X)} \tag{2}$$

where N is the total number of transactions, X and Y show two items in the dataset.

An association rule is created by item sets that satisfy the minimum support (minsup) and minimum confidence (minconf) values. It does not imply causality. Causality needs cause and consequent of the rule. Table 3 demonstrates the interestingness of a rule regarding support and confidence. An interesting rule is a rule that has a lower support value and higher confidence value.

ARM represents the uncovered relationships as sets of frequent items or association rules. Frequent item sets generation is the first step of the ARM. It aims to find items or item sets that satisfy the minimum support constraint. Since the generation of frequent item sets has computational requirements, it is more expensive than those rule generations. Therefore, some effective methods were developed. Agrawal and Srikant (1994) presented Apriori algorithm to facilitate frequent item set generation. Apriori algorithm helps to reduce the number of candidate item sets to generate frequent item sets. Han et al. (2000) developed the FP-Growth (Frequent Pattern Growth) algorithm to discover frequent item sets without any item set generation. As the second step, rule generation is used to find item sets that satisfy the minimum support value and a predetermined confidence value.

A rule extracted from the large dataset is shown $X \rightarrow Y$. For example, the rule $\{121372\} \rightarrow \{121289\}$ suggests that there is an important and strong relationship

Table 3 Interestingness of a generated rule

		Support	
		Low	High
Confidence	Low	Uninteresting	Uninteresting
	High	Interesting	Uninteresting

between the location 121372 and the location 121289. This means customers who visit the location 121372 strongly, also visits the location 121289. Finding these types of rules has an opportunity to increase cross-selling by understanding customer needs.

Under normal circumstances, k-items-dataset can generate $2^k - 1$ candidate frequent itemset, excluding the null set. In addition, the total number of rules that can be extracted form dataset is $R = 3^k - 2^{k+1} + 1$. More than 80% of the rules are not useful when minsup is 20%, and minconf is 50%, thus making most of the computations become wasted (Tan et al. 2005). Since many applications have a very large k value, the number of itemsets increase exponentially. Frequent itemsets are determined to reduce the wasted computations. Therefore, two algorithms to avoid that problem in frequent itemset generation step are developed. That is: (i) reduce the number of candidate itemsets (Apriori algorithm) and (ii) reduce the number of comparisons (FP-Growth algorithm).

Apriori algorithm helps to reduce the number of candidate itemsets to generate frequent itemsets. Apriori principle is based on that if an itemset is frequent, then all of its subsets must also be frequent (Tan et al. 2005). This principle known as support-based pruning has a key property, monotonicity property, considering support value. According to the monotonicity property, an itemset never exceed the support value of its subset. In the Apriori algorithm, an anti-monotone itemset that not satisfy monotonicity property is used to reduce candidate itemsets.

FP-Growth algorithm does not need any candidate itemset like Apriori algorithm. It uses a compact data structure, named FP-tree to encode the data and generates frequent itemsets directly from this structure (Tan et al. 2005).

Application

Data Collection and Preparation

The data used in this study is collected from Beacons located in one of the major shopping malls in Istanbul. Beacons broadcast low energy radio signals, interact with the smart devices in their coverage zone, and automatically exchange information with them if the user allows. The data used in this study is collected by Blesh, a Turkish start-up company which has already located the beacon devices in the shopping mall. The system can recognize each smart device by its unique id. Besides, each beacon device has a specific id, which is associated with a single location, in our case retail store. The data is composed of monthly transactions of 12070 unique users in a shopping mall with 293 retail stores. Since the coverage zone of a beacon device is 50 m, it is possible that a smart device can get signals from two or more beacons at the same time. In this case, the approximate distance between the smart device and each beacon is calculated. During the preparation phase, the signals from the closest location are preserved the other signals are deleted.

Results

Association rule mining approach is used for the analysis of the visitor data. As the first step, the frequent item sets are prepared. We used a minimum support value of 0.01, and no frequent sets are observed having more then seven elements. We observed only one set which has seven elements and 100 sets which have six elements. The results show that most commonly used routes have at most seven stores at a confidence level of 0.01.

When we analyze the stores that take place in frequent item sets, we can observe only 19 stores while there are 293 in total. Also, we calculate the number of total observations for each store in the frequent item set. The results reveal that the top seven "most frequent" stores cover more than 80% of the total observations.

Table 4 shows the stores that take place in frequent paths. Due to data security issues, only the IDs of the retail stores can be published. We also calculate the popularity of the stores by summing up the total signals and rank the stores based on their popularity. It is interesting that Store 121599, which is the most popular store, takes the fourteenth place in the share. In the other direction, Stores 121532 and 123881 are most frequent stores. However, they are eighth and seventh in the popularity. Besides, among the top ten most popular stores only six of them takes place in the frequent store's list. This shows that frequent store definition, which is based on association rule mining is different from popular store definition, which is calculated by overall total signals is different.

Table 4 Stores in the frequent paths and their popularity ranking

Store	Share (%)	Popularity rank	Store	Share (%)	Popularity rank
121532	15.7	8	121373	1.7	18
123881	14.7	7	121466	1.5	19
121485	12.1	2	121324	1.5	55
121506	10.5	17	121599	0.8	1
121378	10.3	21	121294	0.8	20
121570	9.4	15	121563	0.5	3
121472	8.2	12	121549	0.5	4
121545	6.0	13	123807	0.3	114
121481	2.8	38	121495	0.2	30
121382	2.6	88			

Table 5 Generated interesting rules

Premises	Conclusions	Support	Confidence
{123881, 121373, 121324}	121485	0.05	0.92
{121563, 121324, 121368}	121485	0.05	0.89
{123881, 121570, 121439}	121532	0.05	0.86
{121532, 121506, 121324}	123881	0.05	0.85

Analysis of the association rules also reveal interesting results. When minsup is 0.05 and minconf is 0.1, 13735 rules are generated. Some of the most interesting rules, which has lower support and higher confidence ratio, are shown in Table 5.

According to Table 5, although visiting the locations 123881, 121373, 121324 and 121485 is a rare route, it has a high confidence. This means that, the number of four locations visited together is low (only 5% of all routes), but when the premises locations are visited together, it is very likely (92%) that the next visit will be the location 121485 (conclusion) for customers who visit the locations 123881, 121373 and 121324. As an example, the rule is shown by $\{123881, 121373, 121324\} \rightarrow \{121485\}$.

Discussion and Conclusion

In this paper, we analyze the visiting data of a shopping mall collected via Beacon devices. Heat maps are prepared based on this type of data, and they show the popularity of locations. In other terms, they graphically demonstrate how many times visitors exist at that location. In this study, we also obtain the popularity of the stores and the most frequent routes. The results reveal that the locations on frequent routes are not always popular. In other terms, frequent routes are different from popular locations. Thus, further studies can be conducted to improve analytic results using route information.

On the other hand, the representative power of the data is a limitation of the study. Although smart device penetration is high, people may choose not to activate their Bluetooth receiver. Thus, the collected data may not represent all visitors of the shopping mall. Data collected using other similar technologies, such as video recording and Wi-Fi may also be used to reach enhanced results.

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Estimating the Expected Cost of Function Evaluation Strategies

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Abstract We propose a sampling-based method to estimate the expected cost of a given strategy that evaluates a given Boolean function. In general, computing the exact expected cost of a strategy that evaluates a Boolean function obtained by some algorithm may take exponential time. Consequently, it may not be possible to assess the quality of the solutions obtained by different algorithms in an efficient manner. We demonstrate the effectiveness of the estimation method in random instances for algorithms developed for certain functions where the expected cost can be computed in polynomial time. We show that the absolute percentage errors are very small even for samples of moderate size. We propose that in order to compare strategies obtained by different algorithms, it is practically sufficient to compare the estimates when the exact computation of the expected cost is not possible.

Keywords Function evaluation · Sequential testing · Cost estimation
Monte Carlo methods

Introduction

In this work, we consider the problem of estimating the expected cost of a given strategy that evaluates a given Boolean function. In general, a feasible strategy to evaluate a Boolean function can be described as a Binary Decision Tree (BDT) whose size can be exponential in the size of the description of the Boolean function. Consequently, computing the expected cost of the strategy may not be

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_19

executed in polynomial time if the standard ways that are described below are used. In this work, we propose to estimate the expected cost of a strategy by sampling the input vectors as in Monte Carlo methods. We demonstrate that the estimation works well on special cases where the expected cost of a strategy can be computed efficiently.

The first component of the input of the problem is a Boolean function in n variables described in some form, a cost vector $C = (c_1, c_2, \ldots, c_n) \in R^n$ whose ith component is the cost of learning the value of the ith variable and a probability vector $P = (p_1, p_2, \ldots, p_n) \in R^n$ whose ith component is the probability that ith variable takes the value 1 with $p_i + q_i = 1,\ i = 1, 2, \ldots, n$. We assume that the variables take values independent of each other. The Boolean function can be described as a Disjunctive Normal Form, Conjunctive Normal Form or via an oracle that provides the value of the function at a certain binary vector in constant time. Certain Boolean functions can be described in a more concise way. As some typical examples, we can mention threshold functions, k-out-of-n functions or Read-Once functions. For more information for Boolean function representations one can refer to (Crama and Hammer 2011).

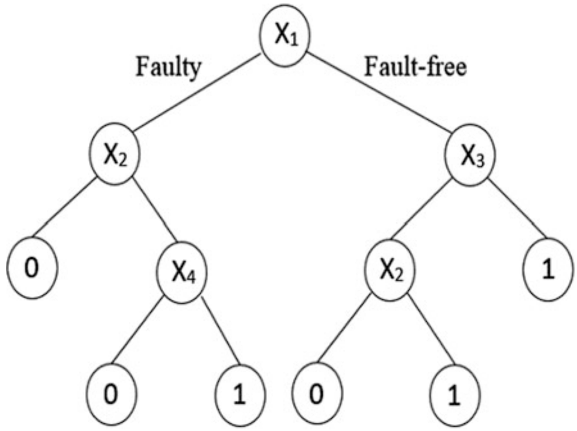
In addition, as part of the input, we assume that we are given a strategy, S that correctly evaluates this Boolean function. In order to evaluate the function at a certain binary vector, we need to learn the values of some of the variables. A strategy S is a feasible solution for our problem if S is an algorithm that describes which variable to learn next or outputs the correct value of the Boolean function, given the values of the variables that have been learnt so far. In general, S can be represented by a Binary Decision Tree. Each internal node of this Binary Decision Tree corresponds to a variable that we will test and learn its value whereas a leaf node corresponds to declaring the value of the function as 0 or 1. For instance, let us consider the following Boolean function given by its Disjunctive Normal Form as, $f(x) = (x_1 \wedge x_2) \vee (x_1 \wedge x_3) \vee (x_2 \wedge x_4)$. In Fig. 1, we provide a feasible strategy for evaluating this function. We will refer to the process of learning the value of x_i as testing variable i. In this strategy, x_1 is tested first. If x_1 is 1, then x_3 is tested next. On the other hand, if x_1 is 0, then x_2 is tested. Then depending on the values of the variables either the value of the function is determined or other variables are tested.

We can compute the expected value of the strategy provided in Fig. 1, by summing up over all leaves, the product of the total cost from the root to that leaf and probability of ending up at that leaf. For instance, the total cost of the rightmost leaf is (c_1 + c_3) and the probability of reaching this leaf is p_1p_3. So the contribution of this leaf to the expected cost is p_1p_3 (c_1 + c_3). The total expected cost can be computed by summing up the contributions of all the leaves. For this example, the total expected cost can be written as:

$$(c_1 + c_2)q_1q_2 + (c_1 + c_2 + c_4)q_1p_2 + (c_1 + c_2 + c_3)p_1q_3 + (c_1 + c_3)p_1p_3$$

We denote by L the set of leaves of the strategy tree. For each $l \in L$, let us define v_l to be the set of variables on the path from the root to leaf l The cost of a leaf l is defined as $c(l) = \sum_{j \in v_l} x_j$ and the probability of a leaf 1 is defined as

Fig. 1 Example strategy



$p(l) = \prod_{j \in v_l \, and \, x_j = 1} p_j \prod_{j \in v_l \, and \, x_j = 0} q_j$. Then the expected cost of a strategy can be defined as:

$$C(S) = \sum_{l \in L} c(l)p(l)$$

There are alternative ways to compute the expected cost of a strategy. A slightly different method than the one described above computes the probability that any variable is tested and sum up over all variables. Another method uses a recursive approach and it computes the expected cost of a given strategy by adding the cost of the variable at the root and the expected costs of the right and left subtrees of the root. The cost of a leaf node is 0. So one can recursively compute the expected cost. In fact, this approach could be used to find the optimal strategy by a dynamic programming formulation.

Although we have these formulations to compute the expected cost of a given strategy S there is a practical problem about all these methods. All of these methods use the Binary Decision Tree representation of the strategy and the size of the Binary Decision can be exponential in the input size. Consequently, the number of leaves of the Binary Decision Tree will be exponential input size. Here the input size can be the size of the description of the Boolean function. So it may change from two integers in the case of k-out-of-n functions to an exponential size in the number of variables in the case of a Disjunctive Normal Form. Consequently, all the methods mentioned above will be exponential time methods, in general, to compute the expected cost of a given strategy described by a Binary Decision Tree.

On the other hand, a strategy S can also be described as a black box (algorithm or function) that computes the next variable to test given the values of already tested variables or outputs the correct value of the function. This black box can run in polynomial time and one can execute this black box at most n times to find out sequentially which variable to test next until the correct value of the function is found. Hence the black box is sufficient for practical execution of a strategy but it is not sufficient to compute the exact expected cost of the strategy. Obviously, one can execute the black box for all $x \in B^n$ to construct the corresponding Binary Decision Tree and then use the methods explained above to compute the exact expected cost. As we have argued before, this requires exponential space and time in the worst case.

This problem has been considered in the literature motivated by applications in various areas including inspection in a manufacturing environment (Duffuaa and Raouf 1990) to project management (Reyck and Leus 2008) and to medical diagnosis (Greiner et al. 2006). A review can found in (Ünlüyurt 2004) describing various applications and results.

In this work, we propose to estimate the expected cost of a given strategy by using random samples and using the black box approach that we mentioned over the samples. So we will generate a number of samples using the probability vector P. Then for each binary vector in the sample, we will apply the given strategy (or the black box) to learn to the value of the function at that binary vector. We will estimate the expected cost by averaging the costs incurred over all samples. In order to evaluate the effectiveness of such an approach, we will use strategies that have been developed for certain Boolean functions whose exact expected cost can be computed efficiently in polynomial time. We will describe these systems in detail in the next section. Another way to evaluate the performance of our estimation procedure can be to measure practical convergence of the average value.

Literature Review

The problem of developing optimal strategies for evaluating Boolean Functions has long been studied in the literature in different contexts for various function classes. For some special classes of functions, algorithms that produce optimal or approximate strategies are known. We will not provide a full review of the results here but we will rather concentrate on the functions that are utilized in this work.

A series function (logical AND function) takes the value 1 if all of the variables are 1 and it takes the value 0 if at least one variable is 0. On the other hand, a parallel function (logical OR function) takes the value 0 if all the variables are 0 and it takes the value 1 if at least one variable is 1. For series and parallel functions, any feasible strategy is just a permutation of the variables. For instance, for a series function one would learn the variables one by one and stop when a variable is 0 or all the variables are learnt. The optimal permutation for a series system is the non-increasing order of c_i/q_i, where q_i is the probability that a variable takes the value 0. The optimal solutions for series (parallel) systems are known for a long time (see e.g., Mitten 1960).

One generalization of series (parallel) functions is k-out-of-n functions. A k-out-of-n function takes the value 1 iff at least k of the n variables takes the value 1. Consequently, for a k-out-of-n function to take the value 0, we need that at least n − k + 1 variable is 0. Clearly, a series function is an n-out-of-n function and a parallel function is a 1-out-of-n function. The optimal evaluation strategy for k-out-of-n functions are known (Chang et al. 1990) and in addition, it is possible to efficiently compute the expected cost of the optimal expected cost. Essentially, the algorithm sorts the variables in non-decreasing order of their c_i/p_i and c_i/q_i ratios. Let us assume π and σ are the corresponding permutations. In other words,

$$\frac{c_{\sigma(1)}}{p_{\sigma(1)}} \leq \frac{c_{\sigma(2)}}{p_{\sigma(2)}} \leq \cdots \leq \frac{c_{\sigma(n)}}{p_{\sigma n)}}$$

and

$$\frac{c_{\pi(1)}}{q_{\pi(1)}} \leq \frac{c_{\pi(2)}}{q_{\pi(2)}} \leq \cdots \leq \frac{c_{\pi(n)}}{q_{\pi(n)}}$$

Then the next variable to learn is in $U_k \cap V_{n-k+1}$ where $U_k = \left\{x_{\sigma(i)};\ i \leq k\right\}$ and $V_{n-k+1} = \left\{x_{\pi(i)}\ :\ i \leq n-k+1\right\}$. Once the value of a variable is learned depending on the value of the variable, we either have a k-1 out of n-1 system or a k out of the n-1 system. So we can apply the same procedure until we obtain the correct value of the function. As a matter of fact, this algorithm was proposed in (Ben-Dov 1981) but the proof in that article was incomplete. A special data structure referred to as "A Block Walking Diagram" allows us to compute the exact expected cost of this optimal algorithm in $O(n^2)$ time. As an example, we consider a 2-out-of-4 system where σ = (1, 2, 3, 4) and π = (4, 3, 2, 1). We show the strategy corresponding to this example in Fig. 2.

Another generalization of a series (parallel) function is referred to as Series Parallel functions (SPS). (These are also known as Read-Once functions in Boolean functions literature) Without loss of generality, let us refer to a series function as a 1-level deep Series–Parallel function. Then we can define 2-level deep Series–Parallel function as a parallel connection of 1-level deep Series–Parallel functions.

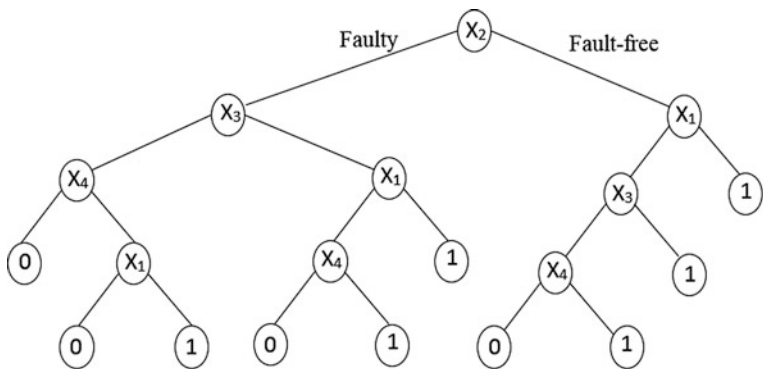
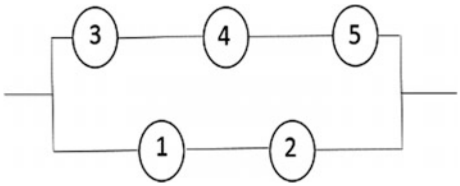


Fig. 2 Example strategy for a 2 out of 4 system

Fig. 3 A 2-level deep SPS



We can continue like this to define more complicated Series–Parallel functions. So a k-level deep Series–Parallel function is either a series or a parallel connection of k-1 level deep Series–Parallel functions.

The optimal solution for 2-level deep Series–Parallel functions is known (Boros and Ünlüyurt 2000; Greiner et al. 2006). Essentially, the optimal solution is a generalization of the optimal solution for a series (parallel) function. We replace each series function by a single variable whose cost is the optimal expected cost of evaluating that series function and whose probability of being 1 is the probability that the series function is 1. We now have a parallel function and we just implement the optimal algorithm for a parallel function. So in fact, we learn whether the series functions are 0 or 1 one by one according to the optimal ratio.

During this process, we continue with the same series function until it is evaluated and we never switch to other series functions without completely evaluating a series sub-system. One can generalize this algorithm to more complicated Series–Parallel functions. For more general functions, this generalization does not provide optimal results. In fact, it can produce very bad results (Boros and Ünlüyurt 2000; Ünlüyurt and Boros 2009). On the other hand, it is possible to compute the expected cost of this strategy in polynomial time by a recursive procedure. Essentially, one has to consider the function at the deepest level and replace it with a single variable according to its optimal solution. Then we end up with a 1 level less deep Series–Parallel function and if we continue applying the same procedure, at every stage the depth will decrease.

We consider the 2-level deep SPS in Fig. 3 and an example strategy for that SPS in Fig. 4.

Proposed Methodology and Numerical Results

We propose a simple sampling based method to estimate the expected cost of a given strategy. We sample binary vectors according to given the probability distributions and compute the average of the costs incurred for each binary vector. Since we can compute the expected cost of the optimal strategy for k-out-of-n functions and 2-level deep Series–Parallel functions efficiently, we utilize these

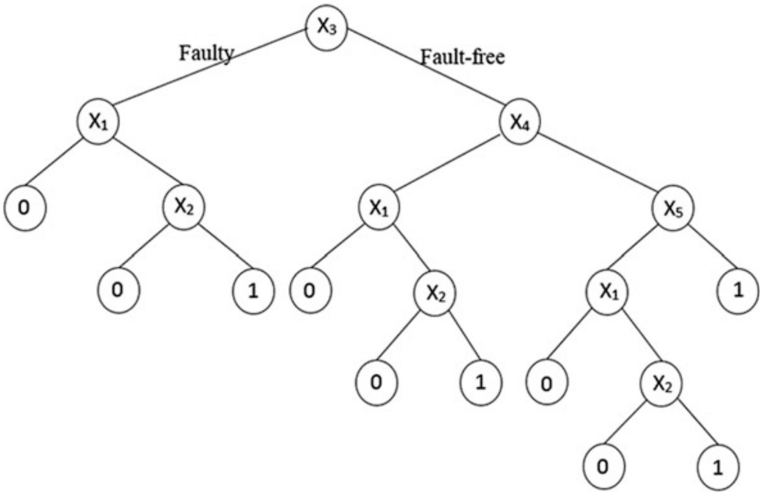


Fig. 4 Example strategy for the SPS in Fig. 3

systems to demonstrate the convergence of the estimation method. We also conduct experiments on a possibly non-optimal strategy for general Series Parallel Systems. All computations are performed using MATLAB.

K-Out-of-n Systems

For k-out-of-n functions, we generate random instances with n = 50, 100, 150 and 200. The k values are taken as n/8, n/4, n/2, 3n/4, 7n/8. Costs are uniformly generated from 0 to 10. There are three sets of probabilities: Uniform (0, 1), Uniform (0.9, 1) and Uniform (0, 0.1) in order to represent a variety of instances. So in total, we have 4 * 5 * 3 * 5 = 300 problem instances. As mentioned before, we implemented the Block Walking Diagram proposed in (Chang et al. 1990) to compute the exact optimal cost in polynomial time. In Table 1, we present the average absolute errors of our estimation process for a different number of samples from 200 to 1000. We also show the results in terms of *n* and the probability distribution since these factors seem to be interesting. In all cases, the estimation error is below 1%. We observe that the worst performance is when the probability distribution is uniform between 0 and 1. The absolute estimation errors decrease as the number of samples increases as expected. The decrease in the estimation errors stabilizes as we approach 1000 samples. It is interesting and somewhat counter-intuitive to observe that the estimation errors do not deteriorate when n increases. In fact, in our experiments, the better estimates are for larger n.

Table 1 Results for k-out-of-n systems

n	Prob	200 (%)	400 (%)	600 (%)	800 (%)	1000 (%)
50		0.93	0.79	0.52	0.51	0.46
	(0, 0.1)	0.78	0.39	0.40	0.28	0.17
	(0, 1)	1.40	1.57	0.87	0.91	0.96
	(0.9, 1)	0.59	0.42	0.30	0.34	0.24
100		0.70	0.55	0.36	0.36	0.31
	(0, 0.1)	0.41	0.29	0.25	0.14	0.14
	(0, 1)	1.29	1.10	0.62	0.68	0.59
	(0.9, 1)	0.39	0.26	0.22	0.25	0.18
150		0.50	0.35	0.35	0.27	0.31
	(0, 0.1)	0.33	0.20	0.18	0.15	0.17
	(0, 1)	0.90	0.55	0.72	0.50	0.59
	(0.9, 1)	0.26	0.29	0.16	0.17	0.17
200		0.48	0.35	0.33	0.26	0.25
	(0, 0.1)	0.30	0.24	0.16	0.18	0.16
	(0, 1)	0.93	0.63	0.66	0.46	0.46
	(0.9, 1)	0.22	0.17	0.17	0.14	0.13
Total		0.65	0.51	0.39	0.35	0.33

2-Level Deep Series Parallel Systems

Similar to k-out-of n functions, we created random 2 level deep Series–Parallel functions. The number of subsystems is determined from 10 to 40. Each subsystem contains a random number of variables between 10 and 20. So on average, we have 325 variables. Again we generated the costs uniformly between 1 and 10 and probabilities are determined in three different ways as described in k-out-of n functions. For each set of fixed parameters, we generate 5 independent instances. The average absolute estimations are presented in Table 2. For these systems, the worst estimations turn out to be when probabilities are drawn between 0.9 and 1. This indicates that the performance of the estimation procedure is dependent on the type of the function that we are dealing with. We again observe no deterioration of the estimation error as the number of variables increase.

General SPSs

As mentioned before optimal algorithms are not known for general SPSs. On the other hand, the algorithm that provides optimal solutions for 1-level deep SPSs and for 2-level deep SPSs can be generalized and used for general SPSs. This does not always provide an optimal strategy but an important property of such a strategy is

Table 2 Results for 2-level deep SPSs

n	Prob	200 (%)	400 (%)	600 (%)	800 (%)	1000 (%)
10		1.94	1.50	1.24	0.91	0.69
	(0, 0.1)	0.69	0.61	1.04	0.42	0.59
	(0, 1)	2.16	2.26	0.69	0.71	0.66
	(0.9, 1)	2.95	1.65	1.99	1.61	0.82
20		1.26	1.08	1.02	0.54	0.78
	(0, 0.1)	0.55	0.31	0.33	0.28	0.14
	(0, 1)	1.17	1.60	0.92	0.77	0.71
	(0.9, 1)	2.06	1.33	1.80	0.57	1.48
30		1.13	1.16	0.85	0.36	0.56
	(0, 0.1)	0.88	0.17	0.38	0.25	0.16
	(0, 1)	1.52	1.71	0.94	0.34	0.64
	(0.9, 1)	0.98	1.59	1.22	0.50	0.89
40		1.16	1.27	1.02	0.63	0.74
	(0, 0.1)	0.22	0.14	0.36	0.26	0.16
	(0, 1)	0.77	1.13	0.60	0.35	0.68
	(0.9, 1)	2.50	2.54	2.11	1.28	1.39
Total		1.37	1.25	1.03	0.61	0.69

Table 3 Results for general SPSs

Depth/sample size	2000 (%)	4000 (%)	6000 (%)	8000 (%)	10,000 (%)
2	0.45	1.18	0.97	0.67	0.40
3	2.31	2.16	1.98	1.20	0.95
4	3.37	2.84	1.29	1.05	1.07
5	2.61	1.23	1.42	1.50	1.29
6	0.62	0.72	0.34	0.35	0.52
7	3.11	1.17	1.21	0.76	0.71
8	2.54	1.57	1.18	0.82	0.61
9	3.94	2.27	1.29	0.96	0.85
10	1.08	0.88	0.76	0.74	0.74
Total	2.23	1.56	1.16	0.89	0.79

that the exact expected cost can be computed by a non-trivial recursive algorithm. The non-triviality comes from the fact that while the values of the variables are learnt, the depth of the resulting SPS can decrease and/or some sub-systems may disappear. Consequently, the resulting strategy can be considered more complicated than the case when the depth is only 2. We also tested our estimation procedure for random general SPSs whose depth varies from 2 to 10. It is also not a straightforward task to generate general random SPSs. We set the maximum number of components at any level to 5 and 25% of the components constitute other subsystems. We vary the depth from 2 to 10. We generate 5 independent instances for each combination of parameters and we generate all probabilities uniformly. So we have in total 45 instances. We report the absolute percentage gaps with respect to sample size and depth of the system in Table 3. We observe that the quality of estimations does not deteriorate too much as the depth of the systems increase. For these systems we kept the sample sizes larger to achieve good results. Still, the whole estimation process takes almost no time.

Conclusion

In this work, we demonstrate the effectiveness of a sampling based estimation method for estimating the expected cost of a strategy that evaluates certain Boolean functions. Our results indicate that it is possible to estimate the expected cost of a strategy within a good accuracy even by 1000–10,000 samples for certain classes of functions very efficiently in terms of time. So one can adapt this approach for more general functions when it is not possible to compute the expected cost efficiently. These estimations can be used to compare different algorithm. A similar analysis can be conducted for more complicated Series–Parallel functions since for some (not necessarily optimal) strategies for which the expected cost can be computed efficiently. As another continuation of this work, one may investigate the effectiveness of using a similar approach in order to compare different algorithms in a statistical manner.

Acknowledgements The authors gratefully acknowledge the support provided by TUBITAK 1001 programme, project number 113M478.

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The Effects of the Dimensions of Organizational Justice Over the Perception of General Justice

Ozgun Albayrak and Cahit Ali Bayraktar

Abstract The purpose of this study is to investigate the effect of the dimensions of organizational justice over the perception of general justice, specifically concerning the architects and the civil engineers working in the construction sector. The study firstly defines organizational justice and the dimensions of this concept. Afterwards, the study model used that is used in the research is constructed. The data was received from a data collection form that was prepared based on similar studies in the literature. A total of 313 subjects participated in the study: 157 civil engineers and 156 architects. The analysis has shown that the dimensions of organizational justice (distributive justice, procedural justice, and interactional justice) have a positive effect on the perception of general justice. The results of the study provide important data for the construction firms who aim to create a sense of organizational justice among their employees.

Keywords People management · Organizational justice · Distributive justice Interactional justice · Procedural justice · Management

Introduction

Organizational justice is directly related to the performance of a company's performance. In addition, organizational justice can determine the economic welfare of an employee (Yean and Yusof 2016). The perception of organizational justice can be defined as the way in which the employee perceives the distribution of

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*, Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_20

organizational resources (Greenberg 1987). The employees compare themselves to their co-workers to make a judgement of the justness of this distribution. If the employees generally conclude that the costs and benefits conceived by the operation are divided evenly and that the regulations are implemented equally among workers, it can be said that their perception of organizational justice is high (Black and Porter 2000).

One of the factors that require attention when considering the improvement of the quality and efficiency of the construction sector is the management of human resources. In this sense, the engagement of workers is an aspect that requires attention. This study aims to provide suggestions to the sector for the improvement of organizational justice perceptions, and thus to enhance the quality and efficiency of the sector.

The study initially examines the concept of organizational justice and its dimensions to form the framework of the subject. Afterwards, these concepts were measured with the field-study, and the correlation between the concepts and the sample was evaluated. Finally, the limitations of the study were indicated with a general evaluation of the study, and suggestions are offered.

Organizational Justice

The studies regarding organizational justice have started with the "equity theory" of Adams. This theory suggests that the equity in the workplace affects the individuals' job satisfaction and their subsequent success (Luthans 1997). Deutsch (1975) has defined the rule of justification to be the ratio of the individual's inputs (contributions) over the outputs they receive (attainments and results). If the employee's efforts towards the company are proportional to the benefits that they obtain, it can be said that the work is "justified". According to Greenberg (1990), the organizational justice depends on the employees' beliefs concerning the fairness of the organizational decisions. As a result, it can be said that organizational justice depends on the distribution of workload, rewards, and punishments; the participation of employees in decision-making processes; how equitably and consistently these decisions are implemented among employees; and the how attentive the managers are when dealing with employees. Olkkonen and Lipponen (2006) indicated that organizational justice has three dimensions: distributive, procedural and interactional.

Distributive Justice

According to Lambert et al. (2007), distributive justice is the honest and fair distribution of organizational values. If the employee's efforts are proportional to the attained values, they have a better sense of distributive justice. The employees decide whether the distribution is fair in the workplace by comparing themselves to each other (Yıldırım 2007). Yean and Yusof (2016) have indicated that distributive justice is perceived when they appraise their efforts as equal to their obtained rewards. In this respect, it can be said that distributive justice is the employee's judgement that results from the comparisons they make regarding pay, promotion, work hours and workload.

Procedural Justice

Procedural justice is a concept concerning the perceived fairness of the procedures that are used to determine the values that will be attained by the employees, to make decisions regarding the distribution and the application of these decisions (Greenberg 1987). Procedural justice is associated with organizational justice and helps these procedures to be impartial, consistent, right and ethical (Akram et al. 2017). Topics such as disciplinary action, reward system and the reliability of the decision-making authorities are also a part of procedural justice (Yean and Yusof 2016). Briefly, the participation of employees in the decision-making process for every step regarding the organization, their ability to object to the decisions and their right to demand information regarding the content of decisions depend on the extent of procedural justice.

Interactional Justice

Interactional justice concerns the managers' treatment towards employees (Akram et al. 2017). According to Kwak (2006), interactional justice emphasizes the social aspect of organizational justice. Bies and Moag (1986) have defined interactional justice as the type of justice that concerns the interpersonal aspects of organizational applications, and subjects such as courtesy and honesty in the communication process. Interactional justice can be briefly defined as the employee being respected in the workplace, trusting that they are vindicated, the employee receiving logical explanations regarding decisions, and being treated courteously by the managers throughout the process.

Research Model and Hypotheses

The purpose of this study is to investigate the effect of the dimensions of organizational justice over the perception of general justice among the architects and the civil engineers working in the construction sector (Fig. 1).

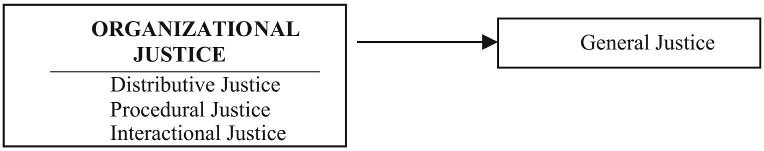

Fig. 1 Research model

In the light of the definitions from the literature, we expect a positive relationship between the dimensions of organizational justice and perception of general justice. Thus, the following hypotheses are developed:

H1: Distributive justice positively affects the perception of general justice.
H2: Interactional justice positively affects the perception of general justice.
H3: Procedural justice positively affects the perception of general justice.

Methodology

The research aims to examine the relationship between organization justice dimensions and the perception of general justice. For this purpose, a data collection survey was conducted among the architects and civil engineers working in the construction sector.

There were 20 expressions regarding the determination of organizational justice in the survey. The organizational justice scale developed by Niehoff and Moorman (1993) was used for quantitative measurement. The responses were expressed as a 5-point Likert scale, ranging from 'Strongly Disagree' (1) to 'Strongly Agree' (5).

The study sample consisted of architects and civil engineers working in the construction sector. A total of 313 subjects participated in the study, 157 of which were civil engineers and 156 were architects. Considering the alpha-coefficients graph developed by Hair et al. (1995), the sample size was determined to be large enough for the results to be significant at the level of $p = 0.01$.

The data collection forms were created on Google Forms and were delivered to the participants in an online medium. The answers were classified to allow only one survey to be filled out per e-mail address, to prevent the participants from filling out multiple forms. The data were collected for almost one month, between October 26, 2017 and November 22, 2017. During this time, TMMOB Chamber of Civil Engineers and TMMOB Chamber of Architects have supported the study by conveying the form to civil engineers and architects.

Findings

Regarding the used data set, the asymmetry and kurtosis values for the entire survey must be in the range of ±1.96 for 0.01 significance (Hair et al. 1995) and the values from the set are found to be in this range. Considering all the answers to the survey, the asymmetry values are ranging between −1.160 and 0.857, and the kurtosis values are ranging between −1.1418 and 0.564.

Papacharissi and Rubin (2000) indicate that Cronbach's Alpha must be between 0.6 and 1. When the organizational justice and organizational commitment dimensions were tested for confidence between themselves, all dimensions were found to have Cronbach's Alpha values above 0.6 (Table 1).

Hair et al. (1995) state that to be able to perform a factor analysis on a sample, the sample size must be at least n = 100. This study is suitable for factor analysis with its sample consisting of 313 subjects. In the factor analysis, it was confirmed that the correlation matrices were above 0.30, and the anti-image matrices were above 0.50. As a result of the factor analysis, a total of 4 factors were determined.

When we looked at the correlation table obtained from the analyses, we concluded that there is a positive correlation between distributive, interactional and procedural justices and the perception of general justice (Table 2).

Using regression analysis, the effects of the dimensions of organizational justice over the perception of general justice were determined. It was confirmed that the Durbin-Watson coefficients were between 1.5 and 2.5 in the analysis. The collinearity between independent variables was tested using the variance inflation factor (VIF) and tolerance values. If tolerance values are >0.1, and VIF values are <5.3, this indicates an absence of collinearity between independent subjects (Hair et al. 1995). It was confirmed that the values for the study's sample were within the required ranges. The results indicate that distributive justice is 18.2%, interactional justice is 51.8% and procedural justice is 34% effective regarding the perception of general justice (Table 3).

Table 1 Results of factor analysis and values for Cronbach's Alpha

Factor	Cronbach's Alpha	KMO	% Variance
Distributive justice	0.782	0.725*	61.082
Interactional justice	0.920	0.922*	67.677
Procedural justice	0.834	0.804*	66.748
General justice	0.821	0.834*	58.564

*p < 0.001

Table 2 Results of correlation analysis

	General justice
Distributive justice	0.656*
Interactional justice	0.865*
Procedural justice	0.809*

*p < 0.01

Table 3 The regression analysis results for perception of general justice

	Durbin-Watson	R^2	β
Distributive justice	2.205	0.841	0.182
Interactional justice			0.518
Procedural justice			0.340

Dependent variable: general justice $p < 0.001$
The sample supports hypotheses H1, H2 and H3
H1: Distributive justice positively affects the perception of general justice
H2: Interactional justice positively affects the perception of general justice
H3: Procedural justice positively affects the perception of general justice

Conclusion

This study examines organizational justice dimensions and the concept of general justice, and in the light of previous research suggests a research model and hypotheses. The analyses of the collected data indicate that organizational justice dimensions are positively correlated with the perception of general justice. The level of this effect provides important insights regarding what needs to be done to achieve the goal of improving employees' perceptions of justice.

The results indicate that distributive justice is 18.2%, interactional justice is 51.8% and procedural justice is 34% effective regarding the perception of general justice. Subsequently, it was determined that interactional justice has the most prominent effect on the perception of justice.

The concept of interactional justice involves the managers' attitudes towards their employees. The definitions in the literature and the expressions in the conducted survey indicate that interactional justice involves the managers' behaviors towards and their appreciation of their employees. In this regard, we can conclude that one-on-one interactions of workers are the most important determinant of justice in the workplace.

Procedural justice demonstrates the employees' perceptions regarding decision making and application processes. When the expressions in the survey are examined, it is observed that procedural justice depends on the involvement of employees on the decision-making process, such as collecting correct and impartial data before making a decision, employees' entitlement to object to the decisions, and the consistent application of these decisions. In this regard, it can be said that procedural justice is an important aspect of improving employees' perception of justice.

Distributive justice concerns the perceived fairness of the distribution of organizational resources, rewards and punishments, and the workload among employees. The results of the analyses indicate that distributive justice has a minor effect on the employee's perception of justice when compared to the other dimensions. It was determined that distributive justice was 18.2% effective on employees' perception of justice.

It can be said that the sample should be demographically evaluated for future studies. Futures studies may investigate the differences among office workers' and field workers' perceptions of justice, and what may cause these differences (length of employment, etc.). The suggestions also indicate the limitations of this study.

Improving employees' perceptions of justice in the workplace is important for the construction sector. The study aims to provide a framework for possible courses of action. If the organizations invest in the more effective dimensions of organizational justice, they can obtain successful results. The employees' perception of a fair workplace will result in higher quality and productivity. The construction firms that intend to enhance quality and productivity should elaborate on the establishment of a fair workplace.

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A Literature Review for Hybrid Vehicle Routing Problem

Busra Gulnihan Dascioglu and Gulfem Tuzkaya

Abstract With the increased volume of environmental studies, hybrid vehicle routing and recharging stations location problem for electric vehicles have become more important. The aim of this paper is to review the literature on hybrid vehicle routing problem from 2000 to latest researches in order to identify the current research and to provide direction for future research in this field. Researches are classified considering the research publication year and research fields. Research gaps are identified for future research areas.

Keywords Electric vehicle routing · Green supply chain management
Hybrid vehicle routing

Introduction

According to EDGAR (Emission Database for Global Atmospheric Research) survey, CO_2 emission consumption increased by 4% between the years of 2014 and 2016. With the decline in the rate of cultivation in land use, in 2017 it reached approximately 41 billion metric ton and the percentage of increase reached 2%. Figure 1 summarizes CO_2 emission from fossil fuels over the past 59 years in the graph form the Global Carbon Project (GCP) surveys (Olivier et al. 2017).

According to Nakata (2000), the energy sector predicts that future estimates will be a serious loss of energy systems by 2040. The main cause of this loss, as well as the damage caused by unnatural energy resources, is to prevent these damages by reducing the damage caused by fuel consumption of technological developments.

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
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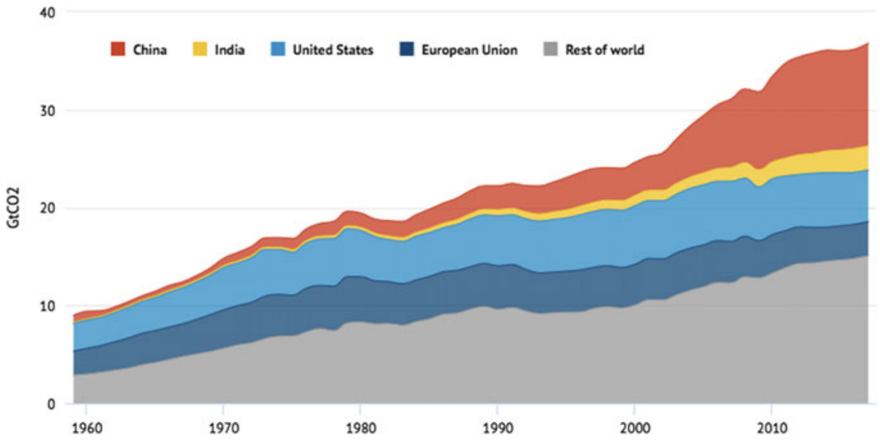
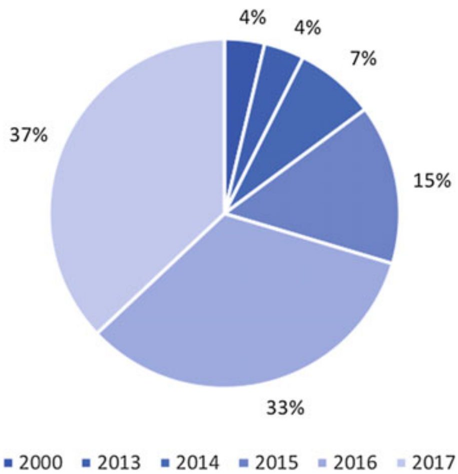


Fig. 1 The amount of CO_2 emissions from countries from using fossil fuels, 1959–2017

For this reason, researchers are able to further reduce carbon emissions by using hybrid vehicles to regulate the roots of normal vehicles.

The main part of an electric vehicle is the usage of the battery which directly affects the vehicles driving performance and cost of the path (Rahman et al. 2016). Even though the hybrid and regular vehicle types are not fully exploited, researchers have been examining them since it is important for reducing the environmental damage (Iwata and Matsumoto 2016). For this purpose, we have examined the articles in hybrid vehicle routing subject and analyzed for finding research gaps for future researches. Figure 2 shows the number of studies for each year, and according to the graph, we can claim that HVRP studies are increases day by day.

Fig. 2 Number of studies each year



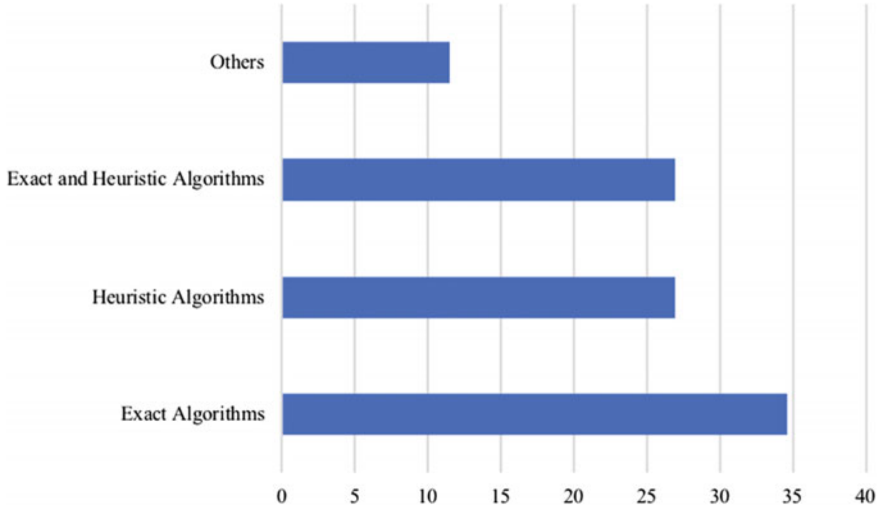


Fig. 3 Solution methods of researches

The paper is organized as follows: Articles are classified by the solution methods of researches as in Fig. 3 and presented in Sect. "Hybrid Vehicle Routing". Section "Conclusion" describes a number of potential further research directions and concludes the paper.

Hybrid Vehicle Routing

Exact Algorithms

Afroditi et al. (2014) implemented a mathematical model for solving the electric vehicle routing problem for a real-life problem. The model considers the capacity, time window constraint and vehicle's battery and solves the capacitated electric vehicle routing problem. Pourazarm and Cassandras (2015), proposed a Mixed Integer Non-Linear Programming and alternative flow optimization problem model for solving the routing problem of both electric and non-electric vehicles. The model was solved by minimizing the total completed time for vehicles account the travelling times and recharging times for electric vehicles.

Liao et al. (2016) conducted a comprehensive study on the use and routing of electric vehicles that reduce greenhouse gas emissions to halt and reduce the effects of increasing global warming. The authors solved the problem of finding the shortest distance in the fastest time taking into account the completion and recharging of the battery in a given route network. Lin et al. (2016) have worked on a model that minimizes the time spent on the road and the cost of energy consumed.

Every customers' route can be optimized with the mathematical model that determines the minimum number of vehicles that will necessarily meet their demands.

Catay and Keskin (2017) have pointed out the problem of electric vehicle routing with time windows. The charging stations of the vehicles are divided into normal and fast chargeable, and in the fast charging system, the battery is charged faster and costlier than the normal system. It is aimed to provide services at with minimum cost. Schiffer and Walther (2017) also considered the time window constraint in their work. The researchers aimed to minimize both the distance traveled and the number of necessary vehicles and charging stations, taking into account the time constraints as well as capacity constraints. In the study, two different mathematical models were established according to the types of charging stations and the effect of the selected charging station on the financial system was investigated. Murakami (2017) aimed at solving the mixed integer nonlinear programming model for routing the electric and diesel fuel powered vehicles by taking into account the slope of the road, the speed, and acceleration of the vehicle. In this study, the traffic lights, the maintenance costs of the vehicle and the structure of the vehicle were also taken into consideration and the effects of the factors were analyzed with graphs. Carignano et al. (2017) developed a model test simulator to estimate the amount of energy needed for the internal combustion of vehicles, which does not cause any fuel emissions, despite the high efficiency of the hybrid vehicles, and the hydrogen consumption and power of the hybrid electric buses. They are compared to different situations.

Heuristic Algorithms

Goeke and Schneider (2015) have considered the speed and the load of the vehicle and the slope of the road in order to make the model more realistic instead of the linear formulas used in the models that measure traditional energy consumption. Adaptive Large Neighborhood Search algorithm is applied and examined the algorithms in test problems. They assumed that the vehicles had arrived at the stations and that the charge period changed according to the level of the battery. The authors have extended the energy consumption of the vehicle to the model of Demir et al. (2012) to take into account the energy of the battery.

Yang and Sun (2015) have adapted the two new algorithms to position the charging stations of hybrid vehicles and aim at creating the most appropriate routes that the vehicle fleet can reach the stations without falling below the battery low limit. The algorithms they adopt are two-stage intuitive algorithms consisting of a modified Sweep algorithm, a recursive greedy algorithm, a 4-step heuristic algorithm, including adaptive large neighborhood search and enhancement heuristic algorithms, and a Clarke-Wright saves algorithm with tabu search. The authors tested these algorithms for the test problems that were generated.

Electric vehicles which are produced to reduce greenhouse gas emissions have recently been the subject of researchers' work, and a lot of work has been done on the widespread use of vehicles and increased productivity. One of the most serious problems with vehicles is the length of the charge period and investigated by Penna et al. (2016). The authors have considered electric vehicles in different types of operation, which have different capacities, driving range and service maintenance costs. They found an ideal number of the electric vehicle fleet and offered a local search algorithm on their route, taking into account the time windows and charging times of these vehicles. In another time windows, electric vehicle routing problem Hiermann et al. (2016) dealt with time windows according to customer's location in terms of being more suitable for real life problems. The problem they are aiming at is to solve with the algorithm that they created by hybridizing local search algorithms with Adaptive Large Neighborhood Search algorithm.

Montoya et al. (2017) evaluated and solved the existing electric vehicle routing problem more extensively than other studies, considering the level of recharging of the battery evaluated linearly as a nonlinear equation. They compared the validity of the model by testing the generated hybrid metaheuristic algorithm in 120 different case studies. Hof et al. (2017) aimed to minimize the total cost of the route and the installation costs of the stations, taking into consideration the positioning of the electric power converters for the most suitable of the battery exchange stations from the candidate points and the compulsory visits of the electric vehicles to these points. The researchers adapted the Adaptive Variable Neighborhood Search algorithm to their probes in these studies and tested the results on known problems in the literature. Yu et al. (2017) presented a Simulated Annealing algorithm that aims to minimize the cost of the route, taking into account the use of Boltzman and Cauchy functions for hybrid vehicle routing, these models were compared with the prepared test problems and their results were analyzed.

Exact and Heuristic Algorithms

Abdallah (2013), with his thesis, has introduced both plug-in hybrid vehicle routing problems and tried to solve this problem by considering the time window restriction of these vehicles. Hybrid vehicles with plugs are vehicles with greater battery capacity than normal hybrid vehicles. These vehicles, which are advantageous for going short distances, are disadvantageous compared to other electric vehicles due to the length of the charging period and the length of the charging cycle. The mathematical model established, Lagrangian relaxation and tabu search algorithms were developed to solve this problem and the results were compared. Felipe et al. (2014), presented various heuristic algorithms such as a constructive and local search for solving the electric vehicle routing problem. A mathematical formulation is also presented and the results of both methods are compared to well-known test problems and a special benchmark which is created for this specific problem.

Bruglieri et al. (2015) have worked on establishing rates for all customers who are less harmful to the environment and that allow electric vehicles to provide cheaper access for motor vehicles with internal combustion, taking into account time constraint. The researchers have set up a mixed integer mathematical model that reduces both the total path, the wait and the charge of the vehicle to the greatest extent. In order to solve this problem, the Variable Neighborhood Search Branching algorithm was implemented. In another study, a three-stage heuristic algorithm based on general variable neighborhood search and dynamic programming models is designed for solving problems with 20 customers in short computing time. This algorithm is intended to solve the traveling salesman problem with the electric perspective and time window. The problems that have been created have been set up so that the vehicle can work both with a full battery and half full battery. By comparing the results obtained, the applicability of electric vehicles to real problems has been investigated (Roberti and Wen 2016).

Keskin and Çatay (2016) are intended to solve the time windows, electric vehicle routing problem, taking into consideration full and fractional battery charge. They constructed a mixed-integer linear model and an adaptive large neighborhood search algorithm from Schneider et al. (2017) model and the other well-known problem solutions. Wen et al. (2016), tried to optimize the set of timetabled bus trips. The authors first minimized the number of necessary buses or vehicles to cover each route starting from a specific point and ending at another, at a specific time. Then the electric vehicles are routed optimally while minimizing the total distance. The problem is solved by both proposed mixed integer programming model and adaptive large neighborhood search algorithm. Results are compared by creating the test problem.

Mancini (2017) introduced a hybrid vehicle routing problem, a subproblem of the green vehicle routing problem, which established an integrated mixed-integer linear programming model that minimizes the damage to the environment by running the vehicle in electric mode as much as possible and adapt the Large Neighborhood Search algorithm to solve the problem in larger problem types. Strehler et al. (2017) aimed at reaching their shortest distance targets for hybrid vehicles in their work. With the model installed, the most suitable route alternatives were found and then this problem was adapted for public transport and vehicle fleet.

Conclusion

Table 1 shows the methods used for solving problems presented below. With the increase in global warming, green awareness comes to the agenda with focusing an ecological value on a stage not only producing a product, but also its service processes. The recent researches focused on hybrid vehicles to make improvements both economically and environmentally. This paper has presented a review of the recent papers on the hybrid vehicle routing problem. A total of 26 papers were presented. By classifying the studies in terms of scopes and solution methods, this paper not only serves as a guideline for researchers and practitioners that are not familiar with this area, but it also aims to help researchers in the field of hybrid vehicle routing to detect research gaps in this body of literature. We found that in

Table 1 Methods used for solving HVRP[a]

Articles	Exact solution methods		Metaheuristic methods				
	MILP	MINLP	LNS	ALNS	SA	LS	VNS
Abdallah (2013)	✓			✓			
Afroditi et al. (2014)	✓						
Felipe et al. (2014)					✓		
Goeke and Schneider (2015)	✓			✓			
Bruglieri et al. (2015)	✓						✓
Yang and Sun (2015)				✓			
Pourazarm and Cassandras (2015)		✓					
Liao et al. (2016)	✓			✓			
Roberti and Wen (2016)	✓						✓
Hiermann et al. (2016)	✓			✓			
Keskin and Çatay (2016)	✓						✓
Penna et al. (2016)	✓						
Iwata and Matsumoto (2016)	✓		✓				
Lin et al. (2016)	✓						
Wen et al. (2016)	✓			✓			
Mancini (2017)	✓		✓				
Montoya et al. (2017)						✓	
Schiffer and Walther (2017)	✓						
Hof et al. (2017)							✓
Çatay and Keskin (2017)	✓						
Strehler et al. (2017)	✓		✓				
Yu et al. (2017)					✓		
Murakami (2017)	✓						
Carignano et al. (2017)	✓						

[a]*MILP* mixed-integer linear programming, *MINLP* mixed-integer non-linear programming, *LNS* local neighborhood search, *ALNS* adaptive local neighborhood search, *SA* simulated annealing, *LS* local search, *VNS* variable neighborhood search

HVRP energy consumption problems of Plug-in Hybrid Vehicles are not many studied areas and there is a gap in this area. Also researches mostly studied on time window vehicle routing models and other VRP models can be adapted to HVRP.

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Goeke, D., & Schneider, M. (2015). Routing a mixed fleet of electric and conventional vehicles. *European Journal of Operational Research, 245,* 81–99.

Hiermann, G., Puchinger, J., Ropke, S., & Hartl, R. F. (2016). The electric fleet size and mix vehicle routing problem with time windows and recharging stations. *European Journal of Operational Research, 252,* 995–1018.

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Wen, M., Linde, E., Ropke, S., Mirchandani, P., & Larsen, A. (2016). An adaptive large neighborhood search heuristic for the electric vehicle scheduling problem. *Computers & Operations Research, 76,* 73–83.

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Short Term Electricity Load Forecasting with a Nonlinear Autoregressive Neural Network with Exogenous Variables (NarxNet)

Ibrahim Yazici, Leyla Temizer and Omer Faruk Beyca

Abstract Electricity load forecasting and planning have vital importance for suppliers as well as other stakeholders in the industry. Forecasting and planning are relevant issues that they provide feedback to each other to increase the efficiency of management. Accurate predictions lead to more efficient planning. Many methods are used for electricity load forecasting depending on characteristics of the system such as stationariness, non-linearity, and heteroscedasticity of data. On the other hand, in electricity load forecasting, forecasting horizons are important issues for modeling time series. In general, forecasting horizons are classified into 3 categories; long-term, mid-term and short-term load forecasting. In this paper, we dealt with short-term electricity load forecasting for Istanbul, Turkey. We utilized one of the efficient nonlinear dynamic system identification tools to make one-step ahead prediction of hourly electricity loads in Istanbul. In the final, the obtained results were discussed.

Keywords Prediction · NarxNet · Short-term electricity load forecasting

Introduction

Electricity load forecasting is a multifaceted task which encompasses various sides of economical and safety operations of power supply systems. The forecasting makes assistance for security analysis of supply systems, system control,

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_22

maintenance etc. It also provides feedback for planning. By considering these important facets of the forecasting, many methods have been applied to predict electricity load forecasting over years to get more accurate results for efficient planning, however, the prediction has still remained a challenging issue that contains many uncertain factors affecting electricity load utilization (Song et al. 2011).

Electricity load forecasting can be classified into 3 categories according to the prediction horizon; long term, mid term, and short term load forecasting. Long term forecasting may have prediction horizon from one year to several years while mid-term may have the horizon from few weeks to few months, and short term forecasting may have the horizon from few hours to few days ahead (Din and Marnerides 2017). In addition to this classification, in the literature, authors may come across with another category; very short term forecasting that associates with the horizon from minutes to hours (Zheng et al. 2017a, b). It is not surprising that factors affecting prediction horizon types may vary. In short term and mid term load forecasting, most important factor for load prediction is temperature and humidity, however, in long term load forecasting, GDP, expected economical situations, changes in the demography etc. are most common factors which affects load usage.

Electricity load forecasting is considered as a type of time series, and the nature of time series may get utilization of certain types of methods required in relation to whether the time series is stationary or non-stationary. Besides that, availability and seasonality may get required to utilize any certain type(s) of prediction methods. In the literature, many types of methods have been applied for electricity load forecasting. These methods may be traditional and non-traditional ones. Some of the traditional methods are statistical forecasting models such as ARMA, ARIMA, SARIMA, Holt-Winter's methods, and some of them are artificial intelligence and machine learning techniques such as neural network methods including Recurrent Neural Network, NarxNet, Long-short Term Memory, Gated Recurrent, random forest, and gradient boosted regression trees. Traditional methods may have disadvantages in modeling the nonlinear relation between load and exogenous variables whereas non-traditional methods may overcome this problem provide better modeling of the problem (Deihimi and Showkati 2012). In Table 1, we briefly presented some examples both on traditional and non-traditional methods used for STLF and few VSTLF. The review was given in tabular form for simplicity.

Table 1 Literature reviews on STLF

Study	Method(s)	Application
Cao et al. (2015)	ARIMA	Intraday load forecasting
Li et al. (2015)	RBFNN	A day-ahead forecasting
Pang et al. (2010)	Simple NN	Very short term forecasting
Zhang et al. (2013)	ELM	STLF in Australian energy market
Ghofrani et al. (2015)	Bayesian NN	One-day ahead prediction
Mocanu et al. (2016)	CRBM	Different time horizons used

(continued)

Table 1 (continued)

Study	Method(s)	Application
Marino et al. (2016)	LSTM	One-minute and one-hour ahead prediction
Nataraja et al. (2012)	AR-ARMA-ARIMA	STLF in India
Shrivastava and Bhandakkar (2013)	RBFNN-FFNN-CFNN	Short term and mid term forecasting
Niu et al. (2012)	BNN+Monte Carlo	Hourly load forecasting
Nie et al. (2012)	ARIMA+SVM	STLF
Che and Wang (2014)	SVR	STLF
Chaturvedi et al. (2015)	Fuzzy ANN	STLF
Dudek (2016)	Linear Regression	Daily load forecasting
Vermaak and Botha (1998)	RNN	STLF
Khan et al. (2013)	CGPRNN	Next half hour forecasting
Dedinec et al. (2016)	Deep Belief NN	Hurly load forecasting
Yang et al. (1996)	ARMAX	STLF
Yoo and Pimmel (1999)	NN	STLF
Sharif and Taylor (2000)	NN	Real-time load forecasting
Regawad and Soanwane (2009)	NN	Hourly and daily load forecasting
Singh and Singh (2001)	NN	Hourly load forecasting
Kong et al. (2017)	LSTM	Household electricity LF
Zheng et al. (2017a, b)	LSTM	Prediction of STLF and result comparisons
Zhang et al. (2017)	RNN, LSTM, and GRU	STLF in Poland
Din and Marnerides (2017)	FF-Deep NN and RNN	STLF in New England
Ryu et al. (2016)	Restricted Boltzman Machine	Industrial area STLF in Korea
Chitsaz et al. (2015)	RNN	Grid load forecasting(STLF)
Li et al. (2015)	Bayesian ESN	Electricity load production (STLF)
Mehmood and Hawary (2014)	CNN+RNN	STLF prediction in Canada
Kalaitzakis et al. (2002)	RNN	STLF prediction in Crete island
Marvuglia and Messineo (2012)	Elman RNN	STLF in Palermo, Italy
Siddaemeshwara et al. (2010)	Elman NN	Household electricity LF
Showkati et al. (2010)	ESN	STLF in Slovakia
Chao et al. (2010)	Dynamic Fuzzy RNN	STLF in Northern China
Marin et al. (2002)	Elman RNN	STLF in Spain

NN neural network, *RBFNN* radial basis feedforward neural network, *ELM* extreme learning machine, *CRBM* conditional restricted boltzman machine, *LSTM* long-short term memory, *FFNN* feedforward neural network, *CFNN* cascade forward neural network, *BNN* bayesian neural network, *SVM Support Vector Machine*, *SVR* support vector regression, *RNN* recurrent neural network, *CGPRNN* cartesian genetic programming recurrent neural network, *GRU* gated recurrent unit, *ESN* echo state network

Methodology

As mentioned in the literature, there are 4 forecasting horizons; very short term, short term, mid term, and long term load forecasting. In this study, we tried to make one-step ahead prediction with a system identification method considering it as time series prediction method; Nonlinear Autoregressive Neural Network with Exogenous Variables. This method is an advanced kind of simple autoregressive method and a special kind of Recurrent Neural Networks. NarxNet is primarily one kind of powerful tool for modeling dynamical systems (Siegelmann et al. 1997). In the modeling, it utilizes characteristic of feedback prediction recurrently as recurrent neural networks do. NarxNet can be applied to many nonlinear system identification problems such as heat exchanger, fluid flow state control, magnetic state control, pH neutralization process control, and pollution mortality. Narxnet is based on linear ARXNet (Auto Regressive with Exogenous Variable) commonly used for time series prediction. Narxnet is an extension of ARX(Autoregressive with exogenous variable) and the advantage of using Narxnet is to insert non-linearity to the modeling of the system while applying auto regressive movement for predicting ahead steps.

In the following, simple mathematical background was given [Leontaritis and Billings (1985), Norgaard et al. (2000)]:

$$y(n+1) = f[y(n), \ldots, y(n-dy+1); (1)u(n), u(n-1), \ldots, u(n-du+1)] \quad (1)$$

In the compact form, we can rewrite Eq. 1 as follows;

$$y(n+1) = f[y(n); u(n)] \quad (2)$$

where $u(n) \in R$ and $y(n) \in R$ denote the input and output of the model at discrete time n, respectively, and $d_u \geq 1$ and $d_y \geq 1$ where $d_y \geq d_u$, and dy, du are the input and output memory orders, respectively. The vectors of y(n) and u(n) are external input(s) and internal input(s), respectively.

The topology of NarxNet can be seen in Fig. 1.

NarxNet can be trained in two modes; series-parallel mode and parallel mode.

- **Series-parallel (SP) mode**: In this mode, the output regressor is computed by only utilizing actual values of both internal and external inputs. The formula is given in the following equation:

$$\begin{aligned} \hat{y}(n+1) = f\left[\mathbf{y_{sp}}(n); \mathbf{u}(n)\right] = \mathbf{f}[y(n)\ldots\mathbf{y}(n-d_y+1); \\ u(n)u(n-1)\ldots u(n-d_u+1)] \end{aligned} \quad (3)$$

- **Parallel (P) mode**: In this case, regressor of output is computed by utilizing internal input and estimated output feedback to the system. The formula is given by in the following equation:

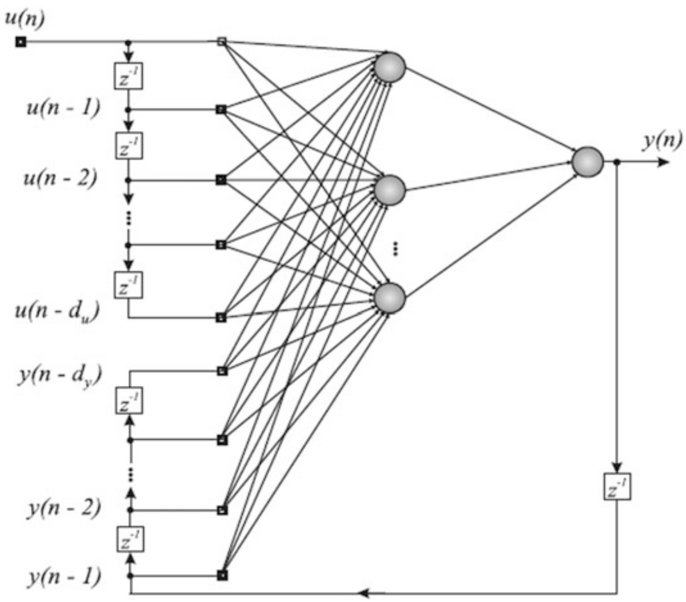

Fig. 1 Narxnet with internal (u) and external (y) input (Menezes and Barreto 2006)

$$\begin{aligned}\hat{y}(n+1) = f\left[\mathbf{y_p}(n); \mathbf{u}(n)\right] = \mathbf{f}[\hat{y}(n), .., \hat{y}(n-d_y+1);\\ u(n), u(n-1), \ldots, u(n-d_u+1)]\end{aligned} \tag{4}$$

The modes mentioned above were illustrated in the following figure.

As seen from Fig. 2, in parallel mode, estimation of time t + 1 is computed by estimated value for time t and internal input for time t + 1 whereas both internal and external inputs of actual values are utilized in series-parallel architecture. In this paper, we used series-parallel architecture for both training and testing (prediction) parts in order to apply one-step ahead prediction which is one step later prediction performed only by the previous actual values.

Application

In the application phase of the study, it was proposed to predict hourly electricity load with one-step ahead type prediction for hourly loads. Due to the confidentiality reasons, obtained data is transformed data. The data supplied to us is hourly load data of the European side of İstanbul, which spans from the beginning of the year 2015 to the end of September 30, 2017. In the first part of the application, some descriptive characteristics were illustrated, then obtained results by NarxNet were given.

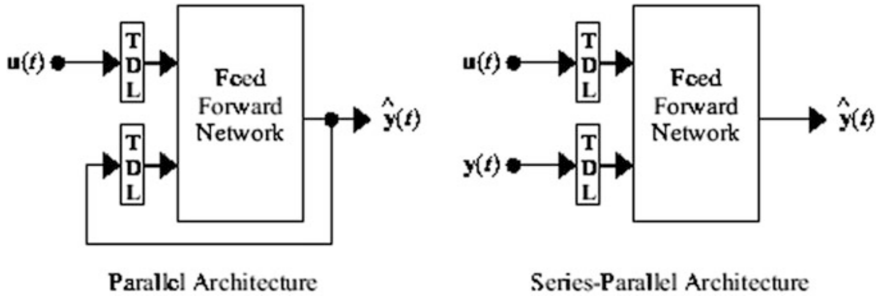

Fig. 2 Parallel and series-parallel modes of Narxnet (Labde et al. 2017)

In the below figure, total load consumption nearly over three years can be seen. In Fig. 3, the third bottom of the figure belongs to 9 months of the year 2017 not only for a full year, but other parts belong to the full years of 2015 and 2016. By looking at Fig. 3, it may be said that our time series is stationary since there is no trend for consumption over the years. By looking at unit root tests, we have also found that our data is stationary. In Fig. 3, there is an eccentric pattern in all three parts. This pattern is a sharp decline in loads two times in a year and the pattern is not at the same time of each year whereas these patterns have similar characteristics. This eccentricity stems from the type of calendar used in Turkey. Turkey uses a solar calendar, however, religious holidays are celebrated according to the lunar calendar. Due to the day differences between lunar and solar calendar, religious holidays' patterns are seen at different times in the solar calendar. Apart from this eccentricity, the load pattern shows stationary time series characteristics. In addition to that, the consumptions are intense both in winter and summer seasons, and less intense in autumn and spring seasons. Summer season's intensity may be caused primarily by temperature increments' boosting of air-conditioner usage. Winter season's intensity may be caused by depending on the productivity of industries since obtained data belongs to the biggest industrial city of Turkey. Daily load patterns of a week in 2016, from Monday at the top to Sunday at the bottom, were depicted in the following figure.

From Fig. 4, it is concluded that the consumption in business days are much more than weekends where Saturday has the characteristic somehow alike business days since some industries may be working on this day. It can be concluded from these facts that consumption data primarily is based on industrial consumption. In the following figure, the hourly load pattern was illustrated for Monday.

In underdeveloped and developing countries, consumptions are intensely available at 7–9 a.m. and p.m. (prime time) whereas more intense consumptions are available between 9 a.m and 5 p.m. in developed countries due to industrial production. By looking at Fig. 5, it can be concluded that the consumption characteristic of İstanbul is nearly similar to the consumption pattern of developed countries. This fact is compatible with reality since İstanbul is the leading industrial city of Turkey.

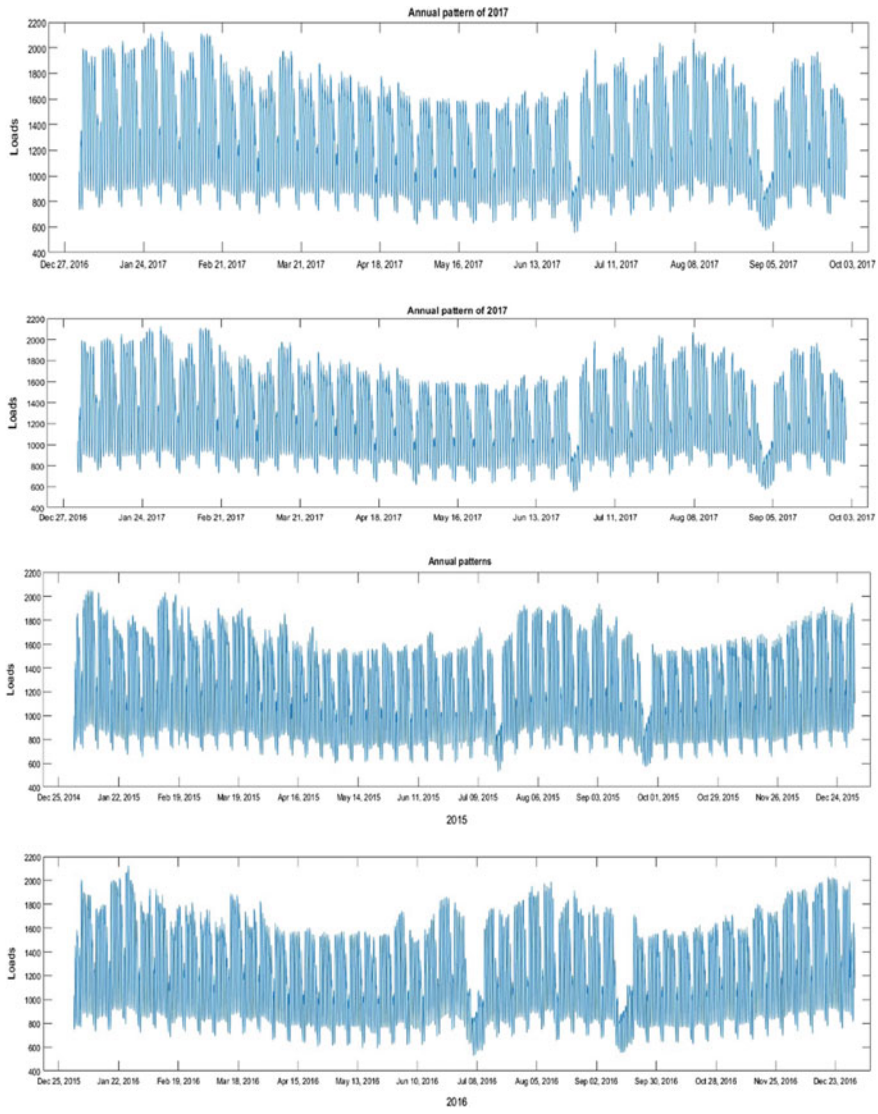

Fig. 3 Annual patterns of load consumption over three years

As mentioned in the methodology section, we modeled the prediction problem by utilizing a nonlinear system identification model. Both for training and testing, open loop structure was utilized. The hourly temperature for İstanbul was used as an exogenous variable for Narxnet. The data was split into three parts for prediction. Data partition was 70, 15, 15% for training, validation, and testing, respectively. 2 years and 6 months were used for training, and in the test stage, one-step ahead prediction for hourly loads of next 3 months was performed. In the model,

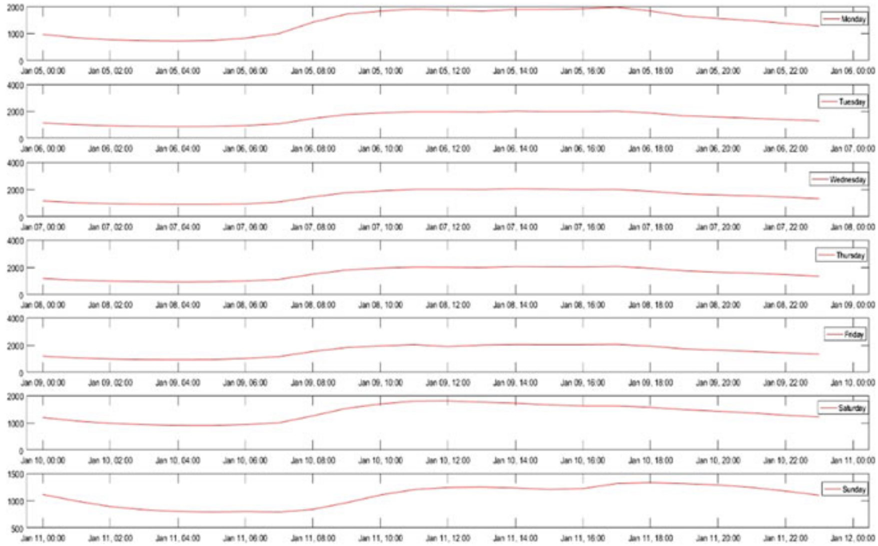

Fig. 4 Daily load patterns for all days

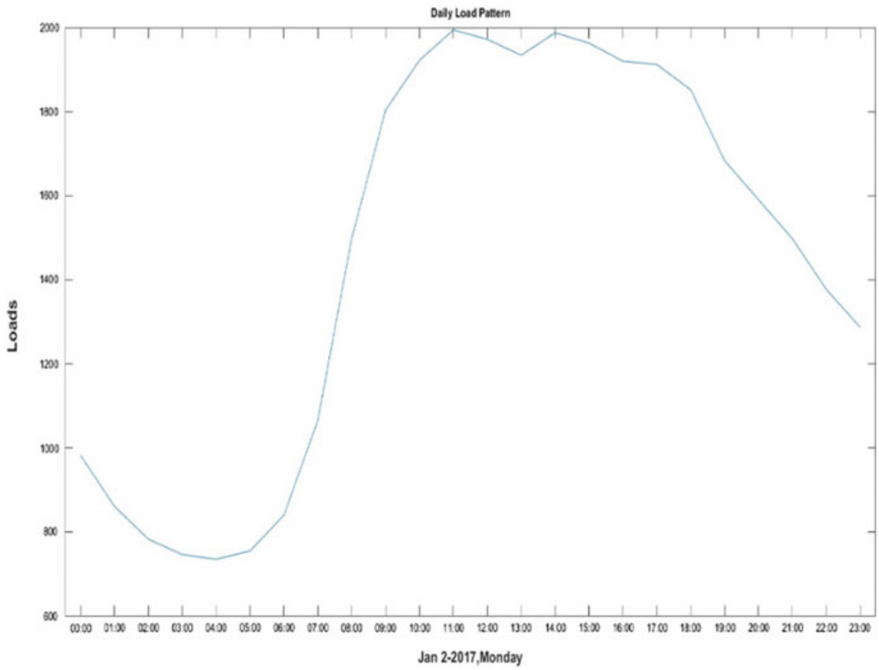

Fig. 5 Daily load pattern

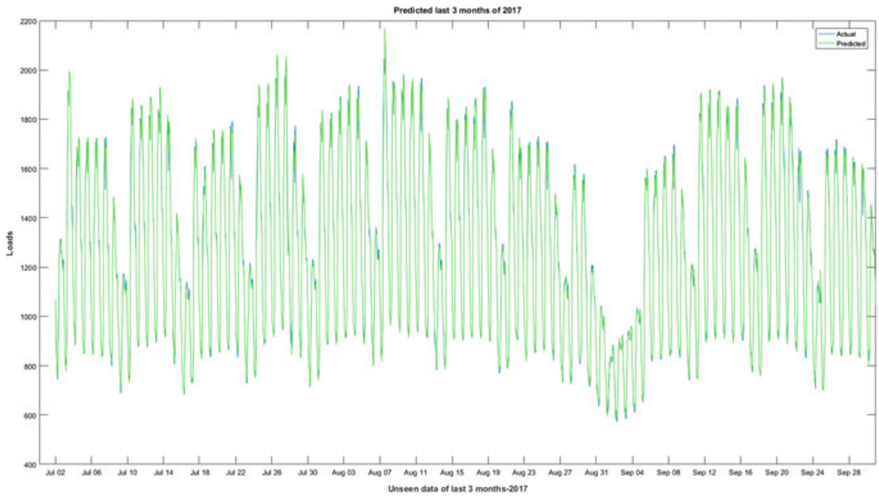

Fig. 6 Predicted versus actual loads for unseen 3 months

open loop mode was utilized with 20 hidden neurons by utilizing Bayesian regularization optimizer method. Bayesian regularization method is an efficient algorithm in order to avoid the risk of overfitting so that we chose to use it. At the end of training, results were given after validation checks were performed. In prediction problems, error rate measurement is an important indicator to assess the model's efficiency. Root Mean Square Error (RMSE), Mean Square Error (MSE), Mean Absolute Deviation (MAE) and Mean Absolute Percentage Error (MAPE) methods can be used for error measurement tool. MAPE is not scaled dependent and provides an easy interpretation of the results and comparisons. However, MAPE should not be used in low data amount since it may mislead decision maker. Since we had a large amount of data, MAPE was used for error measurement. As the result, it was found after validation checks that error rate for one-step ahead prediction of unseen 3 months, as MAPE, was 0.0135 and prediction can be seen in Fig. 6.

Discussion and Conclusion

This study was conducted for the purpose of prediction of hourly electricity load of the leading industrial city in Turkey. We presented the results of the study at the end of the application section. Firstly, the mathematical foundation of Narxnet was briefly introduced. Secondly, some graphical representations were given for visual examination of time series characteristics. Our time series was found stationary after examination since it has no trend. Unit root test validated the stationary state of the time series. We got some inferences from the time series data. The load characteristic has the typical characteristic of developed countries' load patterns. This fact is compatible with reality since İstanbul is an industrial city. Business days and weekend days have different loads since the data was structured by mostly industrial consumptions. Thirdly, in the analysis stage, the data was split into two parts, and the second part was used for comparison of prediction. Bayesian regularization optimizer and 20 hidden neurons were used in the series-parallel mode for 24 h time delay. Between the NarxNet modes, open loop structure (series-parallel mode) was utilized for one-step ahead prediction. As the result, MAPE of Narxnet prediction was found 0.0135. Predicted vs actual loads visual representation can be seen in Fig. 6. Prediction is nearly compatible as seen from Fig. 6 that supports found MAPE.

In the further studies, industrial and residential electricity consumptions may be separated and analyzed distinctly. Analyses performed in this way are likely to give more accurate results than the results of the current study since residential electricity consumption has different patterns than industrial consumption patterns. In addition to that, different NarxNet architectures and different combinations of parameters may be used for getting better results, and some other system identification and state space models such as SARIMA, SARIMAX, and Gaussian Process Regression methods may be used for the data and their results may be compared to the obtained results in this study.

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The Optimization of Aggregate Production Planning Under Fuzzy Environment: An Application From Beverage Industry

Merve Gul Topcuoglu, Fatma Betul Yeni, Yildiz Kose and Emre Cevikcan

Abstract Aggregate production planning (APP) can be considered as a great picture of the planning process. Rather than focusing on individual products or services, APP focuses on total or collective capacity. Therefore, it has a very important place in production and operation management functions. In the literature, different kind of methods has been proposed for the solution of APP problems. In some situations where the cost and demand parameters cannot be defined as crisp values due to the environment of the problems, fuzzy logic is used to handle the imprecise data. This paper provides a fuzzy optimization approach for aggregate production planning problems. After given information about fuzzy linear programming and solution approaches, a case study in a beverage industry is carried out. The results are analyzed using different a-cut values.

Keywords Fuzzy linear programming · Aggregate production planning
Fuzzy logic

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_23

Introduction

The importance of production planning increases day by day due to the competitive business environment, increasingly complex and intensifying production systems, growing and diversifying demands, the transition to multifunctional structures and increasing quality competition. It is possible to create a production planning by obtaining basic knowledge of some sub-processes and resources. However, uncertainty in environmental conditions and resources occurred by the dynamic environment of the real world have caused differentiation in optimization approaches.

Production planning is a production management technique consisting of identifying the product to be produced, determining the requirements for the production and performing scheduling process to ensure that products are produced at the desired quality and cost, in the desired time and quantities. It is an important tool that leads the firm to reach the target in a short time and high efficiency (Baskak and Tanyaş 2013).

Aggregate production planning (APP) involves a planning process ranging from 6 to 18 months and shows the production, demand and stock quantities of the future periods in the form of aggregate values (ton, hectoliter, man * hour, machine * hour, etc.) over time. This type of planning is created on an annual basis, based on product families (groups). Many methods have been proposed for the solution of APP problems in the literature including linear programming, goal programming, transportation models, simulation models, heuristic approaches and decision rules (Saad 1982). In real life, some information or parameters of APP problems such as demand, resources, cost or objective function can be imprecise due to the environment of the problem. To handle this situation, most of these approaches are extended in a fuzzy environment.

The concept of fuzzy logic was first presented by Zadeh (1965) and used in many studies in the literature as a new field of application. Later, Zimmerman (1978) proposed a fuzzy linear programming (FLP) method to deal with problems in the fuzzy environment. In his work, Zimmerman has addressed linear programming problems with fuzzy objective and fuzzy constraints. In the following years, fuzzy linear programming has become a fuzzy optimization method for solving APP problems. Different approaches of FLP for production planning problems are presented in the literature. Torabi et al. (2010) proposed a 2-leveled fuzzy hierarchical production planning model. In the study, firstly an APP, later a disaggregated production plan is defined by solving the FLP model to create a disaggregated production plan in the final level. Weng and Zeng (2013) proposed a flexible aggregate production planning system to handle with unclear manufacturing factors. Firstly, they defined the uncertain demand and cost and proposed a fuzzy linear programming model. They aimed the profit maximization strategy in their model. Karaatlı et al. (2014) have optimized a firm's profit considering the Zimmermann approach while creating an aggregate production planning for the firm. The objective function, lower and upper demand quantities and total machine time were considered as fuzzy and a plan was created to increase the operating profit in the result of the study. Baykasoglu and Gocken (2010) proposed a multi-objective fuzzy APP problem, where the fuzzy parameters were defined as triangular fuzzy numbers. They used different ranking methods and heuristic algorithm for the solution. Mirzapour Al-e-hashem et al. (2011) presented a multi-objective APP problem by considering multi-manufacturers/suppliers/customers in a supply chain. Modarres and Izadpanahi (2016) presented a multi objective linear aggregate planning model where energy saving and carbon emission were taking into consideration. In the study, the dynamic optimization approach was applied to deal with vague parameters.

This paper presents an application of aggregated production planning with fuzzy linear programming. Firstly, the basic formulation of the FLP model for APP and necessary assumptions are introduced. Later, a real case study in a beverage industry is carried out with the proposed model and results are discussed using different a-cut values.

Methodology

Fuzzy Linear Programming

Fuzzy linear programming (FLP) is a method used in imprecise situations that occur in decision processes in linear programming (LP) problems. FLP models have the assumptions of proportionality, additivity, and divisibility that LP models have, yet the assumption of certainty in an LP becomes the assumption of uncertainty in FLP. For this assumption, there should be vagueness in some/all parameters in the model. In its most general form, the FLP model, in which all the parameters are fuzzy, can be expressed as:

$$maksimize \sum_{j=1}^{n} \widetilde{c}_j x_j \tag{1}$$

Subject to:

$$\sum_{j=1}^{n} \widetilde{a_{ij}} x_j (\leq, =, \geq) \widetilde{b}_i \quad i = 1, 2, \ldots, m \tag{2}$$

$$x_j \geq 0 \quad j = 1, 2, \ldots, n$$

where

x_j decision variable
$\widetilde{\mathrm{c}}_\mathrm{j}$ the coefficient of the *j*th decision variable in the objective function
$\widetilde{a_{ij}}$ the coefficient of the *j*th decision variable in the *i*th constraint
$\widetilde{b}_i$ right side value of the *i*th constraint.

Unlike the LP model, a fuzziness symbol ($\sim$) is added to the FLP model. Fuzzy parts are evaluated in the range [0.1].

The most general classification of decision models in the literature is presented by Zimmermann (1996). Accordingly, FLP models can be classified in three categories such as 'non-symmetric model with fuzzy constraints and crisp objectives', 'symmetric model with fuzzy constraints and fuzzy objectives' and 'symmetric model with crisp constraints and fuzzy objectives' (Tuş 2006). Many approaches to FLP have been proposed in the literature, among which the most commonly used approaches are Zimmerman (1996), Chana's (1983) and Julien's (1994) approaches. Usually, the results obtained from these approaches are close to each other (Shih 1999). In this study, it is decided to use Julien's approach not only because it gives an alternative way of handling fuzzy parameters but also gives optimal solution on the large-scale problems.

Julien Approach

The Julien (1994) approach uses the α-cut concept in the solution of FLP including fuzzy objective and fuzzy right-hand side (RHS) by solving pairs of crisp linear programming problems. In the Eqs. (3) and (4), the upper indices represent the α-cut, while the lower indices L and U represent the low and high points, respectively.

$$Max\, c_L^{\propto} x \tag{3}$$

$$\text{s.t. } A_U^{\propto} x \le b_L^{\propto} \quad \mathrm{i} = 1, 2, \ldots, \mathrm{m}$$

$$x \ge 0$$

$$Max\, c_U^{\propto} x \tag{4}$$

$$\text{s.t. } A_L^{\propto} x \le b_U^{\propto} \quad \mathrm{i} = 1, 2, \ldots, \mathrm{m}$$

$$x \ge 0$$

Likewise, if Julien's approach is applied to a minimization problem, the modeling would be as Eqs. (5)–(7). Accordingly, the objective function will be between the minimum values of lower and upper bounds (Iris and Çevikcan 2014).

$$\widetilde{Min}\, cx \tag{5}$$

$$a_i x \ge b_i \quad \mathrm{i} = 1, 2, \ldots, \mathrm{m}$$

$$x \geq \tilde{0}$$

$$Min\, c_U^{\propto} \tag{6}$$

$$A_L^{\propto} x \geq b_U^{\propto} \quad \mathrm{i} = 1, 2, \ldots, \mathrm{m}$$

$$x \geq 0$$

$$Min\, c_L^{\alpha} \tag{7}$$

$$A_U^{\propto} x \geq b_L^{\propto} \quad \mathrm{i} = 1, 2, \ldots, \mathrm{m}$$

$$x \geq 0$$

Fuzzy Aggregate Production Planning Model

The fuzzy multi-objective linear programming (MOLP) model to be developed for APP follows the steps in Fig. 1.

The model given below is based on the model developed by Gallego (2001):

Index attributes

i type of the product i = 1, 2
t time horizon in periods t = 1, 2,…,12.

Parameters

m_{it} the unit cost of the product i for period t
S_{it} holding cost in period t
$\widetilde{D}_{it}$ the fuzzy demand of the product i for period t
$\tilde{k}_{it}$ the fuzzy capacity of the product i for period t
n_t cost of regular labor in period t (man-hour)
f_t cost of overtime labor in period t (man-hour)
a_t cost of hiring in period t (man-hour)
$ç_t$ cost of firing in period t (man-hour)
b_t number of workers at the beginning of period t
$çg_t$ working days in period t
$çs_t$ working hours in period t.

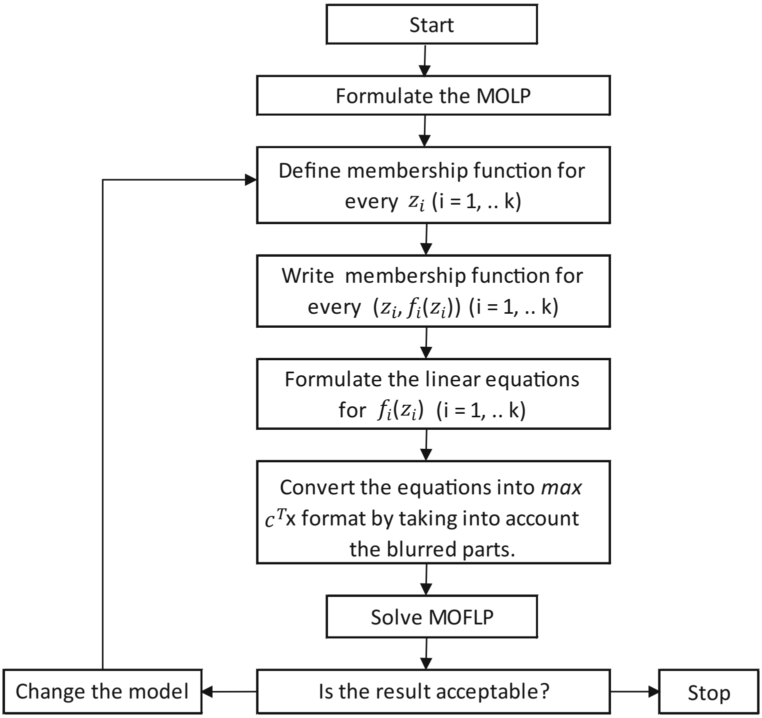

Fig. 1 Flow diagram of multi-objective fuzzy linear programming (MOFLP) model

Decision Variables

X_{it} units of product i to be produced in period t
A_t regular work force hired in period t (man-hour)
$Ç_t$ regular work force fired in period t (man-hour)
N_t regular labor used during period t (man-hour)
F_t overtime labor used during period t (man-hour)
e_{it} units of product i as an inventory in period t.

The linear program will be;

$$Min \sum_i \sum_t [m_{it} X_{it} + s_t e_{it}] + \sum_t [n_t N_t + f_t F_t + a_t A_t + ç_t Ç_t] \tag{8}$$

s.t.

$$F_t \leq mf_t + b_t + A_t - Ç_t \quad \forall t \tag{9}$$

$$\frac{(F_t + çs_t \times kb_t)}{üs_t} \geq X_{1t} + X_{2t} \quad \forall t \tag{10}$$

$$e_{it} + X_{it} \geq \widetilde{D}_{it} \quad \forall i, t \tag{11}$$

$$X_{it} \leq \tilde{k}_{it} \quad \forall i, t \tag{12}$$

$$A_t, Ç_t = integer \quad \forall\, t \tag{13}$$

$$X_{1t} \geq 400{,}000 \quad \forall t \tag{14}$$

$$X_{2t} \geq 70{,}000 \quad \forall t$$

$$e_{1t} \geq 25{,}000 \quad \forall t$$

$$e_{2t} \geq 10{,}000 \quad \forall t$$

$$X_{1t}, e_{1t}, N_t, A_t, Ç_t \geq 0, \qquad O_{1t} \in \{0,1\}\ \forall i, t \tag{15}$$

The model given above is a fuzzy linear model. In this model, demand and capacity values are considered as fuzzy. The objective (8) is minimizing the total cost of production. Constraint (9) is about overtime working hour capacity. Constraint (10) satisfies the limitation of the total production capacity being greater than the total production quantity. Constraint (11) ensures the restriction on the amount of product available to satisfy the demand. Constraint (12) is a product-based capacity constraint. Constraint (13) is about hiring and firing situation. This constraint ensures these activities to be an integer. Constraint (14) shows minimum production quantities and security stock constraints. Constraint (15) is the sign constraint.

Application

A real case study of aggregate production planning is conducted in a beverage industry that produces juice and milk products over 60 years. One of the company's biggest product families has been selected for the planning process and the term of aggregate production planning is set to be 12 months. Sale forecasting for the next 12 months is obtained by regression and seasonal adjustments methods using sales data of 53 months belonging to two products (Products 1 and 2). These two methods are chosen to better analyze the relationship and seasonal effects on the data. The data obtained via two different forecasting methods is given in Table 1. According to the analysis, the seasonal adjustments method gives results with less deviation for Product 1 while the regression analysis gives better results for Product 2. Forecasting methods giving the closest values to the truth are chosen for the FLP model.

After computing the production forecasts, the fixed cost and values used in the production is determined to create the FLP model and these values are given in Table 2. In the model, demand and capacity values are considered as fuzzy. The model is solved with the Julien approach, which is one of the FLP solution approaches.

Before the implementation of Julien approach, it is decided to create a solution to the model in a crisp environment. Therefore, the fuzzy constraints of the model are

Table 1 Forecasting via regression and seasonal adjustment

Month		Regression analysis		Seasonal adjustment	
		Product 1	Product 2	Product 1	Product 2
54	June	1,196,813	175,940	1,442,762	170,051
55	July	1,206,763	176,168	1,087,504	146,738
56	Aug.	1,216,712	176,396	1,371,331	138,085
57	Sep.	1,226,662	176,624	1,299,670	116,081
58	Oct.	1,236,612	176,852	1,309,104	118,306
59	Nov.	1,246,562	177,080	1,437,386	151,079
60	Dec.	1,256,511	177,308	1,334,527	132,660
61	Jan.	1,266,461	177,536	1,455,439	164,875
62	Feb.	1,276,411	177,764	1,238,689	205,082
63	Mar.	1,286,361	177,992	1,183,601	152,911
64	Apr.	1,296,310	178,221	1,104,417	134,850
65	May	1,306,260	178,449	1,023,351	147,021
Toplam		15,018,438	2,126,330	15,287,781	1,777,739

Table 2 Information for the Product 1 and Product 2

k2t	Production capacity of Product 2	384,000
k1t	Production capacity of Product 1	2,400,000
ust	Man/hour required for 1 lt	0.0187
nt	Monthly salary for 1 worker	1300
at	Recruitment cost for 1 worker	1835
ct	Dismissal cost for 1 worker	2018
ft	Overtime pay per hour	9
m2t	Material cost of Product 2	0.07
mlt	Material cost of Product 1	0.13
st	The holding cost	5
b	Total number of workers at the beginning	176
	Standard working hour	8
	Overtime working hour	4

obscured, and the model is solved with the objective of cost minimization. According to the results obtained, the aggregate production plan is created as in Table 3. The table indicates the monthly total production cost and total production amounts for both Products 1 and 2. According to this plan, by the end of 12 months, the normal working cost will be 2,550,600 TL; the overtime working cost will be 17,091 TL; the total material cost will be 2,183,713 TL; the dismissal cost will be 66,578 TL and the holding cost will be 84,875,109 TL. Depending on these costs, the total cost is calculated as 89,875,109 TL.

Table 3 The APP obtained by solution of the model where the fuzzy constraints are ignored

		June	July	August	Sept.	Oct.	Nov.
Product 1	Beginning inventory	100,000	25,000	373,378	597,826	25,000	227,073
	Production amount	1,367,762	1,435,882	1,595,779	726,844	1,511,176	1,423,662
	Net usable amount	1,467,762	1,460,882	1,969,157	1,324,670	1,536,176	1,650,735
	Demand	1,442,762	1,087,504	1,371,331	1,299,670	1,309,104	1,437,386
	Final inventory	25,000	373,378	597,826	25,000	227,073	213,348
Product 2	Beginning inventory	25,500	239,449	162,711	160,611	114,530	66,224
	Production amount	384,000	70,000	135,985	70,000	70,000	157,515
	Net usable amount	409,500	309,449	298,696	230,611	184,530	223,739
	Demand	170,050	146,738	138,085	116,081	118,306	151,079
	Final inventory	239,449	162,711	160,611	114,530	66,224	72,660
	Total production amount	1,751,762	1,505,882	1,731,764	796,844	1,581,176	1,581,177
Costs	Standard working cost	228,800	228,800	228,800	218,400	218,400	218,400
	Overtime working cost	16,038	–	–	1,053	–	–
	Material cost of Product 1	177,809	186,665	207,451	94,490	196,453	185,076
	Material cost of Product 2	26,880	9100	17,678	9100	9100	20,477
	Recruitment cost Dismissal cost	–	–	–	16,140	–	–
	Holding cost	8,758,812	7,529,412	8,658,824	3,984,222	7,905,882	7,905,882
	TOTAL cost	9,208,339	7,953,977	9,112,753	4,323,405	8,329,835	8,329,835
		Dec.	Jan.	Feb.	March	April	May
Product 1	Beginning inventory	213,348	94,810	25,000	31,368	101,914	25,000
	Production amount	1,215,989	1,385,629	1,245,057	1,254,147	1,027,503	1,023,351
	Net usable amount	1,429,337	1,480,439	1,270,057	1,285,515	1,129,417	1,048,351
	Demand	1,334,527	1,455,439	1,238,689	1,183,601	1,104,417	1,023,351
	Final inventory	94,810	25,000	31,368	101,914	25,000	25,000

(continued)

Table 3 (continued)

		June	July	August	Sept.	Oct.	Nov.
Product 2	Beginning inventory	72,660	10,000	31,261	10,000	10,000	10,000
	Production amount	70,000	186,136	183,820	152,911	134,850	147,021
	Net usable amount	142,660	196,136	215,081	162,911	144,850	157,021
	Demand	132,660	164,875	205,082	152,911	134,850	147,021
	Final inventory	10,000	31,261	10,000	10,000	10,000	10,000
	Total production amount	1,285,989	1,571,765	1,428,877	1,407,058	1,162,353	1,170,372
Costs	Standard working cost	217,100	217,100	217,100	185,900	185,900	185,900
	Owertime working cost	–	–	–	–	–	–
	Material cost of Product 1	158,079	180,132	161,857	163,039	133,575	133,036
	Material cost of Product 2	9100	24,198	23,897	19,878	17,530	19,113
	Recruitment cost Dismissal cost	2018	–	–	48,421	–	–
	Holding cost	6,429,947	7,858,824	7,144,385	7,035,294	5,811,765	5,851,862
	Total cost	6,816,244	8,280,254	7,547,239	7,452,532	6,148,770	6,189,911

The Solution with Julien Approach

After the initial solution, the model is reformulated by Julien approach using fuzzy demand and fuzzy capacity values. The new model uses 6 different α values as 0–0.2–0.4–0.6–0.8–1. According to each alpha value, lower limit and the upper limit for capacities and demands are determined and membership functions are established.

- **Membership function for capacity**

For Product 1, the lower bound is set as 2,000,000 lt. while upper bound is set as 3,000,000 lt. In the same way, the lower limit for product 2 is set as 350,000 lt. and the upper limit is set as 450,000 lt. The membership functions of Products 1 and 2 are given in Fig. 2.

- **Membership function for demand**

While membership functions of demands are calculated, lower and upper bound values are determined separately for each month. Since the demands obtained from the regression analysis were used for the Product 2 demand, the lower and upper limit values are obtained based on the average of the monthly deviations according to the regression analysis. In the same way, the method that gave the least deviation for the Product 1 was the seasonal adjustment method. Thus, monthly averages of the deviations obtained according to the seasonal adjustment methods are used to determine the upper and lower limits. Membership function values of monthly demands are given in Table 4. Lower and Upper *a*-cut values are indicated as L and U at the table.

- **Constraints by the Julien Approach**

The representation of Julien's approach has already shown in the Eqs. (5)–(7) when it is applied to a minimization problem. In this model, b values represent the right side of the constraint, A values represent the matrix of constraint coefficients,

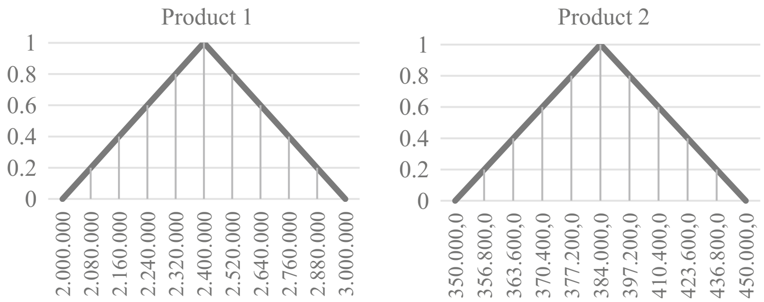

Fig. 2 Membership function of Products 1 and 2

Table 4 Membership function of monthly demands

a	L/U	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May
Product 1													
1	–	1,442,762	1,087,504	1,371,331	1,299,670	1,309,104	1,437,386	1,334,527	1,455,439	1,238,689	1,183,601	1,104,417	1,023,351
0.8	L	1,414,762	1,075,504	1,351,331	1,267,670	1,267,104	1,417,386	1,323,527	1,414,439	1,223,689	1,159,601	1,084,417	987,351
	U	1,470,762	1,099,504	1,391,331	1,331,670	1,351,104	1,457,386	1,345,527	1,496,439	1,253,689	1,207,601	1,124,417	1,059,351
0.6	L	1,386,762	1,063,504	1,331,331	1,235,670	1,225,104	1,397,386	1,312,527	1,373,439	1,208,689	1,135,601	1,064,417	951,351
	U	1,498,762	1,111,504	1,411,331	1,363,670	1,393,104	1,477,386	1,356,527	1,537,439	1,268,689	1,231,601	1,144,417	1,095,351
0.4	L	1,358,762	1,051,504	1,311,331	1,203,670	1,183,104	1,377,386	1,301,527	1,332,439	1,193,689	1,111,601	1,044,417	915,351
	U	1,526,762	1,123,504	1,431,331	1,395,670	1,435,104	1,497,386	1,367,527	1,578,439	1,283,689	1,255,601	1,164,417	1,131,351
0.2	L	1,330,762	1,039,504	1,291,331	1,171,670	1,141,104	1,357,386	1,290,527	1,291,439	1,178,689	1,087,601	1,024,417	879,351
	U	1,554,762	1,135,504	1,451,331	1,427,670	1,477,104	1,517,386	1,378,527	1,619,439	1,298,689	1,279,601	1,184,417	1,167,351
0	L	1,302,762	1,027,504	1,271,331	1,139,670	1,099,104	1,337,386	1,279,527	1,250,439	1,163,689	1,063,601	1,004,417	843,351
	U	1,582,762	1,147,504	1,471,331	1,459,670	1,519,104	1537,386	1,389,527	1,660,439	1,313,689	1,303,601	1,204,417	1,203,351
Product 2													
a	L/U	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	March	Apr.	May
1	–	170,051	146,738	138,085	116,081	118,306	151,079	132,660	164,875	205,082	152,911	134,850	147,021
0.8	L	164,051	139,738	133,085	103,081	114,306	145,079	127,660	154,875	195,082	147,911	126,850	141,021
	U	176,051	153,738	143,085	129,081	122,306	157,079	137,660	174,875	215,082	157,911	142,850	153,021
0.6	L	158,051	132,738	128,085	90,081	110,306	139,079	122,660	144,875	185,082	142,911	118,850	135,021
	U	182,051	160,738	148,085	142,081	126,306	163,079	142,660	184,875	225,082	162,911	150,850	159,021
0.4	L	152,051	125,738	123,085	77,081	106,306	133,079	117,660	134,875	175,082	137,911	110,850	129,021
	U	188,051	167,738	153,085	155,081	130,306	169,079	147,660	194,875	235,082	167,911	158,850	165,021
0.2	L	146,051	118,738	118,085	64,081	102,306	127,079	112,660	124,875	165,082	132,911	102,850	123,021
	U	194,051	174,738	158,085	168,081	134,306	175,079	152,660	204,875	245,082	172,911	166,850	171,021
0	L	140,051	111,738	113,085	51,081	98,306	121,079	107,660	114,875	155,082	127,911	94,850	117,021
	U	200,051	181,738	163,085	181,081	138,306	181,079	157,660	214,875	255,082	177,911	174,850	177,021

and c values represent the objective function coefficients. The Julien approach is applied to the model that is formulated to produce the Products 1 and 2. In each alpha value, the cost for lower and upper boundaries are calculated once again.

- minc_L^α lower boundary constraints;
  $X_{it} + e_{it} \geq \widetilde{D_{it}}{}_L^\alpha$
  $X_{it} \leq \widetilde{K_{it}}{}_U^\alpha$
- $minc_U^\alpha$ upper boundary constraints;
  $X_{it} + e_{it} \geq \widetilde{D_{it}}{}_U^\alpha$
  $X_{it} \leq \widetilde{K_{it}}{}_L^\alpha$

The above constraints for lower boundary are calculated according to the values obtained from membership functions for each alpha value. The model is solved using GAMS v24.9.1 and cost values are procured for each alpha value separately.

Results

The costs that get as a result of the APP created with a solver for each alpha values and upper/lower boundaries with Julien approach are given in Table 5 below. According to these results, it is observed that the costs found using the lower limits are lesser.

When the differences between the upper and lower bounds according to the α values are considered, it is seen that the highest difference is at the a = 0 by 20%. Same way, a = 1 gives the minimum difference by 0% and here, the cost 89,693,091 TL is equal to the cost of the first model where the fuzzy constraints were ignored.

Table 5 Costs at Lower and Upper Boundaries

a	Cost for lower bound	Cost for upper bound	%
0	79,530,261	99,862,983	20
0.2	81,563,870	97,827,924	17
0.4	83,595,419	95,794,007	13
0.6	85,627,676	93,759,228	9
0.8	87,660,109	91,725,610	4
1	89,693,091	89,693,091	0

Discussion and Conclusion

This paper presents a real case study related to the aggregate production planning using fuzzy linear programming. The FLP is selected considering such factors as the blurred environment of the problem, the multiplicity of resources, the needs of the decision maker's opinions, and so on. Julien approach, one of the FLP techniques, is used to solve the formulated model. The results obtained show the effect of the value of α on the cost. According to these, the cost increases as the α value increases for the lower bounds, while the costs decrease as the α value increases for the upper bounds. The model provides various options for the decision maker to get the decision process easier. Fuzzy decision sets in the FLP model show that there can be an infinite number of alternative solutions to a problem. In the FLP model, a solution that will satisfy the decision maker is searched. It offers more flexible solutions than LP models.

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Identifying Talent Attributes for Talent Management in Automotive Industry in Turkey

Aylin Ozel and Gaye Karacay

Abstract Talent management has become an increasingly popular area in the human resource management. Over the past decade, talent management has gained importance and become an effective tool for organizations that want to have a competitive advantage and achieve maximum organizational performance. For a successful talent management process, organizations need to identify talent attributes or in other words characteristics that a talented employee should have. The main purpose of this study is to define talent attributes in the automotive industry in Turkey through a qualitative research. Within the scope of the study, in-depth interviews were carried out with the participation of 20 employees who works in different companies that operates in the automotive industry in Turkey. 29 talent attributes were identified as a result of face-to-face in-depth interviews.

Keywords Talent management · Talent identification · Talent attributes Automotive industry · Content analysis

Introduction

Although Talent Management (TM) is one of the most popular terms in the human resource management area nowadays, it has not appeared in the literature until the late 1990s. As a term "talent management" was first used in 1997 in the report "The War For Talent" which was published by McKinsey&Company. This report reveals that the most important resource that will provide a competitive advantage for a company is valuable, rare, inimitable and non-substituted human resource

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_24

according to the resource-based view. However, companies do not pay attention to managing human resources as they manage physical and financial resources.

Talent management has become one of the rising trends in human resource management both in the business world and in the academic world, with the realization of the importance of the talented employees to gain a competitive advantage in today's uncertain and dynamic environment. Talented employees could be everywhere from the bottom line to the top management in an organization and play an important role in organizational outcomes (Aguinis and O'Boyle 2014).

An effective TM process begins with talent identification. How an organization identifies talent is closely related to how the talent management system is established within the organization. Accordingly, attributes that a talented employee should have a need to be identified.

In this study, talent attributes in the automotive industry in Turkey tried to be revealed through face-to-face in-depth interviews.

Talent and Talent Management

TM is a very effective tool for companies that want to gain and maintain a competitive advantage in such a compelling economy and market conditions. Over the past decade, organizations realized that the importance of talent in order to gain a sustainable competitive advantage and achieve maximum organizational performance. However, a survey which was conducted by The Chartered Institute of Personnel and Development (CIPD) in 2012 revealed that only 6% of companies are able to manage the TM process effectively. One of the important reasons for this problem is that there is no exact answer to the question "What is Talent?" (Meyers et al. 2013).

The term "talent" was defined by Iles et al. (2010) as a combination of strategic intelligence, leadership, maturity, communication capabilities, entrepreneurship, influencing other people and achieving business outcomes in order to meet job requirements.

Basically, there are two perspectives for the definition of talent in TM literature (Gallardo-Gallardo et al. 2013; Iles 2013). In the first perspective, object, talent is considered as the characteristics of an individual, whereas in the second perspective, subject, talent is considered as the individual himself/herself. In the human resources and TM researches, dominant perspective is subject perspective.

According to Collings and Mellahi (2009), TM is the whole of the activities and processes to determine the key positions that will provide a sustainable competitive advantage to the organizations, to create the talent pools that necessary to fill key positions and to ensure the commitment of the talented employees to the organizations.

TM has become an increasingly popular area in the human resources management. For example, at the end of 2004, the expression "*talent management hr*" was searched about 2.7 million times on the popular search engines on the internet.

However, this number reached about 8 million by the end of 2005 (Lewis and Heckman 2006).

In the TM literature, there are two different perspectives for TM practices according to employee groups that the company focused on. In exclusive TM, companies focus on only specific employee groups that they call “talented” or “high potential”. This specific employee group plays an important role in the value creation process (Iles et al. 2010). In the another TM perspective, inclusive TM, there is a humanistic philosophy. Regardless of their talent, all employees must be supported by TM practices so they could reach their maximum potential (Ashton and Morton 2005).

Talent Management Practices

Today, many organizations in the manufacturing and service sector are conducting TM practices.

TM practices that are conducted in the manufacturing sector aim to find out the effect of talented employees on overall organizational performance whereas in the service sector to find out the importance of talented employees on service quality (Zheng 2009).

TM practices basically include attraction, selection, development, and retention of the talented employees (Meyers and van Woerkom 2014).

- Talent attraction is ensuring to attract talented employees via applying for various key positions in an organization.
- Talent selection is activities for generating talent pools and to select the right person at the right time for the right position from these talent pools.
- Talent development is supporting to talented employees with training and education for improvement of their capabilities and abilities.
- Talent retention includes retention of talented employees via increasing their commitment to the organization.

Similarities and differences between human resource management and talent management are frequently discussed in the literature.

In some studies, talent management has been described as re-submission of existing ideas and practices in the field of human resources management under different concepts, which is named as “old wine in a new bottle” (Schuler et al. 2011).

In response to this, TM also has supported as a more comprehensive process than human resource management to improve organizational performance by gaining competitive advantage (Iles et al. 2010).

Talent Management Outcomes

The main goal of TM is to attract, select, develop and retain talented employees who have the capability to improve organizational performance. Besides, it aims to support strategic missions of organizations and adds them a sustainable competitive advantage.

TM has vital outcomes on both organizational and employee level. At the employee level, TM provides motivation and performance increasing as well as talented employee turnover rates regarding employee commitment (Festing and Schäfer 2014). At the organizational level, TM has outcomes such as increases in productivity, product and service quality, financial performance and growth rate of the company (Sabuncu and Karacay 2016). Moreover for the 21st century organizations, one of the main outcomes of TM could be sustainability (Boudreau and Ramstad 2005). TM outcomes create financial and non-financial value at the individual, organizational and societal level (Thunnissen et al. 2013).

Many organizations that conduct TM process are trying to balance human resources strategies, human resources processes and policies as well as TM strategies to maximize organizational and employee productivity, customer satisfaction, quality, operational and financial performance and to minimize environmental risks (Schiemann 2014).

Automotive Industry

Today, the automotive industry is a key industry for developed and developing countries. The automotive industry is connected to many other industries. It is the buyer of plastics, glass, textile, petrochemical, iron-steel and electric-electronic industries and supplier of tourism, transportation, construction, and defense industries.

The companies that are operating in the automotive industry also want to have a competitive advantage and high organizational performance like many other industries that are operating in various sectors. The way for achieving these is to have talented employees in such a dynamic business environment.

For the automotive industry, a talented employee is someone who has a minimum bachelor degree and technical, sales and marketing, management skills (Mao et al. 2009).

The automotive industry has an important position for Turkey. Especially in the recent years, it has become one of the fastest growing industries in Turkey. According to Automotive Manufacturers Association in Turkey, the total capacity of the automotive industry has reached 1.9 million units as of 2017. The automotive industry accounted for 5.5% of total employment in Turkey and the number of employees that are employed in the automotive sector is 53,337. Turkey's share of the automotive industry in the gross domestic product (GDP) is 3% and Turkey's export in the automotive industry has a share of 17%.

The automotive industry is a technology and capital based industry so talented employees is very important for companies that operate is the automotive industry (Mao et al. 2009). The turnover of talented employees in the automotive industry leads to the loss of technology, knowledge, experience as well as financial losses. To sum up, this would affect the productivity and competitive power of an organization.

Methodology

In the scope of the study, face-to-face in-depth interviews are made to identify the attributes of the talent for the automotive industry in Turkey.

The face-to-face in-depth interviews were realized with 20 different employees who work in different companies in the automotive industry. Among the participants of the in-depth interviews, 40% are males, 60% are females, 45% are younger than 25, 30% are between 25 and 34, 15% are between 35 and 44 and 10% are over 45. Also, 20% are managers, 80% are non-manager employees. Finally, 60% holds an undergraduate and 40% holds a graduate degree.

During interviews, the most important thing is that to not direct employees. Moreover, these interviews were conducted by asking the question "How do you define talent in your company and your job?".

Content Analysis

Content analysis is a qualitative technique to make replicable and valid inferences from meaningful matters to the contexts of their use. Content analysis is a well-established method in the qualitative analysis since it gives meaning to gathered data (Krippendorff 2004). In this study, qualitative data is derived from in-depth interviews. In content analysis, qualitative data draw an interpretation of the results (Bengtsson 2016).

After the interviews with employees in the automotive industry in Turkey, a content analysis was conducted by analyzing all the conversations obtained during these interviews.

The results of the content analyses are summarized in Table 1. The symbol + indicates that the interviewee mentioned the related talent attribute whereas the symbol - indicates that the interviewee did not mention the related talent attribute. Frequency is the number that how many times did the interviewee mention the related talent attribute. Besides, E and F refer to existence and frequency.

During the face-to-face in-depth interviews, 20 different interviewees from the automotive industry mentioned 29 different talent attributes.

Table 1 Content analysis

Interview no	1		2		3		4		5		6		7	
Talent item	E	F	E	F	E	F	E	F	E	F	E	F	E	F
Bachelor degree	+	1	+	1	-	0	-	0	+	1	-	0	-	0
Foreign language	+	1	+	1	-	0	-	0	+	1	+	1	-	0
Technical knowledge	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Sales, marketing, management knowledge	+	2	-	0	-	0	-	0	-	0	-	0	-	0
Communication skills	+	1	+	2	+	1	+	1	-	0	+	2	+	1
Teamwork skills	+	1	+	1	+	1	+	1	+	1	+	2	+	1
Time management skills	+	1	+	2	-	0	-	0	+	2	-	0	+	1
Leadership skills	-	0	-	0	-	0	+	1	-	0	-	0	-	0
Customer orientation	-	0	+	1	-	0	-	0	-	0	-	0	+	1
Proactivity	+	2	+	3	-	0	+	1	+	1	-	0	+	1
Result orientation	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Having a driving licence and driving actively	+	1	-	0	-	0	-	0	-	0	-	0	-	0
No travel restriction	+	1	-	0	-	0	-	0	-	0	-	0	-	0
Able to work under the stress	+	2	-	0	-	0	-	0	+	1	+	2	+	1
Able to work in shifts	-	0	-	0	-	0	-	0	-	0	+	1	-	0
Experience	+	1	-	0	-	0	-	0	-	0	-	0	+	3
Problem solving skills	-	0	+	1	+	1	-	0	-	0	-	0	-	0
Analytical thinking	-	0	-	0	+	1	+	2	+	1	-	0	-	0
Having responsibility	+	1	-	0	-	0	+	1	-	0	+	1	+	2
Taking initiative	+	1	-	0	-	0	+	1	+	1	-	0	-	0
Being critical	-	0	-	0	+	3	-	0	-	0	-	0	-	0
Making quick decisions	-	0	-	0	-	0	+	3	-	0	-	0	-	0
Innovative thinking	-	0	-	0	-	0	-	0	-	0	+	2	+	1
Having ethical values	-	0	-	0	-	0	-	0	-	0	-	0	+	1
Multi-tasking	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Longsightedness	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Being open-minded	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Being practical	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Open to learning	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Interview no	8		9		10		11		12		13		14	
Talent item	E	F	E	F	E	F	E	F	E	F	E	F	E	F
Bachelor degree	+	1	-	0	-	0	-	0	-	0	+	1	-	0
Foreign language	+	1	-	0	-	0	-	0	-	0	+	1	-	0
Technical knowledge	+	1	-	0	+	1	-	0	-	0	+	1	+	1
Sales, marketing, management knowledge	+	1	-	0	+	1	-	0	-	0	+	1	+	1
Communication skills	+	1	+	1	+	1	+	1	+	1	-	0	+	2
Teamwork skills	+	3	-	0	+	3	+	2	+	2	+	1	+	1

(continued)

Table 1 (continued)

Interview no	8		9		10		11		12		13		14	
Talent item	E	F	E	F	E	F	E	F	E	F	E	F	E	F
Time management skills	-	0	-	0	-	0	+	2	+	1	-	0	+	1
Leadership skills	-	0	-	0	+	3	+	2	+	1	-	0	-	0
Customer orientation	-	0	-	0	+	2	+	1	-	0	-	0	-	0
Proactivity	+	1	+	1	-	0	+	1	+	1	+	1	-	0
Result orientation	-	0	+	3	-	0	+	1	-	0	-	0	+	1
Having a driving licence and driving actively	-	0	-	0	-	0	-	0	-	0	-	0	-	0
No travel restriction	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Able to work under the stress	-	0	+	1	-	0	-	0	-	0	+	1	+	1
Able to work in shifts	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Experience	+	2	-	0	+	2	+	1	-	0	+	1	+	1
Problem solving skills	-	0	-	0	-	0	+	2	+	1	-	0	+	3
Analytical thinking	+	1	-	0	-	0	+	1	+	1	+	1	-	0
Having responsibility	+	1	+	2	+	2	+	1	-	0	-	0	-	0
Taking initiative	+	2	+	2	+	1	+	1	-	0	-	0	-	0
Being critical	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Making quick decisions	+	1	-	0	-	0	+	1	-	0	-	0	-	0
Innovative thinking	-	0	+	1	-	0	+	1	-	0	-	0	+	1
Having ethical values	-	0	-	0	+	1	-	0	-	0	-	0	-	0
Multi-tasking	-	0	+	2	-	0	-	0	+	1	-	0	-	0
Longsightedness	-	0	-	0	-	0	-	0	+	2	-	0	-	0
Being open-minded	-	0	-	0	-	0	-	0	-	0	-	0	-	0
Being practical	-	0	-	0	-	0	-	0	-	0	-	0	+	2
Open to learning	-	0	-	0	-	0	-	0	-	0	-	0	-	0

Interview no	15		16		17		18		19		20		Total	
Talent item	E	F	E	F	E	F	E	F	E	F	E	F	E	F
Bachelor degree	-	0	+	1	-	0	-	0	-	0	+	1	7	7
Foreign language	-	0	+	1	-	0	-	0	-	0	+	1	8	8
Technical knowledge	-	0	+	1	-	0	-	0	-	0	+	1	6	6
Sales, marketing, management knowledge	-	0	+	1	-	0	-	0	-	0	-	0	6	7
Communication skills	+	1	+	1	+	1	-	0	-	0	-	0	15	18
Teamwork skills	-	0	+	1	+	1	+	2	+	1	+	1	18	26
Time management skills	-	0	+	1	+	1	+	1	+	2	+	1	12	16
Leadership skills	+	1	-	0	-	0	+	1	+	1	+	2	8	12
Customer orientation	-	0	-	0	-	0	-	0	-	0	-	0	4	5
Proactivity	-	0	+	1	-	0	+	1	-	0	-	0	12	15
Result orientation	-	0	-	0	-	0	-	0	+	1	-	0	4	6
Having a driving licence and driving actively	-	0	-	0	-	0	-	0	-	0	-	0	1	1

(continued)

Table 1 (continued)

Interview no	15		16		17		18		19		20		Total	
Talent item	E	F	E	F	E	F	E	F	E	F	E	F	E	F
No travel restriction	-	0	-	0	-	0	-	0	-	0	-	0	1	1
Able to work under the stress	+	1	+	1	-	0	+	1	+	1	-	0	11	13
Able to work in shifts	-	0	-	0	-	0	-	0	-	0	-	0	1	1
Experience	-	0	+	1	-	0	-	0	-	0	+	1	9	13
Problem solving skills	-	0	-	0	-	0	+	1	-	0	+	1	7	10
Analytical thinking	-	0	+	2	-	0	-	0	-	0	-	0	8	10
Having responsibility	-	0	-	0	-	0	-	0	-	0	-	0	8	11
Taking initiative	-	0	-	0	+	1	+	1	-	0	+	1	10	12
Being critical	-	0	-	0	-	0	-	0	+	1	-	0	2	4
Making quick decisions	+	1	-	0	-	0	-	0	-	0	+	1	5	7
Innovative thinking	-	0	-	0	-	0	-	0	-	0	+	2	6	8
Having ethical values	-	0	-	0	-	0	-	0	-	0	-	0	2	2
Multi-tasking	+	1	+	1	-	0	+	1	-	0	-	0	5	6
Longsightedness	-	0	-	0	-	0	-	0	-	0	+	2	2	4
Being open-minded	-	0	-	0	+	1	+	1	-	0	+	1	3	3
Being practical	-	0	-	0	+	1	+	1	-	0	-	0	3	4
Open to learning	-	0	-	0	+	1	+	2	+	1	-	0	3	4

The five most frequently mentioned talent attributes determined as teamwork skills, communication skills, time management skills, proactivity and able to work under the stress.

Having a driving licence and driving actively, no travel restriction and able to work in shifts are the least frequently mentioned talent attributes during the interviews.

Conclusion and Future Studies

Since talented employees are the most important assets for 21st century's organizations, classical human resource management function has started to evolve towards talent management. Under this evolution for an effective talent management, organizations should first identify the talent attributes.

The result of the study provides insight into the definition of talent in the Turkish automotive industry. These results could be utilized for quantitative researches for the automotive industry.

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A Policy Proposal for Effective Energy Management

Beyzanur Cayir Ervural and Ramazan Evren

Abstract Effective energy management is the key to achieving national objectives and sustainability goals for governments depending on international policies. A reasonable energy management should be cost-effective, environmentally sensitive and aim to optimize the use of available resources. Fossil-based resources are not enough to meet the rapidly growing energy need. Some urgent measures should be taken against the rapid depletion of fossil fuels. In this context, it is necessary to investigate alternative energy sources. Renewable energy sources are seen as one of the most important alternative energy sources. The geographical location of Turkey provides a great advantage in renewable energy sources. However, there are some obstacles to the use of renewable energies such as market structure, political and legal regulations, the intermittent nature of renewable resources and the financial burden on technological investments. A proper energy policy should be developed considering all these factors. Research and development activities continue for new alternative energy sources. Given the diversity in the energy portfolio, new trends for alternative sources such as nuclear power plant, shale gas, wave and tidal energy are expanding. This study proposes an appropriate policy for effective energy management using some statistical tools and evaluates the current situation to reveal the future energy situation.

Keywords Energy management · Alternative energy resources
Sustainability · Renewable energy

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_25

Introduction

Energy management is a complex and multi-stage process of all applications from energy production to final energy consumption (Fernando et al. 2018). It offers the opportunity to optimize energy costs by following energy supply and economy sides by taking energy flows and ecological balance into consideration. Management decisions in the energy sector require a multidimensional assessment of the economic, technical, political, social, and environmental concerns of various stakeholders (Kowalski et al. 2009).

Growing energy needs requires accurate energy planning practices. Energy demand projections are strategically important to sustain energy security and uninterrupted energy flow for the future (Suganthi and Samuel 2012). The gap between energy consumption and production requires urgent measures such as new investment decisions, capacity expansion projects and alternative energy sources (Pohekar and Ramachandran 2004; Kumbaroğlu et al. 2008). The limited reserves of domestic resources lead to import of energy, where some financial burdens and political commitments emerge and energy independence is avoided. Effective energy management should be sustainable, independent, cost-effective and environmentally sensitive.

The energy efficiency studies in the literature are mainly focused on environmental management (Qian et al. 2018), carbon management (Mohanty 2012), and barriers to energy management (Brunke et al. 2014; Lee 2015). Effective energy management practices are still necessary to improve the performance/efficiency of energy systems.

Turkey's geopolitical position makes it a significant energy player among the neighbors surrounding it. Turkey is a noticeable energy corridor between East and West countries and aims to allow a well-balanced energy flow depend on mutual benefits and reliable energy trade agreements. By the end of December 2017, with building new plants and adding some capacity expansion activities, the total installed electricity power increased to 78.497 MW (megawatt). According to Ministry of Energy and Natural Resources (MENR) of Turkey, electricity production in Turkey has been obtained as 274 TWh (terawatt-hour) and electricity consumption is emerged as 279 TWh by the end of December 2016 (MENR 2016). It is obvious that the energy gap between electricity production and electricity consumption should be rapidly compensated with improving new energy investments at the country level.

Turkey is one of the fastest growing countries among Organisation for Economic Co-operation and Development (OECD) members in terms of electricity consumption. However, the average per capita electricity consumption is still lower than the OECD average. In 2014, average per capita consumption for OECD countries is approximately 8 MWh (megawatt-hour), while it is around 2.8 MWh in Turkey (given in Fig. 1). This is another instrument indicating the growth potential of Turkey's electricity consumption.

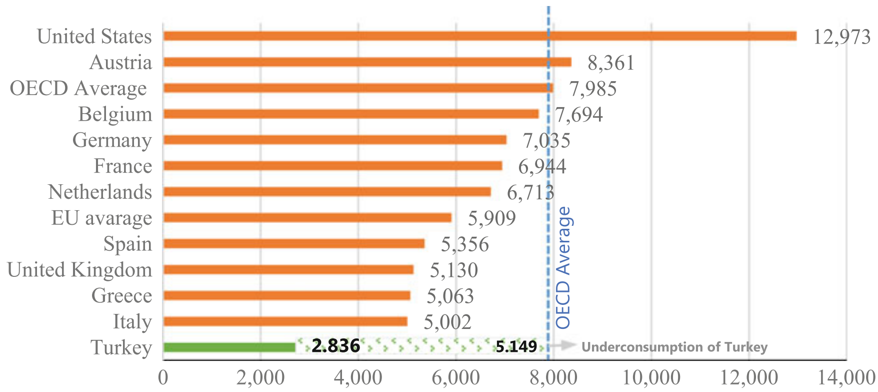

Fig. 1 Electricity consumption by countries (kWh per capita) (IEA 2014)

Energy security is also a critical issue for Turkey as well as all over the world. In this context, Turkey's energy market, including the transparency of competitive energy markets, has made significant progress in the technical and legal issues. The main principles of Turkey's energy policy can be summarized as follows: Increasing the share of the renewable energy in the electricity production, adding nuclear power plants in the energy mix, maximizing the energy efficiency, finding new routes and sources for imported oil and natural gas and investing in clean and energy-saving technology (MENR 2015).

In the light of this information, the management of energy systems and the selection of appropriate energy policy at a national scale can be considered as a key issue. With the help of the national energy policy, in this study, it is aimed to propose a strategic energy policy to meet energy needs by expanding the diversity of energy portfolio towards alternative sources. There is no standard model for Turkey's energy planning (Cayir Ervural et al. 2018a). The proposed approach is based on the needs of the country related to energy, environmental and economic concerns.

The rest of this study is organized as follows; Sect. "Overview of Energy System" describes an overview of energy systems. Section "Energy Situation in Turkey" presents the energy situation in Turkey according to energy resources. Results are discussed and some future works are drawn in Sect. "Conclusion".

Overview of Energy System

The structure of the electricity system is composed of a complex grid network. Figure 2 summarizes all stages of the complex electrical network structure from production to distribution and finally to the customer. The generated electricity at power plants moves through transformers and power lines to customers.

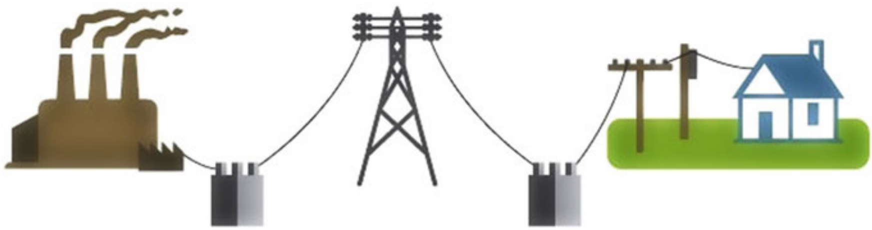

Fig. 2 Electricity generation, transmission, and distribution (IEA 2017)

The electricity grid consists of thousands of kilometers of high and low voltage power lines with distribution transformers to transfer of power plants to each electricity user entire the country (IEA 2017). Because of the complicated and multi-stage process of energy management, energy efficiency is critical. The use of sophisticated technology equipment reduces the losses of the energy distribution system (Carrasco et al. 2006; Li et al. 2010).

Effective energy management envelopes day-to-day operations as well as general strategic decisions, such as determining appropriate types of energy, location selection, and energy projections (Thunder Bay Corporation 2012; Nicholas 2017). With increased fuel costs and climate change awareness, energy systems need to be utilized intelligently and efficiently. One of the most important ways of this is the efficient use of domestic resources. The following section presents Turkey's energy situation according to fossil fuels, renewable energy resources, and alternative energy resources.

Energy Situation in Turkey

Fossil Fuels

Turkey has various type of energy sources with a total installed power capacity of 84 GW (Fig. 3). As seen in Turkey's energy outlook, fossil fuels play a major part in the energy mix. In order to maintain energy security and long-term energy sustainability, the share of fossil fuels should be reduced with new energy plans (Cayir Ervural et al. 2018b). In Turkey, natural gas, coal, and oil are the major sources of primary energy consumption. Turkey is an energy importing country with 72%.

Fossil fuels are consuming earlier in line with the global economic growth, population growth rate and industrialization rates (EIA 2017). Figure 4 shows future energy reserves for coal, gas, and oil.

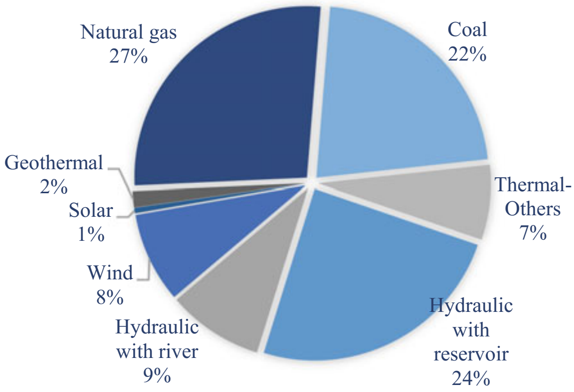

Fig. 3 The distribution of energy resources in Turkey's electricity production (ETKB 2017)

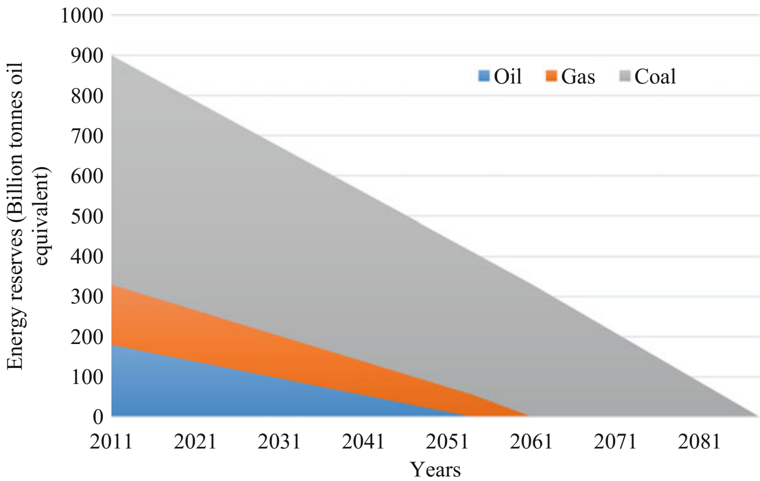

Fig. 4 The future energy reserves for coal, gas, and oil (Ecotricity 2017)

To ensure independent and uninterrupted energy supply, the government decided to build nuclear power plants. The construction of two nuclear power plants in Akkuyu and Sinop is expected to be completed in 2020. In addition, feasibility studies have been completed for the third one in Igneada, Kırklareli. Turkey's electricity consumption is growing 5% on average each year. Akkuyu nuclear power plant is expected to meet 9.2% of the total electricity consumption of the country when it is totally included in the electricity system in 2022 (MENR 2017a).

Renewable Energy Resources

Turkey's geographical position and climatic conditions are extremely favorable for the use of renewable energy sources. Turkey has emerged as one of the most important countries in terms of the great potential of renewable energy with the current conditions (ETKB 2016; IEA 2016).

In details, Turkey has an average of 7.5 h of sunshine per day. Despite receiving more sunlight than Germany, Turkey lags behind Germany related to solar power energy due to the insufficient utilization of solar energy potential (SETA 2017). Wind energy potential is substantially high when compared to OECD countries. The wind speed is calculated as average 7.5 m/s. The technical potential of wind power in Turkey is two times more than Spain and seven times more than Germany. Turkey is ranked seventh in the world and is ranked first in Europe in terms of geothermal energy potential. It also has a high potential for biomass energy from forest, agriculture and animal wastes (MENR 2017b). The total amount of waste that can be obtained is about 4.8 million ton, or 1.5 million ton of equivalent petroleum (Mtep) (SETA 2017). Turkey forms 16% of European hydraulic power potential and constitutes 1% of world potential in terms of theoretical hydraulic potential. The hydraulic potential is measured theoretically as 433 billion kWh, the technical potential is 216 billion kWh and the economic potential is estimated at 140 billion kWh/year (MENR 2017c).

Alternative Energy Resources

Turkey aims to manage all domestic resources in an efficient manner to produce maximum power. In order to respond to the increasing energy demand in the best way, power plant investment studies are being carried out and alternative resource exploration activities are carried out. The identified potential of domestic energy resources by the end of 2015 is given in Table 1.

Table 1 Potential of energy resources in 2015 (EUAS 2017)

Energy resources	Potential (reserve amount, Unit)
Lignite	14.8 Billion ton
Hard coal	1.3 Billion ton
Asphaltite	82 Million ton
Crude oil	7167 Million barrels
Hydraulic	160 Billion kWh/year
Natural gas	23.2 Billion m^3
Wind	48,000 MW
Geothermal	4.99 Btep
Biomass	20 Mtep
Solar	1500 KWh/m^2-yıl
Natural uranium	9129 Ton

Oil, gas and domestic coal exploration works continue rapidly. Alternative energy sources are explored to meet the growing energy needs (MENR 2017d, e, f). Shale gas can be alternative to oil and natural gas. The US is actively using the shale gas to significantly reduce its dependence on oil and natural gas. There are studies on the use of shale gas, coal gas and boron in electricity generation in the coming years in Turkey. The substantial shale gas reserves were determined in Thrace and Southeast basins in Turkey. Besides, Turkey ranks first with a 73% share in the world in terms of boron reserves (MENR 2017g).

Turkey is encircled on three sides by the sea and so has an advantageous position in terms of wave energy. As an alternative energy source for future energy needs, it is thought that wave and tidal energy will be included in renewable energy sources (Fatih 2017). The necessary technological investments and infrastructure works are progressing rapidly.

Figure 5 illustrates the general perspectives of the proposed energy management approach. The aim of the energy policy is to invest heavily in renewable energy resources to contribute to ecological balances and to prevent dependence on energy imports. Therefore, the share of renewable resources in the energy generation system should be increased with a gradual transition plan.

Another way to improve energy efficiency is to reduce the loss and theft during electricity distribution in the network line. Utilizing highly qualified equipment and advanced technology investments decrease the inefficiencies of the energy system. In addition, capacity expansion efforts should be increased steadily to meet the energy demand.

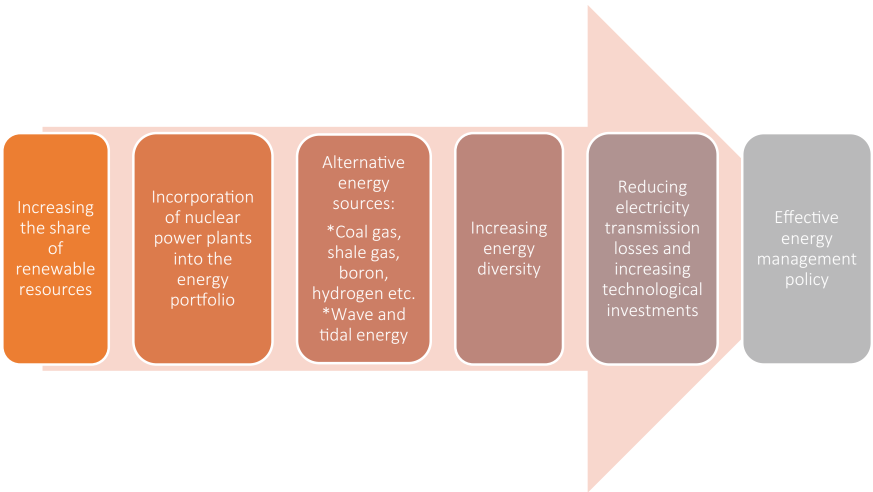

Fig. 5 Effective energy management approach

Conclusion

Effective energy management is a fundamental issue for most governments to ensure sustainable development, reduce carbon emissions and promote economic growth. In this study, we propose an energy management policy evaluating the current energy situation in Turkey to reveal the future energy scheme. The obtained results are summarized as follows: Due to the limited reserves of fossil fuels, alternative energy resources are significant. In addition to research and development activities on alternative energy sources, renewable energy investments should also be encouraged. Turkey is aware of environmental issues such as greenhouse gas emissions and climate change. Renewable energy sources are clean, reliable, independent and sustainable. Turkey has a remarkable renewable energy potential, so it should be properly planned and utilize them in an optimal way. Owing to the intermitted nature of the renewable energy sources, the nuclear power plants should be included in the energy portfolio. The capacity expansion activities should be accelerated to meet growing energy need. Finally, the loss and theft rate should be reduced in order to increase energy efficiency.

The results of the work can help policy makers make decisions about energy management and investment strategies. In future work, the energy management structure can be analyzed using decision-making and optimization tools.

Acknowledgements This research was supported by Istanbul Technical University Scientific Research Projects Unit (ITU/BAP) (Project no. 39617).

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Exploring the Adoption of ERP Systems: An Empirical Investigation of End-Users in an Emerging Country

Gulsah Hancerliogullari Koksalmis and Seckin Damar

Abstract Enterprise resource planning (ERP) is an integrated management system that aims to bring together all the data and processes of an organization. There are many factors influencing the use of ERP systems. The purpose of this study is to analyze a variety of factors that affect end-users' behavioral intention to use ERP implementation based on the technology acceptance model (TAM). Besides the basic constructs of TAM, we determined other constructs such as consultant support and user guidance. The data was collected from end-users who used or have been using an ERP system in the companies. A total of 136 responses were obtained. SmartPLS software was used for the data analysis and testing of the validity of the hypotheses. The results show that perceived usefulness affect behavioral intention to use an ERP system, while perceived ease of use is not a significant determinant of ERP system usage. Moreover, both perceived ease of use and user guidance affect perceived usefulness and consultant support affect perceived ease of use.

Keywords Enterprice resource planning · Technology acceptance model Consultant support · User guidance

Introduction

In recent years, it has become increasingly difficult for companies to compete in global markets with developments in technology. Therefore, firms need new information systems in order to gain a competitive advantage in this changing and developing market environment. In this context, enterprise resource planning

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_26

(ERP) systems have gained a great importance along with the progress in information systems. ERP system is defined as a central database that makes easier an organization to administrate the efficient use of resources such as materials, human resources, and finance by automating and integrating business operations, data sharing throughout the enterprise and facilitating information access (Agaoglu et al. 2015). According to Weinrich and Ahmad (2009), enterprise resource planning systems are commercial software packages that combine several business processes of an organization containing manufacturing, supply chain, sales, financial, human resources, budgeting, and customer service activity. Despite the possible benefits of ERP systems and their growing market, the failure rate of ERP system projects is high and this brings about huge financial losses that cause a company may go bankrupt (Mahmud et al. 2017). Because of the significant investments of resources made by organizations to adopt ERP systems, researchers need to determine the factors that lead to good performance with ERPs and what factors affect implementation success and failure (Abugabah and Sanzogni 2010). In this context, the technological acceptance model (TAM) is one of the most widely employed models for interpreting the behavioral intention and actual usage and can progress our apprehension of how affect on actual usage could help enhance efficiency and effectiveness of ERP system usage (Sternad and Bobek 2013). TAM is the most widely applied model of user acceptance and usage and put forward two particular beliefs which are perceived ease of use and perceived usefulness. These beliefs identify individual's behavioral intention to use a technology that has been linked to latter behavior (Venkatesh 2000).

The purpose of this study is to analyze a variety of factors that affect users' behavioral intention to use ERP implementation based on the TAM. Data have been collected from end users who are using an ERP application in companies. The research model is analyzed using SmartPLS software. The rest of the study is regulated as follows: literature review and hypotheses development, methodology, results, and conclusion.

Literature Review and Hypotheses Development

In our study, we investigated factors affecting the behavioral intention to use the ERP system by using TAM. We identified our constructs as behavioral intention, perceived ease of use, perceived usefulness, user guidance, and consultant support. The research model is shown in Fig. 1.

Behavioral Intention (BI)

Behavioral intention means "the degree to which a person has formulated conscious plans to perform or not perform some specified future behavior" (Venkatesh and

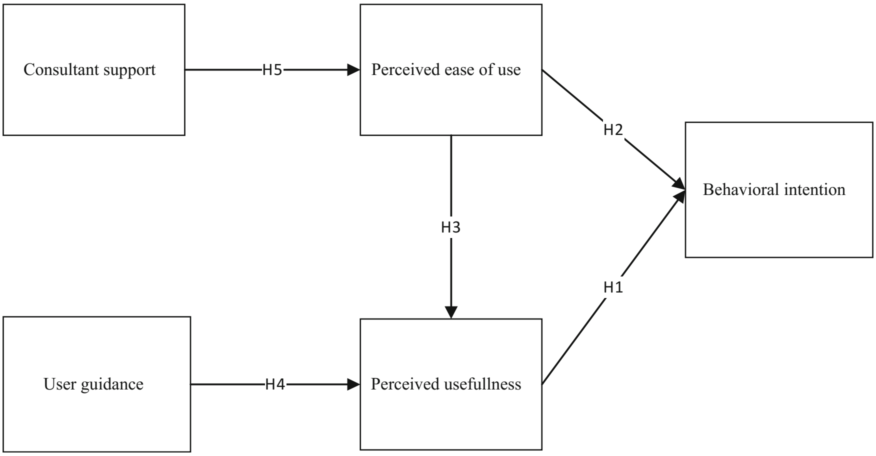

Fig. 1 Research model

Davis 2000). In a business context, it evaluates the intention of the end-user to use a technology once it has been applied in an organization (Mahindroo et al. 2012).

Perceived Usefulness (PU)

PU refers to, "the degree to which an individual believes that using a particular system would enhance his or her job performance" (Davis 1989). In other words, it means that the use of the ERP system by the user will increase the performance of the user and ultimately result in a successful ERP implementation (Mahindroo et al. 2012). According to the TAM, PU positively influences BI. As a result, we have formed our hypothesis as:

H1. There exists a positive relationship between perceived usefulness and behavioral intention.

Perceived Ease of Use (PEOU)

Perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989). Alias, it is a sign of the cognitive effort required to learn and use an information system (Arasanmi et al. 2017). TAM claims that PEOU has a direct positive effect on BI and PU. As a result, we have formed our hypotheses as:

H2. There exists a positive relationship between perceived ease of use and behavioral intention.
H3. There exists a positive relationship between perceived ease of use and perceived usefulness.

User Guidance (UG)

Generally, it is easier to learn a computer system if there is a good user guidance which reduces the mental workload of the individuals as no additional effort will be required for the users to perform their assigned tasks (Lin et al. 1997). Previous research suggests a significant relationship association between user guidance and perceived usefulness (Lin et al. 1997; Calisir and Calisir 2004). As a result, we have formed our hypothesis as:

H4. There exists a positive relationship between user guidance and perceived usefulness.

Consultant Support (CS)

Consultant support refers to the perceived level to which consultant support assists to perform ERP implementation accomplished (Kwak et al. 2012). Consultants play an important role in the ERP implementation process. They can take place at various stages of the application, for example, making requirements analysis, recommending an appropriate solution, and operating the implementation (Somers and Nelson 2001). Maditinos et al. (2010) found that consultant support had a positive effect on ERP system effective implementation. There is a little research related to consulting support in technology acceptance literature. Kwak et al. (2012) found that consultant support positively related to PEOU. As a result, we have formed our hypothesis as:

H5. There exists a positive relationship between consultant support and perceived ease of use.

Methodology

Survey Design

An online survey was employed to test our model. The questionnaire was sent to the customers of a consulting company that providing an ERP application to the firms. Data were obtained from end users who are using an ERP application in these firms.

The first part of the questionnaire consisted of questions about the demographic characteristics of the users. These are; gender, age, educational status, working years in the current company, majored in computer related discipline and experience in ERP systems. The second part of the questionnaire consisted of questions about the items of constructs which are consultant support, user guidance, perceived usefulness, perceived ease of use and behavioral intention.

Data Collection

The data was collected from end-users who used or have been using an ERP system in the companies in Turkey; a total of 136 responses were obtained. About 71% of the respondents were male and the average age of the respondents was 36.5 years. When we look at the educational status of the respondents, 64.5% was undergraduate, 29% was Post graduate/Ph.D. and 6.5% was high school. Mentioned and other demographic characteristics of the respondents are shown in Table 1.

Table 1 Demographic characteristics of the respondents

Gender (%)		
Female: 29	Male: 71	
Age (year)		
Max: 50	Min: 26	Avg: 36.5
Educational status (%)		
Primary school:	High school: 6.5	Undergraduate: 64.5
Post graduate/Ph.D.: 29		
Working years in the current company (years)		
Max: 24	Min: 1	Avg: 7.3
Majored in computer related discipline (e.g. Information systems, computer science or computer engineering) (%)		
Yes: 61.3	No: 38.7	
Experience in ERP systems (%)		
Less than 1 year: 6.5	1–3 years: 12.9	3–5 years: 22.6
More than 5 years: 58.1		

Measurement Development

The items selected for the constructs were taken from previous research in the literature. Behavioral intention (BI) was measured using the four items from Davis (1986), Taylor and Todd (1995) and Al-Aulamie (2013). Perceived usefulness (PU) had five items which developed by Davis (1986). The items for perceived ease of use (PEOU) were taken from Davis (1986), Davis et al. (1992) and Venkatesh and Davis (2000). The items for user guidance were adapted from Calisir and Calisir (2004). Lastly, consultant support was measured by two items taken from Kwak et al. (2012). These items were measured on a five-point Likert scale, ranging from (1) strongly disagree to (5) strongly agree. The items are shown in Table 2.

Table 2 The items for constructs

Construct	Code	References	Items
Consultant support	CS1 CS2	Kwak, Park, Chung, and Ghosh (2012)	I think consultants led us in a right direction during ERP implementation I think consultants can help us to have a successful ERP implementation
User guidance	UG1 UG2 UG3 UG4 UG5	Calisir and Calisir (2004)	Error messages are helpful It provides a CANCEL option HELP is provided It provides UNDO to reverse control actions Whenever I make a mistake using the system, I recover easily and quickly
Perceived usefulness	PU1 PU2 PU3 PU4 PU5	Davis (1986)	Using ERP to reach my employee information would enable me to accomplish tasks more quickly Using ERP would increase my productivity by reaching my employee information Using ERP would enhance my effectiveness in reaching my employee information Using ERP would make it easier reaching my employee information I would find ERP useful in order to reach my employee information
Perceived ease of use	PEOU1 PEOU2 PEOU3 PEOU4 PEOU5	Davis (1986), Davis et al. (1992), Venkatesh and Davis (2000)	Learning to operate ERP would be easy for me I would find it easy to get ERP to do what I want it to do My interaction with ERP would be clear and understandable It would be easy for me to become skillful at using ERP Applications I would find ERP easy to use
Behavioral intention	BI1 BI2 BI3 BI4	Davis (1986), Taylor and Todd (1995), Al-Aulamie (2013)	I expect to use the NEW system I expect the information from the NEW system to be used I intend to increase my use of ERP in the future I plan to use more applications in ERP in the future

Data Analysis

The data was analyzed using the partial least squares (PLS) statistical technique which is a multivariate analysis method. Using the PLS method has many advantages (Bayraktar et al. 2017; Sternad et al. 2011). Therefore, the PLS method has been applied to the SmartPLS software to perform the analysis of the data.

Results

Measurement Model

The reliability and validity of the constructs were analyzed by convergent and discriminant validity. The convergent validity was assessed by factor loadings, Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE). Confirmatory factor analysis was applied to test the factor loadings. The satisfactory level of factor loadings was determined as 0.6 (Amoako-Gyampah and Salam 2004). 5 items from 21 items were below the satisfactory level. Firstly, we dropped items which were less than 0.5 and ran the model again. All factor loadings are above 0.6 after the model is run again and all the items have significant t-statistics ($p < 0.05$). The results of confirmatory factor analysis are shown in Table 3.

Table 3 Confirmatory factor analysis

Construct	Item	Mean	Standard deviation	Factor loadings	t-statistics
Behavioral intention	BI1	0.894	0.019	0.894	46.190
	BI2	0.884	0.022	0.887	39.440
	BI3	0.680	0.069	0.689	9.983
Consultant support	CS1	0.936	0.009	0.935	98.855
	CS2	0.898	0.018	0.898	49.084
Perceived ease of use	PEOU1	0.899	0.012	0.899	76.805
	PEOU2	0.901	0.017	0.901	51.825
	PEOU3	0.735	0.047	0.735	15.528
Perceived usefulness	PU1	0.878	0.014	0.876	61.065
	PU2	0.901	0.016	0.903	56.688
	PU3	0.791	0.047	0.795	16.975
	PU4	0.604	0.082	0.610	7.407
User guidance	UG1	0.872	0.025	0.870	34.383
	UG2	0.871	0.023	0.876	37.845
	UG3	0.756	0.047	0.763	16.200
	UG4	0.772	0.060	0.781	13.029
	UG5	0.589	0.086	0.601	6.990

Table 4 Construct reliability and validity

	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
Behavioral intention	0.785	0.866	0.687
Consultant support	0.812	0.913	0.841
Perceived ease of use	0.814	0.884	0.720
Perceived usefulness	0.834	0.878	0.647
User guidance	0.857	0.887	0.616

Table 5 Discriminant validity

	Behavioral intention	Consultant support	Perceived ease of use	Perceived usefulness	User guidance
Behavioral intention	0.829				
Consultant support	0.344	0.917			
Perceived ease of use	0.396	0.594	0.848		
Perceived usefulness	0.539	0.449	0.617	0.804	
User guidance	0.458	0.324	0.471	0.479	0.785

Acceptable reliability and internal consistency are achieved when the Cronbach alpha and CR exceed the limit of 0.7 (Nwankpa and Roumani 2014). For all constructs, Cronbach alpha and CR values are greater than 0.7. The AVE values for each construct should exceed 0.5 (Rajan and Baral 2015). The AVE values of all constructs are greater than 0.5 that shows each construct clarifies more than half of the variance of its indicators (Gül 2017). All these results are shown in Table 4.

Two conditions are required to define discriminant validity. These are; indicators should load more strongly on their corresponding construct than on other constructs and the square root of the AVE should be greater than the inter-construct correlations (Agarwal and Karahanna 2000). The diagonal elements represented the square root of AVE are larger than non-diagonal elements in the same row and column as shown in Table 5, indicating good discriminant validity (Chang et al. 2011).

Structural Model and Hypotheses Testing

The PLS structural equation modeling has been applied to test the validity of hypotheses. Table 6 shows the results of the analysis. Perceived usefulness significantly influences behavioral intention as indicated by the technology acceptance model ($\beta = 0.476$, $p < 0.05$; H1 supported); but perceived ease of use has not a significant effect on the behavioral intention ($\beta = 0.102$, $p > 0.05$; H2 not supported). Perceived ease of use and user guidance both significantly related

Table 6 Path coefficients

Hypothesis	Standard deviation	T statistics	*P* values	Standardized path coefficient (β coefficient)
Perceived usefulness → Behavioral intention	0.069	6.901	0.000	0.476
Perceived ease of use → Behavioral intention	0.090	1.133	0.258	0.102
Perceived ease of use → Perceived usefulness	0.055	9.064	0.000	0.503
User guidance → Perceived usefulness	0.057	4.273	0.000	0.242
Consultant support → Perceived ease of use	0.047	12.644	0.000	0.594

Table 7 Summary of hypotheses

Item	Path	Hypotheses	Supported
H1	PU → BI	There exists a positive relationship between perceived usefulness and behavioral intention.	Yes
H2	PEOU → BI	There exists a positive relationship between perceived ease of use and behavioral intention.	No
H3	PEOU → PU	There exists a positive relationship between perceived ease of use and perceived usefulness.	Yes
H4	UG → PU	There exists a significant relationship between user guidance and perceived usefulness.	Yes
H5	CS → PEOU	There exists a positive relationship between consultant support and perceived ease of use.	Yes

Table 8 R-square values

Construct	R-square
Behavioral intention	0.297
Perceived ease of use	0.353
Perceived usefulness	0.426

perceived usefulness (β = 0.503, $p < 0.05$; β = 0.242, $p < 0.05$; H3 and H4 supported). Consultant support has a significant effect on the perceived ease of use (β = 0.594, $p < 0.05$; H5 supported). The summary of all hypotheses is shown in Table 7.

R-Square shows explanatory power or variance of the research model. The perceived ease of use and perceived usefulness explain the 30% of the total variance of behavioral intention (R-Square = 0.297); consultant support explains the 35% of total variance of perceived ease of use (R-Square = 0.353); user guidance and perceived ease of use together explain the 43% of total variance of perceived usefulness (R-Square = 0.426). Table 8 shows these values.

The path coefficients and R-Square values are illustrated in Fig. 2. The results show that perceived usefulness significantly influences behavioral intention, while the effect of perceived ease of use is not significant on the behavioral intention. Perceived ease of use has a significant effect on perceived usefulness as technology acceptance model claims. In addition, consistent with the previous studies user guidance is found to be significant in affecting perceived usefulness and consultant support has a significant effect on the perceived usefulness.

Table 9 shows the direct, indirect and total effects of each construct on the behavioral intention to use the ERP system. Consultant support, perceived ease of use and user guidance significantly and indirectly affects behavioral intention. Perceived usefulness as hypothesized by H1, has a significant effect on behavioral intention.

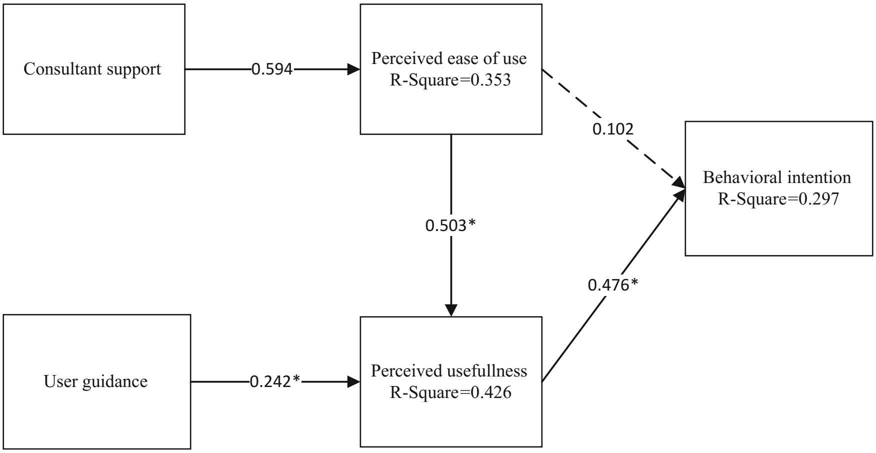

Fig. 2 Research model with results (asterisk: $p < 0.05$, dotted line: insignificant relationship)

Table 9 Direct, indirect and total effects of each construct on the behavioral intention

Dependent variable	Independent variables	Direct effects	Indirect effects	Total effects	*P* values
Behavioral intention to use ERP system	Consultant support	–	0.203*	0.203*	0.000
	Perceived ease of use	0.102	0.240*	0.342*	0.000
	Perceived usefulness	0.476*	–	0.476*	0.000
	User guidance	–	0.115*	0.115*	0.001

*p<0.05

Conclusion

In this study, the effect of consultant support, user guidance, perceived usefulness, and perceived ease of use on the behavioral intention to use an ERP system in Turkey was examined by using the technology acceptance model which is developed by Davis. There is little research on this subject in Turkey in the literature. So, it is expected that the study will be an important source of information for companies targeting to use the ERP system.

As a result of the analyses made, 4 of the 5 hypotheses formulated in the research were supported, that is consistent with previous studies. According to the results, perceived usefulness positively and significantly influences the behavioral intention, while the perceived ease of use does not significantly influence; the effect of perceived ease of use positive and significant on the perceived usefulness; user guidance significantly and positively related to perceived ease of use and consultant support has a significant and positive effect on the perceived usefulness.

The technology acceptance model used in the study will provide significant benefits in explaining and predicting the behavior of users in companies that are beginning to use the ERP system. So that the performance of users will be affected positively, costs will decrease and productivity will increase. Such studies will provide an important source of information for companies that produce, use and plan to use ERP software.

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Part II
Engineering and Technology Management

Measuring the Impact of University Service Quality on Academic Motivation and University Engagement of Students

Fatma Kutlu Gündoğdu and Umut Asan

Abstract This study aims to analyze the impact of university service quality on academic motivation and school engagement as well as the impact of school engagement on academic motivation. In order to analyze the structural model, not only hypotheses about the causal relationships but also indicators operationalizing the concepts have been proposed. Data was collected by means of an online questionnaire, applied to students in private and state universities, and analyzed using structural equation modelling based on partial least squares. According to the findings, academic aspects and physical characteristics among the service quality dimensions are the most important ones explaining the variation in school engagement perception. The results also show that school engagement has a strong significant impact on academic motivation.

Keywords SmartPLS · Structural equational modelling · Service quality
School engagement · Academic motivation

Introduction

In Turkey, where the young population is still growing, the number of universities is gradually increasing. In 2012, there were 168 universities across the country, including 103 state and 65 private universities. However, in 2017, both the number of state and private universities increased to 186. Besides the increase in the number of universities, the quotas of the programs are also increasing promptly every year

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_27

(Yükseköğretim Kurulu 2018). However, the fact that the quotas exceed the number of new students has led to an increasing competition among the universities especially for private universities. Universities as service providers have to satisfy effectively requests of the students, such as teaching quality, qualified academic staff, classrooms, library, computer laboratories as well as all kinds of needs such as food, accommodation, security, social activities, and foreign opportunities. As a student becomes more satisfied, he/she will show a higher commitment to the university, which in turn will positively contribute to the student's academic motivation (Tayyar and Dilşeker 2012). An increase in motivation and engagement will lead the student to recommend his/her university to the next generations, which will help the university to continue its existence (Tayyar and Dilşeker 2012).

One of the most important factors influencing academic achievement is academic motivation. It has been stated in the literature that the increase in academic motivation has a positive affect on students' learning performance (Alderman 2004). One of the leading theories in Academic Motivation is the Self-Determination Theory, which states that any behavior can be motivated internally or externally, or in contrast be amotivated (Deci and Ryan 2000; Eyüp and Bozer 2015).

Deci and Ryan (2000) and Deci (1975) have stated that internal motivation is the power that stimulates people from birth. In other words, intrinsic motivation suggests that people are motivated from within, by their interests, curiosity and care values. These intrinsic motivations are not necessarily externally rewarded or supported, but furthermore, they can sustain passions, creativity, and efforts. The interaction between the extrinsic forces acting on persons and the intrinsic motives and needs inherent in human nature is the territory of Self-Determination Theory (Deci and Ryan 2000).

Valerand et al. (1992) subdivided intrinsic motivation into three categories, which are intrinsic motivation to know, to accomplish things, and to experience stimulation. The intrinsic motivation to know is the continuation of the learning process that originated from the feeling of pleasure and learning pleasure, which one lives. Intrinsic motivation to accomplish things is the impetus to continue to learn for the satisfaction that something has been successful. And finally, the intrinsic motivation to experience stimulation is that one is only willing to do it when he or she is carrying out a work or behavior (Vallerand and Blssonnette 1992).

On the other hand, external motivation, in other words, extrinsic motivation, is usually defined as one's tendency to engage in activities in order to gain some type of external reward (Ryan and Deci 2000). Ryan and Deci (2000) and Vallerand and Blssonnette (1992) have reviewed the concept of external motivation under four headings:

i. External Regulation (External): Students are motivated to learn to get a reward or get rid of the pressure.
ii. Introjection (Somewhat External): Individuals begin to internalize the underlying causes of their behavior they experienced in the past.

iii. Identification (Somewhat Intrinsic): The individual begins to internalize his/her behavior exhibited.
iv. Integration (Internal): Behavior is still dependent on external factors, but it is thoroughly internalized by the individual.

Amotivation can be defined as reluctance to behavior. Amotivation stems from the belief that an activity is worthless or does not lead to a valuable result (Vallerand and Blssonnette 1992; Seligman 1975; Ryan and Deci 2000).

Another concept that has attracted increasing attention as a facilitator of academic achievement is School Engagement. Many definitions have been suggested in the literature for this concept. According to Friedman et al. (1988); school engagement involves spending time on the assignments and projects as well as giving attention to the lectures, asking questions, answering questions and preparing for classes. Finn (1993) defined school engagement as student's own sense of belonging to the school and adoption to the school's goals.

Thomson (2005) suggested that students with positive feelings about school are more effective at various school activities and have a higher level of independent learning motivation. Similarly, according to Finn and Rock (1997), school engagement has a positive effect on other educational outcomes such as academic achievement, continuing to school and having high academic expectations.

The types of school engagement are assessed in three categories: behavioral, emotional, and cognitive. Behavioral engagement relates to the concept of participation to lectures and social activities (Newmann et al. 1992). To illustrate, the behavioral engagement includes participation, observable behaviors, and performance of learners in extracurricular social activities such as sports, dance, and theater (Fredricks et al. 2004). In contrast, emotional engagement can be explained by the concept of identification with school (Finn 1989). Emotional engagement involves a positive reaction of the student to the school and teachers. Finally, cognitive engagement is defined as increasing curiosity of students about why and how they learn in school. Cognitive engagement emphasizes the student's psychological investment in school, the willingness to spend energy on complex and difficult topics (Fredricks et al. 2004). Weinstein and Mayer (1986) reported that high levels of cognitive engagement were associated with a high level of learning and achievement.

As another critical concept in this study, service quality is concerned with the ability of an organization to meet customer expectations. Thus, university service quality can be defined as the ability of the relevant higher education institution to meet the expectations of its student. The students expect opportunities such as high quality teaching services, educational facilities at certain standards (computer, laboratory equipment, projection, etc.), effective communication, and social activities from the institution (Rashid and Raj 2006).

Studies on university service quality have benefited from the SERVPERF scale developed for the measurement of service quality. While Nadiri et al. (2009) proposed dimensions of concrete and abstract features, Sakarya (2006) used academic staff, teaching and learning resources, personnel in administration and departmental offices, university support services, quality of education and support services as the service quality dimensions. In two studies by Firdaus (2006a, b) both HEdPERF (Higher Education Performance) and SERVPERF (Service Performance) scales were used to measure university service quality and findings suggest that the HEdPERF scale is more effective. In addition, several studies emphasize academic aspects as the most important factor in ensuring the quality (Guolla 2015).

A careful review of the literature on university service quality, academic motivation, and school engagement indicate that none of the studies examined the relationships between these three concepts together. In one study it has been found that the university service quality has a positive effect on academic motivation and school engagement (Ilgan et al. 2013), while in another study school engagement has been indicated to affect academic motivation positively (Marimuthu et al. 2009). Thus, this study aims to analyze the impact of university service quality on academic motivation and school engagement as well as the impact of school engagement on academic motivation. Towards this aim, measurement models for the concepts of school engagement, academic motivation, and service quality were developed. Through online questionnaire data were collected from students at state or private universities between December 2016 and January 2017. The statistical significance and strength of the relationships between the concepts were analyzed by constructing a partial least squares structural equation model in the SmartPLS software.

Proposed Model and Hypotheses

Based on the review of the literature, a structural model is developed that describes the impact of university service quality on academic motivation and school engagement as well as the impact of school engagement on academic motivation. The emphasis on theoretical support for the proposed model underlies its confirmatory nature. The suggested structural model is depicted in Fig. 1. The formulated hypotheses representing the relationships between the four dimensions of the latent construct university service quality, academic motivation, and school engagement are given in Table 1.

Methodology

Scales and Data Collection

Within the scope of this study, a questionnaire was designed to assess the impact of university service quality on academic motivation and school engagement as well as the impact of school engagement on academic motivation. The Academic Motivation Scale developed by Vallerand and Blsonnette (1992) consisting of 14

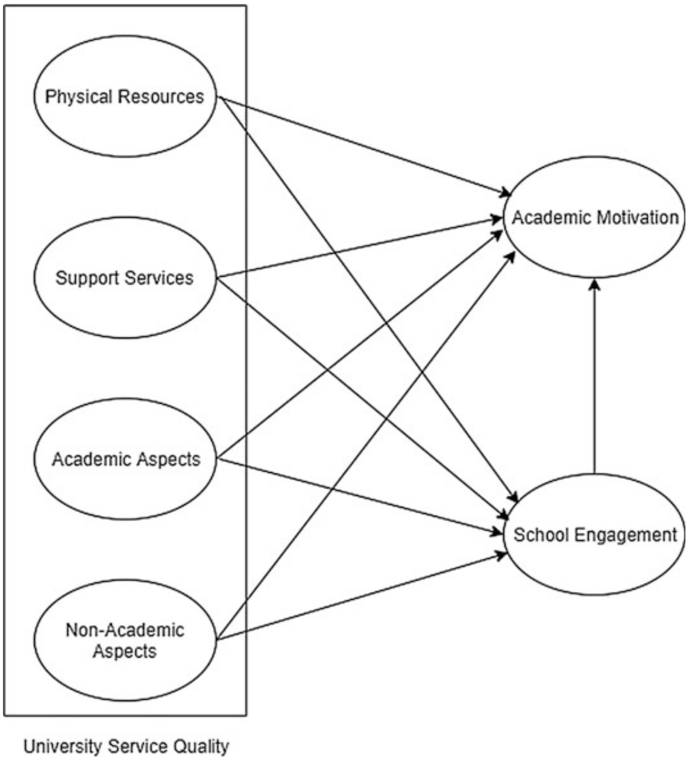

Fig. 1 The proposed structural model

items was used to measure students' academic motivation. In order to measure the level of university engagement, Arastaman's (2006) School Engagement Scale consisting of 12 items was adapted. And finally, to measure the service quality of universities, a new scale of four dimensions was suggested based on the scales Student Satisfaction (Sakarya 2006), SERVPERF (Cronin and Taylor 1992), HEdPERF (Firdaus 2004) and the merged scale HEdPERF–SERVPERF (Firdaus 2006a). The dimensions are physical resources, academic aspects, non-academic aspects, and support services each consisting of seven, nine, six and eight items, respectively.

The suggested questionnaire for the measurement of the concepts was prepared with a 5-point Likert Scale (1 = Definitely Disagree, 2 = Disagree, 3 = Indecisive, 4 = Agree, 5 = Definitely Agree) by using the online survey application Google Forms. The target population of this research consists of students who continue their higher education in any state or private university. After the questionnaire was prepared, the survey's web link was sent to randomly choosen state and private university students via e-mail. A total of 302 students from various universities participated in the survey between December 2016 and January 2017. To determine the demographic characteristics of the students who participated, questions on

Table 1 Hypotheses

Hypothesis H1: School engagement of students has a positive effect on academic motivation
Hypothesis H2: University service quality has a positive effect on school engagement
Hypothesis H2a: Physical resources of the university have a positive effect on the students' school engagement perception
Hypothesis H2b: University support services of the university have a positive effect on students' school engagement perception
Hypothesis H2c: Academic aspects of the university has a positive effect on students' school engagement perception
Hypothesis H2d: Non-academic aspects of the university has a positive effect on the students' school engagement perception
Hypothesis H3: University service quality has a positive effect on academic motivation.
Hypothesis H3a: Physical resources in the university have a positive effect on students' academic motivation
Hypothesis H3b: Non-academic aspects of the university has a positive effect on the academic motivation of students
Hypothesis H3c: University support services have a positive effect on students' academic motivation
Hypothesis H3d: Academic aspects of the university has a positive influence on the academic motivation of students

Table 2 Demographic characteristics of participants

	Sample size (n)	Ratio (%)
Gender		
Woman	175	57.9
Man	127	42.1
Total	302	100
University type		
State University	197	65.4
Private University	104	34.6
Education status		
Prep.	19	6.3
1. Class	27	8.9
2. Class	43	14.2
3. Class	83	27.5
4. Class	89	29.5
5. Class	11	3.6
6. Class	0	0
Master	24	7.9
Ph.D.	6	2

gender, education status, and type of university were also asked. Descriptive statistics of demographic characteristics of survey participants are summarized in Table 2.

Method of Analysis

In this study, Structural Equation Modeling (SEM) considered as a second generation multivariate statistical method was used. SEM, preferred especially in marketing, social sciences, and behavioral sciences, is a combination of covariance, regression, and confirmatory factor analysis. There are different approaches to structural equation modeling. Among these approaches, the first is the covariance-based SEM (CB-SEM) which is analyzed with AMOS, EQS, LISREL and MPlus softwares. The second approach is the Partial Least Squares SEM (PLS-SEM) that can be analyzed with softwares such as SmartPLS, PLS-Graph, VisualPLS (Hair et al. 2012). To be able to use the CB-SEM method strict assumptions must be first satisfied. Among these assumptions are large sample sizes, the normal distribution of the data and the construction of the correct model based on theory. For example, Kerlinger (1978) stated that the sample size should be at least ten times of the number of variables in the study. In the literature, many researchers mention the difficulty of finding such a data set (Hwang et al. 2010; Hair et al. 2012).

In particular, the PLS-SEM method can be used for data sets that are small and has no knowledge of data distribution. Therefore, PLS-SEM will be the appropriate method for explaining the relationship between latent variables, and estimating the existence of a small data set that does not correspond to a normal distribution. This method delivers also better results in cases where the model is not necessarily based on theory (Hair et al. 2012).

For the analysis of the structural equation model suggested in this study, PLS-SEM method was preferred considering the size and distribution of the data set as well as the complexity of the model. The structural model includes the latent construct academic motivation, school engagement, physical resources, academic aspects, non-academic aspects, and support services, while the measurement models consist of questionnaire items, also called indicators.

The model was analyzed using the software SmartPLS 3.2.6. The reliability and validity of the indicators used in the measurement model for each variable were tested. For this purpose, Composite Reliability (CR), Convergent Validity (CV), Average Variance Extracted (AVE) and Discriminant Validity (DV) were calculated. Finally, the structural model and hypotheses were tested.

Before the analysis, the data set should be examined in terms of missing data, outliers and sample size. Box-plot diagrams have been used to detect outliers. In this study, no missing data or outliers were encountered in the collected data. Although PLS-SEM analysis provides good results even for small samples, some researchers argue that the minimum sample size should be carefully considered for PLS-SEM analysis. At this point, Barclay et al. (1995) suggest that the “10 times rule” can be taken as a reference. According to this rule, the one having the maximum sample volume is selected from the conditions of 10 times of the maximum number of indicators used to measure a variable or 10 times of the maximum number of arrows associated with a particular latent variable in the structural model.

Analysis and Results

Testing Measurement Models with PLS-SEM

For the analysis of the reflexive measurement models, the primary criteria to be examined are summarized below.

1. Internal Consistency Reliability (IC): It indicates the internal consistency of the study when the coefficients of Cronbach's Alpha and Composite Reliability is 0.7 or higher than 0.7 (Hair et al. 2014; Bagozzi and Yi 1988).
2. Indicator Reliability (IR): The squares of the indicator loadings give the reliability of the indicators. Three methods have been proposed in the literature to ensure the reliability of indicators (Hair et al. 2014),
   - If the indicator load is smaller than 0.4, the expression must be removed from the system
   - If the indicator load is greater than 0.7, the expression must remain in the system
   - If the indicator load is between 0.4 and 0.7, remove it from the system and check whether the AVE and CR values increase. If there is an increase, these indicators should be excluded.
3. Convergent Validity (CV): It indicates the degree to which items of the same latent construct are correlated. An AVE value greater than 0.5 ensures convergent validity (Hair et al. 2014; Bagozzi and Philips 1982).
4. Discriminant Validity (DV): It indicates the extent to which a latent construct is sufficiently different from other latent constructs in the model (Hair et al. 2014). For this test, the Fornell-Larcker criterion was used in this study. For the first latent variable, the reliability and validity estimates are given in Table 3.

In the first measurement model, among the seven indicators related to physical resources, the indicator Physical_6 is removed since the factor loading of it is below 0.4. When the Physical_5 and Physical_7 indicators were removed, there was no significant increase in AVE and CR values, so they were left in the model. Except for these indicators, the reliability of the rest of the indicators is over 0.5. Although the CR value is much larger than 0.7, the AVE value is smaller than 0.5. The results of the revised measurement model are shown in Table 4.

Similar operations were performed for indicators of other latent constructs but they will not be given here because of space limitations.

For the discriminant validity test of the PLS-SEM model, the square of the AVE of the variables associated with each diagonal value in the Fornell and Lacker matrix is examined. It is expected that these square values of AVE are larger than the correlations given across rows and columns (Kwong and Wong 2013).

Table 3 Loadings, reliability and validity estimates of the construct physical resources

Latent variable	Indicators	Factor loadings	Indicator reliability	Convergent validity	AVE
Physical resources	Physical_1	0.7100	0.5041	0.8440	0.4500
	Physical_2	0.7700	0.5929		
	Physical_3	0.7910	0.6257		
	Physical_4	0.7760	0.6022		
	Physical_5	0.5580	0.3114		
	Physical_6	0.3070	0.0942		
	Physical_7	0.6520	0.4251		

Table 4 Revised loadings, reliability and validity estimates of the construct physical resources

Latent variable	Indicators	Factor loadings	Indicator reliability	Convergent validity	AVE
Physical resources	Physical_1	0.7260	0.5270	0.8680	0.5270
	Physical_2	0.7980	0.6368		
	Physical_3	0.8150	0.6642		
	Physical_4	0.7750	0.6006		
	Physical_5	0.5870	0.3446		
	Physical_7	0.6230	0.3881		

Table 5 Fornell-Larcker criterion assessment

	Academic motivation	Non-academic aspects	Academic aspects	Support services	Physical resources	School engagement
Academic motivation	0.716					
Non-academic aspects	0.326	0.838				
Academic aspects	0.463	0.608	0.827			
Support services	0.408	0.562	0.648	0.720		
Physical resources	0.392	0.445	0.496	0.596	0.726	
School engagement	0.844	0.364	0.502	0.430	0.413	0.707

As shown in Table 5, the square of diagonal values is larger than the correlations in the row and column. This indicates that the discriminant validity of the measurement model is confirmed.

Thus, the measurement model fulfills the requirements on internal consistency reliability, indicator reliability, convergent validity, and discriminant validity. The revised path diagram of the proposed SEM is presented in Fig. 2.

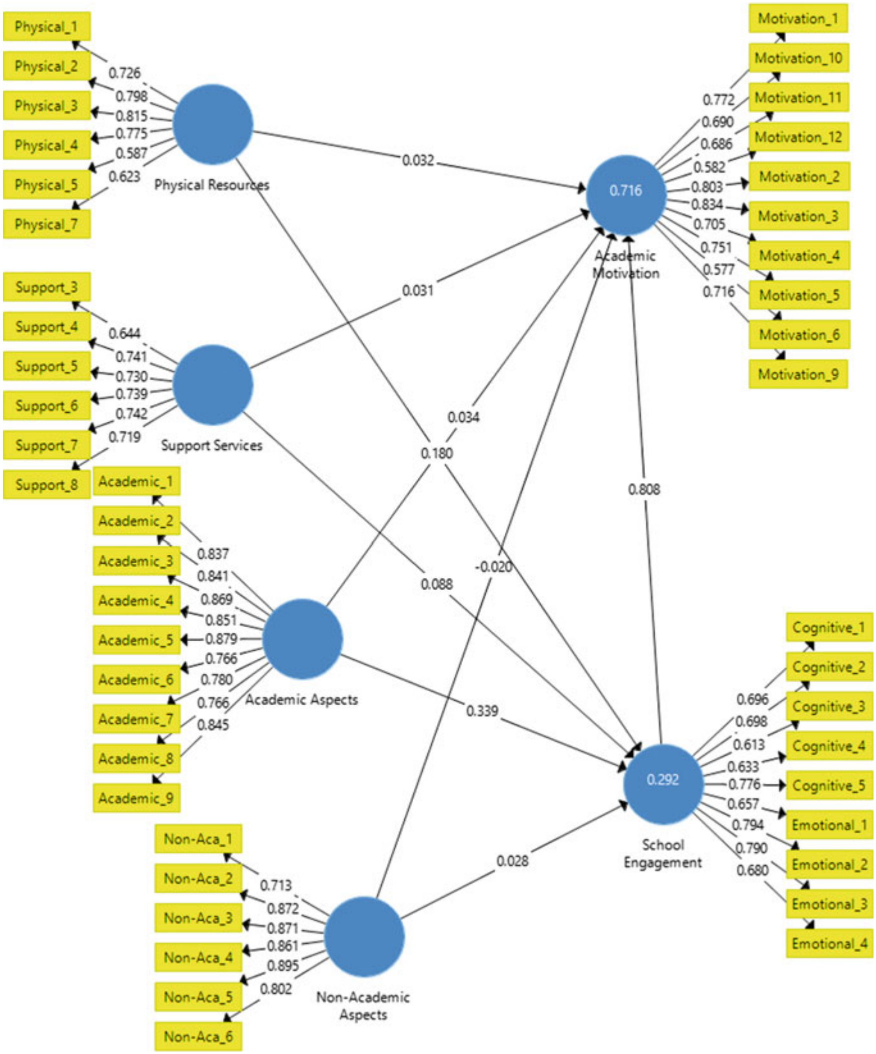

Fig. 2 Revised model

Testing the Structural Model with PLS-SEM

After verifying the reliability and validity of indicators, the relationships between the latent constructs in the model were examined. The main goal is to test how well the proposed model describes the endogenous latent variables. When analyzing the structural model, one of the criteria to be considered is the coefficient of determination (R^2). Table 6 shows the coefficients of determination of the endogenous latent constructs of the structural model.

Table 6 The coefficient of determination of endogenous latent constructs

	The coefficient of determination (R^2)	Adjusted R^2
School engagement	0.292	0.283
Academic motivation	0.716	0.711

The coefficient of determination (R^2) was found 0.711 for academic motivation. This means that physical resources, support services, academic aspects, non-academic aspects, and school engagement latent variables were able to account for 71.1% of the variation in academic motivation. This corresponds to an almost-strong association. The coefficient of determination for school engagement was found as 0.283. This means that the dimensions of university service quality can explain 28.3% of the variation in school engagement. This corresponds to a weak association (75% adequate, 50% moderate and 25% weak) (Kwong and Wong 2013; Hair et al. 2014).

To evaluate the statistical significance of the effect of that variable on each other in the proposed model, the values of t, p-value and effect size (f^2) given in Table 7 should also be considered. If t value is 1.96 or higher, the effect will be significant at

Table 7 The results of the structural model analysis

Hypothesis	t value	p value	f^2 value	Result	Impact
Hypothesis H1: The school engagement concept of students has a positive effect on academic motivation	26.473	0.000	1.629	Supported	Big
Hypothesis H2a: The physical resources of the university have a positive effect on the students' school engagement perception	2.648	0.008	0.028	Supported	Small
Hypothesis H2b: University support services of the university have a positive effect on students' school engagement perception	1.093	0.275	0.005	Not Supported	None
Hypothesis H2c: The academic aspects of the university has a positive effect on students' school engagement perception	4.269	0.000	0.079	Supported	Small
Hypothesis H2d: The non-academic aspects of the university has a positive effect on the students' school engagement perception	0.401	0.688	0.001	Not Supported	None
Hypothesis H3a: Physical resources in the university have a positive effect on students' academic motivation	0.734	0.463	0.002	Not Supported	None
Hypothesis H3b: The non-academic aspects of the university has a positive effect on the academic motivation of the students	0.424	0.672	0.001	Not Supported	None
Hypothesis H3c: University support services have a positive effect on students' academic motivation	0.592	0.554	0.002	Not Supported	None
Hypothesis H3d: The academic aspects of the university has a positive influence on the academic motivation of the students	0.659	0.510	0.002	Not Supported	None

95% confidence level (Kwong and Wong 2013). The effect is significant if the *p*-value is less than 0.05. In addition, if the value of f^2 is greater than;

- 0.02, the effect will be small
- 0.15, the effect will be medium
- 0.35, the effect will be big (Hair et al. 2014)

Discussion and Conclusion

This study aims to analyze the impact of university service quality on academic motivation and school engagement as well as the impact of school engagement on academic motivation. In order to analyze the structural model, not only hypotheses about the causal relationships but also indicators operationalizing the constructs have been analyzed.

In order to test these hypotheses, the indicators of students' school engagement, academic motivation and university service quality were determined and questionnaires were prepared by adapting the existing scales in the literature. The questionnaire was applied to both private and state university students. The collected data was analyzed by establishing a structural equation model in SmartPLS.

The model was tested for reliability and validity of the measurement part before analyzing the structural part. Indicators that did not pass the indicator reliability test in the measurement model were removed. Finally, the revised structural model was examined. The findings indicate that the school engagement has a strong and positive impact on academic motivation. Moreover, it was found that the academic aspects and physical resources dimensions of the service quality construct are the most important explanatory variables in terms of perceived school engagement. However, the findings indicate no significant effect of the dimensions non-academic aspects and support services on academic motivation and school engagement.

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The Potential of Data Analytics in Disaster Management

Peiman Alipour Sarvari, Mohammad Nozari and Djamel Khadraoui

Abstract In the era of social media, big data and Industry 4.0, technology has to make more contributions to help nimble decision making in response to severe disasters, both natural (including climate-related extreme events) and manmade, by providing the right solutions. Different reports and experiences originating from recent disasters and their crisis management processes have highlighted the need for a resilient and innovative disaster decision support system, even at the modern, developed and well-equipped communities working upon real-time big data. The aim of this paper is to propose a tool to foster preparedness, response, recovery, and mitigation as the fundamental steps of catastrophe management via innovation for disaster-resilient societies. The proposed tool consists of a novel conceptual hybridization of virtual experiments, machine learning, block chain, and database management technologies to overcome limitations of currently used technologies. This tool will utilize innovation in information registration and distribution, data exploration and discovery for generating reliable solutions. The most impressive implications of the proposed technology are its ability to measure community sentiments, generate smartly-designed hazard scenarios and propose the best emergency evacuation plot on 3D notifications as an innovative distinct feature.

Keywords Social media · Data mining · Optimization · Blockchain

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*, Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_28

Introduction

Natural disasters have been an integral part of human history, regardless of location. In addition, human-based disasters like terroristic attacks, chemical, biological, radiological and nuclear hazards, pose a threat for endangering natural life and human beings. The reality of potential hazards and disasters is one of the huge concerns of authorities as well as individual members of societies. Dealing with these unfortunate realities and the concepts of societal resiliency, taking under guaranty the security of people, and being well-prepared for predictable and unpredictable disasters are some of the vital functions of any advanced society.

During a disaster, panic, misguiding, misallocation of resources and uncertainty are causing huge costs in terms of the rescue process operations from the rescue time to casualty toll. Lack of viable disaster plans or up-to-date evacuation plans limits emergency response actions. In other words, managers need to be aware of all availabilities and limitations. Improper use and designation of resources rank high as a major complication in disaster operations. Emergency managers must have a comprehensive understanding of the emergency situation based on accurate information in order to avoid making any wrong decisions that might cost people's lives. Simultaneously, focusing on the insignificant data and neglecting the information flow because of too much trivial data causes unfortunate implications such as misidentifying the true first responders.

Considering the most common mistakes that are reported after each disaster, proper communication is critical to a better performance of disaster management practices. With the recent innovations in knowledge and data technologies, businesses have been collecting and analyzing data for decades to discover underlying trends and patterns. From another perspective, this is the IoT (Internet of Things) era, which is growing at a dizzying pace, providing new sources of valuable data. With this amount of information available, authorities and lifesavers should consider using relevant data to optimize disaster management processes.

With 1.79 billion monthly active users on Facebook and 500 million daily tweets, social networks create communities where messages, pictures, and videos are shared within seconds. Thanks to various social media platforms, which can perform as an active and simple database tool, disaster management processes should benefit from these viral abilities to support and trigger first responders. The best example of these kinds of researches is the work of Panagiotopoulos et al. (2016) that focuses on using social media (Twitter) for communicating risks to the public to either increase awareness or avoid escalation of public reaction. The theoretical part of this study combines two perspectives in risk and emergency communication and the Social Amplification of Risk Framework (SARF) (Kasperson et al. 1988) and the Crisis and Emergency Risk Communication model (CERC) (Reynolds and Seeger 2005). Combination of these two models not only aims origin of the risk management but also resolves appropriate risk reduction strategies. The empirical part of the study analyses 10,020 Twitter messages posted by the official accounts of UK local government authorities (LGA) in the heavy snow of December 2010 and the riots of August 2011. Methodology in this study is based on digital research methods. Following data collection, tweets are classified based on their thematic and risk communication content and then findings are considered utilizing CREC. Data filtering and selection were carried out by MS Excel and Nvivo. Twitter was used to communicate and manage associated risks including messages to provide official updates, encourage protective behaviour, increase awareness and guide public attention to mitigating actions (Panagiotopoulos et al. 2016).

This paper looks to support the applications of the credible and innovative technologic approaches aligning with better disaster management activities. The aim is to propose a novel and comprehensive methodology to ensure accurate and effective emergency management procedures. The rest of this paper is organized as follows; relevant literature is reviewed in Section "Literature Review", the proposed methodology is explained in Section "Methodology". Finally, conclusions are provided in Section "Discussion and Conclusion".

Literature Review

In this section, a very complete literature review is conducted to investigate the performed efforts into the usage of the social media to serve disaster management, adopted technologies, the challenges, implications and the reported gaps for the future researches. Additionally, Table 1 is summarizing the blueprints of disaster types, concerning objectives and high trending and recent algorithms and tools.

Kim et al. (2018) investigated the role of social network (Twitter) and user behaviors through Social Network Analysis (SNA) during 2017 Storm Cindy in the US. User's online search behavior was studied using Google Trends in local, state and national levels. Community structure was examined by using the Girvan-Newman algorithm. Then text analysis was performed before and after the incident. One of the limitations of this study was a Twitter dataset, the collected data were under "*storm cindy*" keyword and not able to explore other keywords and text analysis was limited to 140 characters, (limitation for any tweets on Twitter in the event period). The study clarified that certain types of Twitter users such as news and weather agencies were main accounts as information sources and information diffusers. However, several users such as news, agency, weather agencies and the public controlled the information flow in the network (Kim et al. 2018).

Rnne (2017) investigated Emergency Evacuation policy in the US, Hurricane Katrina in 2005, and the UK, coastal flooding in 2013–2014, for vulnerable and carless people. Data was collected using focus groups in five major cities in the US and conducted interviews in the UK. Studies revealed that US lacks a strong policy framework, "The National Response Framework (NRF) in the US is based on the concept that all disasters are local". The UK has an ideal written policy; however, interviews revealed the ruling party had ignored planning for vulnerable and carless people. A comparative and collective case study method was used in this work.

Table 1 The list of conducted researches on using social media in disaster management

Study	Research type		Objective	Disaster type					
				Hurricane	Floods	Earth quake	Terroristic attack	Cyber attack	Others
Renne (2018)		Research	3	Katria (US)	UK				
Rossi et al. (2018)		Research	4		North Italy, Piedmont				
Onorati et al. (2018)		Research	1 and 5				×		
Kim and Hastak (2018)		Research	6		Louisiana				
Whittaker et al. (2015)	Literature review		7						
Simon et al. (2015)	Literature review								
Kirac and Milburn (2018)		Research	8			Haiti			
Panagiotopoulos et al. (2016)		Research	2, 9	Snow storm					Riot
Murthy and Gross (2017)		Research	10	Sandy					
Bañgate et al. (2017)		Research	11			×			
Wukich and Mergel (2015)		Research	12						Different disasters in the US
Spence et al. (2016)	Literature review		13		×				
Fry and Binner (2016)		Research	14		Sheffield, UK				

Study	Social media tools	Emergency authorities/First responders	Algorithm
Renne (2018)	Interviews and focus groups	Emergency management (EM)	1
Rossi et al. (2018)	Twitter	Meteorological offices	1, 13–18
Onorati et al. (2018)	Twitter and Study group	Emergency management (EM)	1, 19, 20
Kim and Hastak (2018)	Facebook	Police and Fire station and local government emergencies	1, 8, 10, 11, 12
Whittaker et al. (2015)		Emergency management (EM)	
Simon et al. (2015)		Emergency management (EM)	
Kirac and Milburn (2018)	Twitter and Facebook and Blog, SMS	Emergency management (EM)	4, 23

(continued)

Table 1 (continued)

Study	Social media tools	Emergency authorities/First responders	Algorithm
Panagiotopoulos et al. (2016)	Twitter	Police and Fire station and local government emergencies	4, 24–26
Murthy and Gross (2017)	Twitter	S&R and First responders and relief orgs	1, 5
Bañgate et al. (2017)	Simulation	Emergency management (EM)	1, 6, 27
Wukich and Mergel (2015)	Twitter	Police and governmental agencies and army and fire station	
Spence et al. (2016)		Meteorological offices	7
Fry and Binner (2016)	Simulation	Meteorological offices	9, 21, 22

Objective codes
1. Developing a decision support system for emergency evacuation based on extraction information from social media
2. Using social media for emergency information diffusion (propagation)
3. Investigating Emergency evacuation policy in US and UK for vulnerable and carless people
4. Using social media for early detection and information extraction for weather-induced floods
6. Using social media for post-disaster mitigation plan
7. Role of informal volunteerism (ordinary citizens) on disaster management
8. Assessing the value of social data for disaster response logistic planning
9. Using social media to communicate risk
10. Using social media for communal expression and self-therapy
11. Model human behavior (simulation)
12. Reusing social media content (Retweeting) for informing public by governmental agencies
13. Challenges for data collection
14. Using social media for elementary modelling

Algorithm codes, models, softwares
0. No algorithm
1. Text mining
2. Image mining
3. Video mining
4. Adaptive large neighborhood search (ALNS)
5. Hand Coding
6. SOLACE (SOciaL Attachment Crisis Evacuation), a model (simulation) implemented by GAMA Platform
7. UCINET software
8. Girvan-Newman algorithm
9. Bayesian algorithm

Focus groups and interviews presented the barriers to effective evacuation planning for needy people (carless and vulnerable) such as complacency of plans, National policy structures, secrecy conundrum, political boundaries, and lack of collaboration across emergency management and transportation planning (Rnne 2017).

Rossi et al. (2018) used social media for early detection and information extraction for weather-induced floods and proposed an automated set of services to provide qualitative feedback. This service linked weather forecasts with event detection and selective information retrieval from online social media. This study focused on floods in Northern Italy, Piedmont, in 2016 using Twitter. The approach used a volume-based Event Detection Module (EDM) that operated on the series of tweets and built upon the generalized Extreme Studentized Deviate Test (ESD). The algorithm also employed the median instead of mean in the original ESD test. In order to capture informativeness, Natural Language Processing (NLP) technique was used. "Ensemble-based early warning products were developed to forecast severe weather events by utilizing both the ECMWF-ENS (European Centre for Medium-Range Weather Forecasts Ensemble prediction system, 51 members) and GLAMEPS (Grand Limited Area Ensemble Prediction System, 52 members) models". Model Output Statistics (MOS) procedure was used as a common statistical method, which was introduced by Glahn and Lowry. MOS utilizes past forecast errors for correcting the current forecast. EDM was implemented in the R language, using Anomaly Detection for ESD, and SparkR for accessing an Apache Spark cluster. The approach could benefit authorities and first responders, who control the emergency response phase as well as monitoring agencies and meteorological offices, in the early warning phase. The proposed system was limited because of using only text without consideration of trustability of account authors (Rossi et al. 2018). Onorati et al. focused on filtering and visualizing information gathered from social media (Twitter) as a visual analytic solution in order to deal with large unstructured data, content, reliability and quality issues to provide a better understanding of the situation for decision making. An exploratory study was performed in which 20 practitioners answered questions about the integration of social networks in the emergency management process. The dataset was a collection of tweets form several terrorist attacks in Paris in 2015. A visual analytic solution was proposed in which a semantic analysis mechanism and several visualization techniques were combined. Some of the common visualisation tools were VisAware, TweetXplorer, Twitscoop, TwitScope, TwitterReporter, EmotionVis and ScatterBlogs. For designing this semantic tool, the *details-on-demand* approach was followed. "In order to have a detail-oriented view, Shneiderman's visual information-seeking mantra was followed: *overview first, zoom and filter, details on demand*. Utilized techniques were *treemap, word cloud, bubble chartand animated map.*" The tool was then assessed in a controlled experiment to evaluate its effectiveness for exploring spatial and temporal data (Onorati et al. 2018).

Fry and Binner (2016) studied behavioural analysis and elementary modelling for emergency evacuation. They modeled the behaviour of individual people and the effects of social media by deriving optimal contrarian strategies. They formulated a *Bayesian algorithm* in order to enable the optimal evacuation under worsening conditions. This study provided several ways to measure the usefulness of information; it addressed overcrowding and optimal model-based interventions. The study introduced a mathematical description of the evacuation problem (Fry and Binner 2016). Kim and Hastak (2018) focused on the role of social media in post-disaster mitigation plan and disaster management by propagating emergency information to a disaster-affected community. This work studied the 2016 flood in the city of Baton Rouge, Louisiana, U.S. The study applied social network analysis (SNA) to convert emergency social network data into knowledge. Google Trends, the *search-term trend* (or *interest over time)*, were explored in local and national levels. Aggregated interactions of online users on Facebook during the disaster was used to create patterns. For this purpose, *Harel-Koren fast multiscale layout algorithm* was utilized. *Degree centrality* was analysed and network graph was created. A community structure of the social network was identified by the *Girvan-Newman algorithm*. Three entities were considered in a social network: individuals, emergency agencies, and organizations. The results of the study would help emergency agencies to develop their social media operation strategies for a disaster mitigation plan (Kim and Hastak 2018).

Kirac and Milburn (2018) investigated the quantitative assessment of the value of social data for disaster response logistic planning. Always there is a tradeoff between the accuracy of social data and timeliness. Their presented framework investigated acting on *user-generated data* or *social data* based on a case study, the 2010 Haiti earthquake, using real social data and real social network; however, some assumptions were made due to unavailability of some types of data. The possible frameworks were revealed through computational study. This could help disaster response logistic planning problems such as mobile delivery, direct delivery and point of distribution (POD) location planning and it has the potential to help planning in a variety of scenarios. The study mainly focused on direct delivery of relief supplies to the impacted population. The framework covered practical considerations such as multiple vehicles, request-specific demand magnitudes and demand-dependant service times. The scope of social data strategies was beyond the extreme "all-or-none" policies. At the time of planning, information from traditional sources considered as verified and user-generated information as unverified, each element of both traditional and user-generated content specified information about a demand point; for example, address. A *decision strategy* would determine how the user-generated data would be admitted in the planning process, such as *Only verified*, *All verified and unverified*, *close proximity*, etc. Emergency manager must quickly choose the decision strategy based on situation and factors such as size and density of the region, etc. Methods for generating realistic problem instances were proposed. After a decision strategy, *response plans* should be developed. Then the performance metric was computed for each alternative response plan. There were some assumptions, such as: "it is feasible to conduct tours with multiple stops in a post-disaster environment" and "centralized information, planning and dispatching organization that receives both unverified and verified demand requests". The problem of mobile delivery could be modelled as a Team Orienteering Problem (TOP). Adaptive large neighbourhood search (ALNS) was modified to solve the TOP in order to bet the best solution. “A simulated annealing based acceptance criterion was used to decide whether to accept or reject a new solution”. ALNS actively monitored and controled the probability of selecting each pair of operators based on a measure of their performance. Information from Haiti dataset was first filtered by date and location and then were categorized to *informative*, *partially actionable* and *actionable* based on perceived useful ness using specifying messages of location, type, and quantity (Kirac and Milburn 2018).

Murthy and Gross (2017) studied first-responders and relief organizations. Social media use during disasters tends to be decentralized and this organizational structure can promote different types of messages to top-down information systems. Using 142,786 geo-tagged tweets collected before and after Hurricane Sandy’s US landfall as a case study, they explored shifts in social media behavior during disruptive events and highlighted that though Sandy disrupted routine life within Twitter, users responded to the disaster by employing humor, sharing photos, and checking into locations, it was used for communal expression and self-therapy. Use of “gallows humor” enables people to distance themselves from disaster also avoids being “distressed by the provocations of reality”. Humor was also most likely used to cope with the psychological and social effects of the disaster. Unlike traditional disaster management systems, social media represents a mode of decentralized communication, social media, Twitter, in particular, is considered a lightweight, low bandwidth communication tool which can function where power or internet access is lost or phone lines are jammed. Data were collected from 50 US cities and filtered by hurricane related terms: *Sandy, hurricane or storm*. This filtering was successful and few false positives data were collected as Hurricane Sandy coincided with NCAA college football season and a team of Miami “Hurricanes” was among their dataset. Data coding was done through *hand coding*. A diverse range of research questions was utilized to understand diverse social content, it was found that relief-related content was low. It was concluded that social media use during disruptive events is complex and understanding these nuanced behaviors is important across the social sciences (Murthy and Gross 2017).

Ba et al. worked on modelling (simulation) human behaviour during the crisis. They presented SOLACE (SOciaL Attachment Crisis Evacuation), a multi-agent model of human behaviour during seismic crisis based on social attachment theory. SOLACE showed the effect of social attachment on the number of victims, and the time that it took, to reach a safe area; this work increased the realism of evacuation modelling. This model integrated social attachment and GIS data. Real-geographic data were used to define the spatial context of the crisis environment, delimit mobility with barriers (e.g. buildings, debris), and constrain movement to free space. A *belief, desire, and intention* (BDI) approach were adopted to integrate social bonds in human agent interaction and mobility. The model attempted to develop a generic agent based model of pedestrian (human) during the seismic crisis. It was set in Grenoble, France. Crisis content was an artificial environment, the spatial framework was built from real geometric data derived from GIS layers. Two types of agents exist in the model, human and inanimate (non-human) objects.

The model was implemented using GAMA platform. "Initial results included realism in (1) the synthetic crisis environment indicated by a power law distribution of earthquake effects: (a) intensities on buildings and shaking felt by human agents, and (b) evacuation delay, (2) agent movement and interaction (e.g. parent with child) influencing speed of evacuation (Bañgate et al. 2018)".

Wukich and Mergel (2016) explored reusing (retweeting) social media content in order to inform the public by governmental agencies. Government agencies evaluated social media content produced by third parties, identified valuable information, and at times reused and reshared the information to inform the public. This can lead to a diversity of social media users to be heard, however to what extent agencies rely on private citizens? Emergency management agencies utilize social media in all phases of the emergency management cycle (e.g., prevention, mitigation, preparedness, response, and recovery). Erroneous data is one of the biggest problems for emergency managers, which can result in rumor spreading and false information. Tweets were collected and analyzed form EM agencies in there month period; attributes were assigned manually for both retweeted accounts and message themselves. The analysis in this work was facilitated using UCINET package; online practices of state-level government agencies were examined. Findings demonstrated that agencies rely predominately on trusted institutional sources rather than new voices, such as private citizens (Wukich and Mergel 2016).

Social media platforms enable us to examine public responses to cataclysmic events. These technologies are also useful for reaching those affected by disasters in a manner not feasible with traditional methods. Most often access to the physical site of disaster is restricted, and because of dangers associated with the site, clean up, ongoing recovery, etc., hazard and crisis research are often conducted long after the trigger event, however, social media network has the potential to solve this issue. On of main obstacles of disaster and crisis researcher is the inability to generate randomized samples and representativeness of the sample. Several studies have used *Monte Carlo* simulation in order to demonstrate what happens in quasi-experimental designs, which proves several potential errors using non-randomized designs. Spence et al. (2016) studied recent advances in the use of social media for recruiting participants, collecting data, and evaluating audience needs and expectations. They discussed challenges in the context of its implications for scholars, social media managers, and emergency practitioners (Spence et al. 2016).

Social media tools are integrated into most parts of our daily lives; mostly in marketing and recently in presidential elections, it is a quite pity that it is not serving the safety of residents and significant components of crisis response. Regarding the future works and concerns coming from the literature review, plus the lessons learnt from disasters and emergencies that occurred globally in the last few years, the following blueprints can be pointed in terms of gaps and to dos.

1. Lack of a systematic and automatic disaster management tool which outperforms human.

2. Some of the social media platforms like Twitter are currently the most widely researched social media tool, thanks to their easiness of information extraction, while the other some like Facebook do not provide a fruitful option to search or collect information from its groups which potentially causes a selection bios to catch true behaviours during emergencies.
3. There is no intelligent, acquisitive and reliable scenario generator for different combinations of hazardous and threats.
4. There is no powerful tool which can consider the cyber-attacks respecting the concept of the resiliency of societies.
5. There is no comprehensive data analytic tool to better measure the sentiments of people during any emergency. This option can help make better decisions and develop more reliable emergency plans.
6. There is no self-improving optimization based simulation tool, which intelligently can help the disaster management councils in terms of decision-making.

Methodology

The proposed decision support system, which is an intelligent, automatic and user-friendly application, is composed of three main phases. The first phase is the information extraction tool, which will turn data into information. The second phase is the virtual experiment based scenario generation tool, which will provide all possible hazardous scenarios and responses based on current and possible situations. Finally, the third phase is the web-based optimization tool to make decisions.

Phase 1: Information extraction tool:

This tool extracts the most accurate and reliable knowledge from different data sources such as social media platforms and cyber security firewalls with different data structures. Artificial intelligence and machine learning algorithms support the development of a decent environment in terms of data mining and data analysis. The most important outputs of this phase are physical, environmental, physiological and sentimental metrics in shapes of numerical and categorical factors to ponder the concepts of deterministic and probabilistic measurements. As it is illustrated in Fig. 1, the tool is composed of 4 stages:

The first stage identifies the major social media platforms, like Twitter, Facebook, Instagram, Google+, Snapchat, etc.

Data mining is the second stage, which uses the machine learning based text mining, image mining and video mining algorithms to realize the creation of data, streaming, and aggregation. It handles raw data through cleaning, categorizing, clustering, and visualizing.

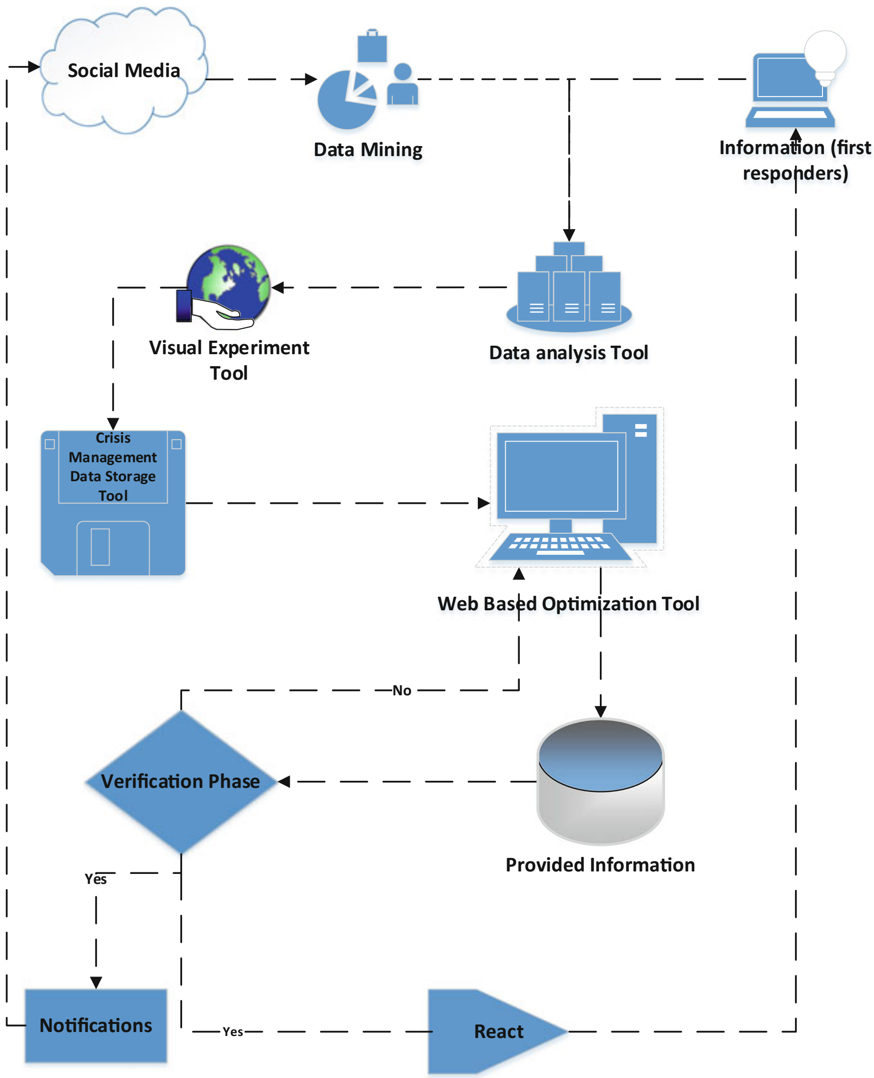

Fig. 1 The framework of the proposed methodology

The third stage is to identify the direct, clean and concrete information obtained from all first responders, tele communication providers, standards and guidelines, such as quantified equipment of hospitals, fire stations, rescue and research teams, police, army, online maps and weather conditions among others.

The fourth stage of information extraction tool phase is data analytics stage, which handles descriptive, predictive and prescriptive analytics to produce inputs for scenario generation and optimization phases. This stage understands the disaster type, identifies the metrics, spots the location, understands the demographics, measures the data legitimacy, identifies risks, identifies attach surfaces, diagnoses reasons for fault and infers weaknesses, predicts the future possibilities, and measures sentiments of people thanks to the artificial intelligence innovations.

Phase 2: The virtual experiment based scenario generation tool:

This tool aims to produce expected causalities, expected evacuation time for infrastructures, expected system disabilities and to forecast urgent needs and mappings of disaster situations. The tool generates different types of scenarios and simulates them in shapes of different combinations of natural hazardous, terroristic attacks, cyber-attacks, infrastructural shortages, different numbers of inhabitants, daytime, nighttime, etc. The outputs of this phase are stocked in the disaster management data storage tool which is using file systems and programming models in alignment with the optimization phase.

Phase 3: The web based optimization tool:

This phase is composed of four different interconnected stages:

Stage 1, which is a web-based optimization tool, composed of mathematical modelling based solvers of routing problem, scheduling problem, and assignment problem.
Stage 2 is the provided information by the optimizer tool and covers hereunder tasks:

- Supports the first responders, people, and disaster managers with classified materials, such as facility and plant plans
- Plans the best routes and assignments
- Provides simulation results like 3D maps of smoke spreading, fire spreading, flood spreading, can be used to identify the best evacuation plan
- Optimizes response operations by using the spatial distribution of trapped people/attackers/terrorists, prediction of evacuation time, number of casualties, lists of critical points and locations and critical information of burn down potentials

Stage 3, Verification tool: validates or modifies the provided information by reviewing the emergency management fundamentals and sending the relief messages. This tool is an interface that is under the supervision of human expert to facilitate and guarantee the accuracy of processes.
Stage 4, React tool: it triggers the cyber security module in case of any cyber-attack the duty of the react tool is feeding back the system with factors to be used by scenario generation tool.

Phase 3, produces enough materials for feeding social media like sharing information secured by block chain technology, enhancing the viral ability of social media by sharing techniques, simplified instructions (plan, photo, video and comments) for trapped people, and provides the information for access to emergency internet (like emergency call that is possible even without sim card).

Discussion and Conclusion

We are living in an era that data is the most valuable asset, and thanks to available technologies, social networks can function as data generating platforms. On the other hand, machine learning continually advances creating more potential tools for solving humanity problems. One of the most important applications of the above-mentioned technologies is an emergency evacuation. Here we proposed a comprehensive responsive tool that can be utilized for emergency evacuation. The main target of this paper was to enhance the fundamental steps of disaster management benefiting a developed and innovative methodology that helps first responders.

A primitive framework of a decision support system is presented, which eventually captures data from different data sources, analyses and feeds the social media and the other first responders with recommendations and information. A tremendous machine learning tool is generating all possible hazardous scenarios, simulates them and presents the best and alternative decisions for the better managing the disaster for disaster management members and first responders.

The most impressive implications of the proposed methodology are its ability to measure community sentiments, generate smartly-designed hazard scenarios and propose the best emergency evacuation plot on 3D notifications as an innovative distinct feature.

For the future work, we will adopt adequate deep learning algorithms and IoT frameworks with the proposed decision support system.

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Blockchain Technology for the Improvement of SCM and Logistics Services: A Survey

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Abstract Since the advent, blockchain has found its application in numerous industries, thus disrupting the current way of design and development of the new applications for supply chain management and logistics. Nowadays for business providers, the efficiency of the service they provide is crucial for the long-term improvement of their operations. This efficiency depends on consumer satisfaction with service delivery and reliable information related to goods, correct delivery and timeliness. These providers are strongly dependent on the application and models they use for planning and managing their daily activities. In this context, information sharing is crucial to ensure a reliable and efficient way of collaborating. This papers aims at surveying the current range of academic literature and applications from the business perspective related to the application of blockchain technology in supply chain management and logistics.

Keywords Blockchain · Logistics · Supply chain management
Trust · Traceability

Introduction

Supply chain management (SCM) represent a complex and dynamic sector while incorporating the systematic coordination of suppliers to ensure business functioning (Mentzer et al. 2001). The SCM includes planning, the management of the flow of goods, services and financial transactions (Diann 2018). The logistics

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_29

services are a component of SCM, and principally focuses on transport of goods in the most efficient way (Diann 2018). The organization of the logistic processes requires strict processing and coordination of tasks and the tolerance of errors tending to zero. Subsequently, these are considered the conditions that should be fulfilled in order to achieve the maximum consumer satisfaction. Any delay or error during the processing of logistic tasks will impact on consumer satisfaction. The growth of markets and the movement of trade has significantly changed with the tendency to be more rigorous with the service delivery side of operations.

For business enterprises, there are many challenges in workflow management in SCM and Logistics. The distributed nature of the supply chain challenges the organization of logistic services. For sustainable logistic services, the synchronization and optimization of processes are very much required. For that, logistics stakeholders, need to share certain information for the coordination of processes. This constitutes a serious challenge when it comes to sharing information with stakeholders in the business field. Especially because this information may contain some business details on capacity, source, destination, current warehousing, the timestamp of the movement of goods and final destination. The currents system does not fully support the required confidentiality, and from the perspective of information security, this remains a challenge (Imeri and Khadraoui 2018). Blockchain technology and its properties promise to solve these issues related to SCM and Logistics. In this context, the purpose of this paper is to provide an outline of the literature related to the application of blockchain technology in supporting SCM and Logistics processes. The focus of this study is to explore the current academic literature and ongoing startups for blockchain-based SCM and Logistics. In this paper, we will first introduce blockchain technology. Next, we will highlight the key factors of introducing blockchain technology to SCM and Logistics. The current research, related to trust, security, and traceability are then presented. We finalize our paper by providing our view on improving SCM and Logistic processes using blockchain technology.

The Problem Scope

As one of the most dynamic components of SCM, Logistics presents important challenges in terms of workflow organization, continuous collaboration among stakeholders and costs reduction. Crespo (2010) highlighted the challenges in SCM such as the trust in the context of stakeholders collaboration, the organization of the transportation of goods, the transparency over SCM and Logistics, the traceability of goods in SCM, network flow optimization, etc. (Lambert and Cooper 2000; Petersen et al. 2017) have further enlisted these problems.

In this paper, we intend to focus the research on trust in SCM and Logistics, the security and traceability of shared information in SCM and Logistics, and examining current startups, which are developed or are in the process of being developed by companies.

Distributed Ledger Technology: Blockchain Background

Blockchain is a distributed ledger database, which enables the storing of digital information and continuously maintaining and adding new information to the ledger (Xu et al. 2016). A blockchain network is composed of several nodes, which have the same ledger, while the information added in the distributed ledger is done by agreement on the shared state from all nodes in the network (Xu et al. 2016). This ultimately leads to the unnecessary central authority to validate information in the network (Xu et al. 2016, 2017; Walport 2016).

The ordered "block" of data stored in blockchain is a set of transactional data, which are appended to blockchain after reaching consensus between nodes in the network. The data structure or "block," beside the transactions from the nodes in the network, contains the timestamp of added into the chain of blocks, the representative hash of previous block, e.g. the block n contains the hash from block $n - 1$ (the previous block); nonce and merkle tree root of transactions (Xu et al. 2016, 2017; Walport 2016). Since each block contains the hash of the previous block, they remain chained and explored up to the *genesis block,* thus forming the chain of blocks or *blockchain* (Xu et al. 2016, 2017).

Blockchain technology has specific properties:

Decentralized. The core architecture of blockchain technology is its decentralization characteristic. This means that nodes are a relay in a peer-to-peer manner instead of a central authority (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016).

Consensus. For the process of consensus, any node in the network can be part of it for a public blockchain, while for the consortium (permissioned) blockchain, for the validation process only some selected set of nodes are responsible (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016).

Immutability and data integrity. The data recorded on blockchain are cryptographically checked and distributed over all nodes in the network. The tendency for changing these data is impossible. Blockchain is considered immutable, the tendency to change the transaction from the block n, means that these data should be changed in all nodes in the network in the same time, and this is impossible while the consensus algorithm compares and denies this change (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016). The data, which are stored in blockchain by using cryptographic mechanisms, ensures *data integrity.*

Non-repudiation. The properties of immutability associate the non-repudiation properties (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016).

Anonymity. Users generate the addresses (account) in blockchain, and the number of accounts is not limited. Since any central authority does not store the information for the user and the information about accounts, does not show much information about users, this provides the *anonymity* properties (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016).

Smart Contracts. The smart contracts are a computer programmemes, coded to solve a specific problem (Ethereum White Papers). They are deployed in blockchain network, and executed depend on the tasks involved for them, e.g., the execution of a smart contract for reaching an agreement, or notification, or solving any common problem (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016).
Permissionless and permissioned blockchain. In the permissionless (public) blockchain any user can join it and start execution transaction, view and explore any transaction executed. While in permissioned (consortium or private) blockchain, only the invited parties are allowed to join blockchain and access rights are managed by a consortium (Xu et al. 2016, 2017; Walport 2016; Zheng et al. 2016).

Enlisting all these, benefits of blockchain technology, especially on data security, make blockchain very likely from the business enterprises to design and develop an application based on blockchain architecture.

Moreover, there are some limitations to this technology like limited scalability latency, lack of governance and standards, etc., but they are not within the scope of this research.

The Value of Blockchain in SCM and Logistics

Blockchain technology enables a new way of designing and developing decentralized applications, which will eventually improve the quality of services in the SCM and Logistics. Information security, record keeping properties, and no need for an intermediary in the service show significant points for overcoming the main issues in SCM and Logistics. The values brought by blockchain in SCM and Logistics are in the field of compliance, transparency, consumer satisfaction, trust and real-time response (Hal Feuchtwanger 2017).

Compliance issues: The logistics and transportation processes are governed by national, international and internal business agreements. For a regular logistics and transport process, the enforcement of the compliance standards is established by the usability of the smart contracts (Anjum et al. 2017).
Consumer satisfaction: The record keeping properties of blockchain allows the customer to access particular information related to the products they are consuming or selling them to other parties. Blockchain technology presents a suitable mechanism for tracking and tracing products in SCM (Falamaki et al. 2017). The consumer may access this information by scanning a barcode or ID number in the product, and the information will show up from the origin of the product up to destination (costumer shelf) (Falamaki et al. 2017).
Trust: The cryptographic algorithms, no single point of failure, and operation without intermediaries, provides a trust mechanism for the stakeholders, which operate in the network of the supply chain (Jeppsson and Olsson 2017). The context

of sharing information in a distributed decentralized database is a valuable asset of blockchain technology since this information is immutable (Jeppsson and Olsson, 2017).
Real-time response: Operation monitoringin the SCM is one of the most highlighted tasks from the stakeholders in SC. The blockchain technology in combination with smart contract allows automation of processes by producing real-time events for the process of transportation, warehousing, and management of goods (Xu et al. 2017; Falamaki et al. 2017).
The Deloitte Survey Results on Blockchain Across Industries (Blockchain-finance 2018), shows that, from 308 US-based senior executives in blockchain technologies, which represent companies with a revenue over $500 million, results as presented in Table 1.

The surveys presented by Barrios (2018) under the questions for the "*level of expectation that blockchain technology with facilitating the administrative work in the context of SCM*". The results showed that 72% of the participant's responded with "Yes", 20% responded "Not sure" and only 8% responded with "No".

Taking into account these surveys and the current state of the art in the academic literature as presented in Fig. 1, and industrial field, we consider that blockchain has already made an impact in the several industries, including SCM and Logistics. Regarding SCM, the surveys from (Chain Business Insights 2017) shows the most preferred use cases in which the stakeholder from SCM would like to solve by using blockchain technology. Among several use cases, we enlist the four most highlighted such as *Tracking product moving through the supply chain*, *Share information with suppliers, Tracking the payment information, and Share information with consumers.*

Considering the potential of blockchain for solving or improving these use cases, we investigate the current state of the art, and provide a synthesis of the current proposed solutions in the following section.

Table 1 The results of the survey presented by Deloitte (Blockchain-finance 2018)

Percentage	Shared opinion
55	In competitive disadvantages, in case they fail to adopt the technology
45	Little, to no knowledge of blockchain technology and believed it would disrupt their industry
33	Over-hyped
25	Top five priorities
28	Already invested up to $5 million
25	To invest up to $5 million in 2017
10	To invest up to $10 million

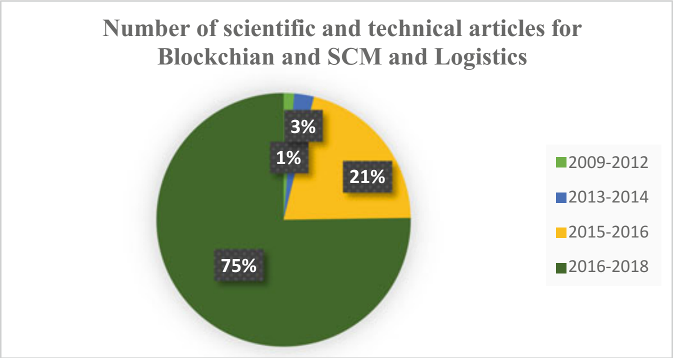

Fig. 1 The number of scientific and technical articles by years for blockchain, SCM, and Logistics (different query combination) from the perspective of different problems. The number of articles and technical reports is incrementing yearly

Blockchain in Supply Chain Management and Logistics

This section is composed of three subsections. In the first subsection, we present blockchain and trust issues in SCM, then in the second subsection we highlight the blockchain properties for the traceability of movement of goods in SCM. In the third section, we illustrate some current blockchain startups for Logistics and SCM.

Blockchain for Solving Trust Issues

This section contains a set of articles that are considered and studied related to blockchain and SCM and trust, blockchain and each research article is abstracted, by summarizing the research artifacts, the strong points, and limitations for each research article.

This aim of the research presented by Nichol and Brandt (2016) is to co-create trust in the healthcare systems. In healthcare systems, there are many breaches and its organization is struggling to manage and guarantee a secure system where the information of patients is managed appropriately. That decreases the trust of these organizations. This research proposes a new way of managing patient data, by creating a new platform for medical communities, based on the blockchain, which minimizes the risk of exposing patient data. The potential of blockchain technology is evaluated as a core for achieving a trusted and sustainable healthcare platform, which uses main blockchain properties like decentralized, distributed, security, audibility, interoperability, transparency, non-reputation, for the management of patient data, thus creating a trust in healthcare communities. The paper explains how blockchain can be used in healthcare, e.g., for patients, health organizations, the possibility for defining the profile by patients, specifics to access the data, the audit possibility and non-repudiation properties. As opposed to current classic IT solution for healthcare, this platform will provide an interoperable platform efficiently by facilitating the access in this platform in the patient side (profile management) and the health provider, thus, solving the interoperability issues, reducing the risk of failure (from a single authority), and cost-efficient. The approach compares the features of blockchain technology against current IT solutions, to achieving interoperability, and creating trusted healthcare platform. This platform will provide the patient with the government over the medical data related to health in cooperation with the health organization.

Jiang and Liu (2017), present a model for the evaluation of trust among enterprises. This model will evaluate the trust between enterprises in the supply chain management (SCM), in a blockchain environment. The trust here (SCM) is defined as the probability that one enterprise predicts to deliver the products to the associated enterprise, as agreed. More concretely this model will evaluate two types of trust: joint enterprise credibility (which is generated from historical cooperation and the interaction of enterprises) and associated credibility (which represents the degree of trust between two enterprises which do not have any direct cooperation), under blockchain technology. The key characteristics for trust evaluation between enterprises are considered, the transaction satisfactory, product ability, risk probability of information concealment and penalty factor.

This research presents by Biggs et al. (2017), explores the way to benefits from using blockchain technology in supply chain management (SCM), such as "Transparency", "Scalability", "Trust", "Security", and "Access to new Markets".

This affects the end users by increasing the trust of the suppliers while the information related to products and the journey of products are well documented and accessible. Further, this research explains the difficulties and obstacles to using blockchain in supply chain management. Among several constraints, the report enlists "Government Regulatory Status" as uncertain and unsettled for blockchain cryptocurrency market. "Large Energy Consumption", as for validation of transaction requires high-energy power; "Cross-Industry Integration" which requires transforming the current systems in a full integration of these systems on blockchain, and this because blockchain is not a stand-alone system; "Black Market", which sees the utilization of cryptocurrencies, e.g., Bitcoin for money laundering and other illegal actions.

Notheisen et al. (2017), present a proof-of-concept prototype for a real case trading of cars in the "market of lemons". The current systems are based on centralized databases managed mainly by a government organization, and they require a specific volume of work and organization for maintaining them. Since many stakeholders are involved, buyers, sellers, government organization, insurances companies, it is challenging to maintain it correctly and to avoid bureaucratic processes. The main intention of this research is to propose a public blockchain-based solution to replace the current system in cars registering and maintaining the history of usage of cars and dealing with changes in ownership. As a public ledger will provide a sufficient set of information for traders, i.e., buyers and sellers of cars, government organization, and other third parties, e.g., insurance companies or banks, which would help to avoid the asymmetry of information. For the implementation of the proof-of-concept prototypes based on blockchain for automation of transaction in real-world assets, the design science research is applied. The approach produces an IT artifact, with the intention to provide a novel way of registering and maintaining car history from private sellers and buyers, in a distributed shared ledger, with automation properties. The features of blockchain technology and the organization of the research work based in design science research provides a trust-free platform with safeguard mechanism in transactions correction in case of possible errors, for trading in "market of lemons". The benefits from using such a solution will be in the efficiency of the public registration system for cars, followed by the mitigation of transaction risks (by dividing the transaction process into several steps) in a blockchain based system, in case of conceding any error, and finally in decreasing the risk on trading in the "market of lemons".

Another approach, which uses the design science research for developing proof of concept prototype, is showed by Beck et al. (2016). This article explains in general how the trust-free based on blockchain can replace the trust-based solution, and this is achieved by designing, developing and prototyping solution. The case study presented is the concept of trust-free coffee shop payment solutions by using the digitalized punched cards, as a part of the cryptographic economic system. The cryptographic economic system presents an autonomous system of transaction, which is not controlled by third parties, e.g., humans, and it follows pre-defined rules as a protocol implemented in computers. For conceptualizing this solution, design science research guidelines are used. The artifacts from this research produce an IT solution based on blockchain technology, which is a new approach and contributes to solving specific problems for society. The smart contracts from the Ethereum blockchain framework are used for implementing this solution. This helps in the creation of trust-free self-service and automation of rules in the process of purchasing coffee. The potential of blockchain related to the trust-free system based on blockchain technology highlights, while its applicability faces some obstacles for real-world implementation. Currently, there are considered some weakness on blockchain technology, which prevents the massive changes from trust-based into the trust-free mechanism. These weakness stem from technological disadvantage in blockchains such as scalability, the costs of issuing smart contracts, and transactions, and the time factor. For example, in Ethereum blockchain, the time needed to add a new block is 12 s, and it is a potential time to wait, so it is a weakness nowadays.

The potential of blockchain as validation tools by practicing the recording transactions, validation processes and its possible usability for access control are presented by Anjum et al. (2017). Following the distributed mechanism, the trust, validation and the compliance issues are studied in this research. The security and trust are enhanced by the decentralized methods, independent verifications which are blockchains properties. This analysis considers that the standardization is a crucial issue for achieving the best usability of blockchain. This research highlights the needs for standardization of Storage algorithms, Signature Algorithms, Web-based access protocols.

The Traceability of Goods in SCM and Logistics

The issue of traceability is one of the most highlighted use cases from the stakeholders of SCM and Logistics. The study from Chain Business Insights (2017) enlists the "*Tracking product moving through supply chain*" use case as the most preferred among all the other use cases by evaluating it with 80% as the most voted from stakeholders in SCM.

The traditional logistic system does not match with the market demands, the low food safety and the losses are considered enormous by logistics processes because of a missing of a traceability system (Tian 2016). The traceability system is based on the usability of RFID technology for data management from logistics sectors, and it uses blockchain technology and its properties to ensure that the shared information among stakeholders is immutable. This research intends to improve the quality of food by providing a solution for traceability system on the agri-food supply chain. This would significantly improve the trustability in the supply chain since the information shared in the blockchain system is immutable. The approach presented is a conceptual solution and, enlists the benefits of using RFID and blockchain in supply chain agri-food. Using these technologies on a traceability system, the benefits are significant on information security and fighting against fraudulent products. While the disadvantages are in the high price of implementation of such a system influenced by RFID price and the immaturity of blockchain (Tian 2016).

The research presented by Badzar (2016) studies the possible improvements of transparency for suppliers and consumers, and the development of contractual coordination concerning sustainability clauses. The potential of blockchain for logistics and transportation is showed by using the measurement of innovation for blockchain in logistics, based on a specific method and analysis of the empirical findings. The evaluation of blockchain in logistics as an innovation is performed using a the well-known method, composed of five main points: Relative advantages, Compatibility, Complexity, Trialability, Observability (Rogers 2003). The conclusions are reached that blockchain has the potential to generate transparency and ensure the fulfillment of contractual terms between suppliers' operations in the supply chain.

Petersen and Jansson (2017) present a framework for businesses to evaluate the possible applicability of blockchain in supply chain management to improve traceability. This framework aims to discover the necessary inputs and evaluation tools needed for the applicability of blockchain technology into supply chain management. This framework is based on the theory of supply chain tractability and blockchain technology, and it is composed of three main steps: (1) identification of drivers for traceability (or areas for improvement), (2) creating the main principles of blockchain and (3) evaluating the sustainability applicability and technical limitations. The process methods could follow these steps in a disorderly manner, and as a result, it outputs the effectiveness from the implementation of blockchain technology in supply chain traceability (or any area targeted for evaluation).

The research by Jeppsson and Olsson (2017), describes the whole process of traceability and it provides an example systematically. Blockchain technology has been integrated with the smartphone, to follow the production from the manufacturer, then through warehouses, to the store (retailer). The research highlights that for the possible implementation of this technology and its continuous usability, the cooperation between suppliers is required, then for having a footprint the usability of the smartphone is mandatory, and finally an integrated system should exist between suppliers involved in the process.

Imeri and Khadraoui (2018), present a new conceptual approach for the security and traceability of shared information in the context of the transportation of dangerous goods. Business contracts are taken into account, and the information related to contractual terms are secured; the goods are traced while moving through the supply chain. The approach compares the current existing technological systems to support the transportation of dangerous goods, and it proposes a new solution based on blockchain.

Blockchain Based Startups for Logistics and SCM

In Table 2, we will present several projects related to SCM and Logistics.

Table 2 Blockchain based startups developed by enterprises for SCM and Logistics

Project name	Description
TKI Dinalog	"The result of the project is for delivering three concrete use cases: chain financing, supply financing, and circular economics. Using blockchain technology for financial routes is just beginning but "stepping stone towards a logistics sector with improved collaboration throughout the entire" (TKI-Dinalog 2017)
SmartLog Project	"The IoT and blockchain proof of concept project with the purpose of sharing information for logistics and supply chain stakeholders. This project intends to connect many stakeholders and to share information about containers' location, surroundings and such to different ERP systems" (SmartLog 2016)
T-Mining project in Antwerp Port	"A pilot project that will make container handling in the port of Antwerp more efficient and secure. Using blockchain technology, processes that involve several parties – carriers, terminals, forwarders, hauliers, drivers, shippers are securely digitised without any central middleman being involved" (Antwerp start-up T-Mining 2018)
Maersk and IBM	"Maersk and IBM launch blockchain-based cross-border supply chain solution. The intention of this solution is to use blockchain technology to help transform the global, cross-border supply chain. The solution will help manage and track the paper trail of tens of millions of shipping containers across the world by digitizing the supply chain process from end-to-end to enhance transparency and the highly secure sharing of information among trading partners" (Taylor 2017; Maersk and IBM 2018)

(continued)

Table 2 (continued)

Project name	Description
Walmart and IBM	The main intention of this project is to provide a distributed ledger technology to track and trace several products, e.g. mangos, and pork in China etc. (Walmart Testing Blockchain Technology for Supply Chain Management 2018)
Provenance	To make opaque supply chains transparent. This project intends to provide trust related to the goods moving in the supply chain (Provenance 2018)
Mahindra	Is developing a blockchain-based solution for financial supply chain based in the permissioned ledger (Shah 2017)
Seam	The SEAM and IBM, forming an ecosystem of suppliers for a cotton industry, based in Hyperledger Fabric (Seam and IBM 2018)
FDA	The FDA and IBM are cooperation for a solution based on blockchain for securing patient data exchange (Mearian 2018)

Our Perspective: Blockchain Technology for the Improvement of SCM and Logistics Services

The advent of blockchain brought a new era of designing and developing an application for SCM and Logistics. The benefits of using blockchain technology in SCM and Logistics brings a new way of design application, whose architecture is decentralized. The scientific community and business enterprises from various domains are researching to solve challenges to their workflow management by using blockchain technology. A considerable effort is shown in the domain of SCM, and the current developments promise future improvements in the SCM and Logistics. Enlisting possible improvements in the workflow management, we consider blockchain technology as a benefit for overcoming the SCM and Logistics issues.

We have analyzed the current state of the art for blockchain and SCM and Logistics, with the focus primarily in trust issues, traceability context and the current state of development of blockchain-based projects for SCM and Logistics. The analysis performed in this study intends to know the level of applicability of blockchain in SCM and Logistics and concludes our future development in the context of extending our blockchain based conceptual solutions. We intend to develop further our blockchain-based platform for securing shared information among stakeholder in the process of the transportation of dangerous goods (Imeri and Khadraoui 2018). We intend to provide a trusted platform by using blockchain technology features that enable stakeholders to rely on the system. This platform will also have a traceability mechanism that allows monitoring of the movement of goods and services of the transportation of dangerous goods processes. The future development of our conceptual approach will produce a technical implementation. This technical implementation of our platform will be based on the Ethereum blockchain framework and Hyperledger blockchain framework. Then we will compare and show the opportunities and drawbacks of both blockchain frameworks with regards to our case study.

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Big Data Concept in Small and Medium Enterprises: How Big Data Effects Productivity

Ahmet Tezcan Tekin, Nedime Lerzan Ozkale and Basar Oztaysi

Abstract The topic of data mining is a popular subject, especially nowadays. Data mining is a process which accesses the information among large-scale data and mine the knowledge. The most widespread use in the literature is to process large amounts of data automatically or semi-automatically to find meaningful patterns. Depending on the pace of the spread of Internet usage, digital media takes the place of traditional media, so the number of textual forms in digital media is increasing day by day. For this reason, text mining techniques should be used for text review. Such as text mining, data mining, machine learning technologies are related to the big data concept, and these technologies are used for increasing productivity in too many areas. According to the analysis in the United Kingdom and the United States, companies adopting decision-making based on data have been observed to be 5–10% higher in output and productivity than firms using only information technology components such as software products. So, even if small and medium enterprises can adopt these technologies in their life cycle can gain more productivity and economic profit in their areas.

Keywords Big data · Text mining · Recommendation systems
Economic impact of big data

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_30

Introduction

Data analytics is a field that is developing under the information and communication technologies and increasing day by day. Because fields such as artificial intelligence, big data, and the Internet of things start to stand out regarding productivity and economic impact, there are also many studies and economic analyzes in this area. The concept of big data is closely related to the economy. Because of the big data, problems that can not be seen and detected by a human can be detected or forecasted so efficiency can be increased. On the other hand, analyzes which are related to consumer psychology sales can be increased by bringing the right product to the right customer.

Global value chains, accelerating with dramatic reductions in the costs of Information and Communication technologies, have created new paths for rapid technological development, information sharing and the development of skills (OECD 2017). Information and communication technologies make it easier to specialize in a field and find technological products at lower prices. It is observed that the competitiveness of firms is increased due to the acceleration of technology transfer in the countries that have achieved these developments (OECD 2016).

The free flow of digital technologies and data has contributed to the growth of trade by reducing trade costs. At the same time, they have provided international trade opportunities for sectors that do not trade internationally and small-medium enterprises. The information technology sector, while contributing to the globalization process, reduces the cost of entering international markets by drastically reducing both global and domestic purchasing costs.

Information Technologies is increasing trade and competitiveness in both the manufacturing and service sectors. While this is known, it is clear that one country's going to trade restrictions in the field of communication and technology will adversely affect the trade of goods and services (Nordas and Rouzet 2015). Another approach in this area is to help increase the price of exports in the electronics sector due to the increase in accessibility at the technological level. At this point, it is estimated that the intra-sector trade level has increased by 7–9% (OECD 2014).

In addition to new manufacturing methods, big data is being used to support decision systems in organizations. Although there is little evidence of the macroeconomic implications of big data use, it is observed that employers increase labor productivity by between 5 and 10% (Brynjolfsson and Kim 2011). In the United States, companies adopting decision-making based on data have been observed to be 5% higher in output and productivity than firms using only information technology components such as software. In a UK-specific analysis, firms with high levels of online data use are observed to be about 13% more efficient than those at lower levels (Bakhshi et al. 2014).

When the countries that are successful in the field of information and communication technologies according to OECD reports, we can easily say that these countries are also prosperous in software technologies export. Also, when PISA Education reports are examined, most successful countries according to science category for PISA are almost same in OECD technology preparation index category's most successful countries. This evaluation shows that education in science is so important for information and communication technologies development.

The use of big data technologies is not only used to provide economical efficiency. Big data and data analysis also support decisions at the city level. With the help of these technologies, drivers can track the traffic situation on a street basis with the data created via the smartphone, or try to avoid possible future crimes using data collected through crime scenes (OECD 2017). Technologies that can be used regarding urban modelings such as intelligent transit tickets, geographically based analyzes remotely perceived due to more data and more processing power have emerged. In this respect, a better quality of life is offered regarding sociology.

Big data, a field of information technologies and information technologies are among the most important factors of development and economic growth in the global economy. At the same time, the use of information technology is also significant for the competitive advantage of each economy. Innovation is also a key driving factor regarding innovation. However, one of the most significant problems in this area is the inadequate number of employees with appropriate knowledge (Maryska et al. 2012). The presence of high expertise in this field of knowledge increases the need for specialists to serve different roles in different countries and regions. The skills of fundamental information technologies such as programming, development, and testing are more important to developing countries than the stable and developed countries. It is also complicated to estimate the total demand for employment in this area as each country needs IT experts in line with their needs (Maryska et al. 2012).

As of 2017, 120,000 people are working in the field of information and communication technologies in Turkey, and there is no precise information on the educational distribution of these people. As a developing country, Turkey, to ensure employment growth in productivity growth and other business areas, are required to perform specific activities on increasing the knowledge of staff to work in this field while increasing the investment made in this area.

Countries having developed economies have lower tax rates in the field of information and communication than developing countries. Despite such a substantial impact on the economic development, ICT sector's growth is slow down in Turkey due to the tax burden. According to analysis carried out in 125 countries, Turkey is the second after Bangladesh in the tax order applied to information and communication technologies in the world (ITIF 2014).

Therefore, information and communication technology are of great importance for the productivity of the trade made in many areas, especially in the manufacturing sector, and for the market development in exporting. Creating more players in the export field, depending on the digital transformation, will give the opportunity to create positive results as well as raise the level of intra-industry trade, as well as create a strong economy.

In this study, we developed a personalized recommendation engine for internet publishing websites to increase the contents' read count. This recommendation engine is based on machine learning and text mining methodologies. Also, it is applied to http://www.gazetemsi.com.

Methodology

Internet publishing is a business model that keeps up to date with new technologies. In internet publishing, it is possible to create revenue by creating content that is interesting to the reader. Within this type of business model, editors create original content which is then published through websites to reach the reader.

The contents published online usually have components such as a title, a subtitle, various tags, and promotional displays. Internet publishing websites display similar content that users might find interesting. This leads the user to spend more time on the website, causing an increase in the revenue through the ads that are viewed and clicked by the user. Traditionally; editors determine the titles, tags, and texts of contents. Editors also manually select the similar content that is to be displayed on the websites.

In this study, it is aimed to automate the process of manual selection of recommended contents for users. This is done through an information-based recommendation engine that is supported by text mining techniques.

Literature Review

As the use of the internet is increasing, digital media is beginning to replace traditional media, and the data created through digital media is increasing very rapidly. Digital media contain text forms as much as the visual forms of content. Therefore, it is necessary to use text mining techniques to examine texts (Roshani and Ranjit 2015).

Text mining is a way of making sense of the unstructured text. It involves automatic detection and elimination of text that is insignificant or incomprehensible through the use of computers.

Text mining is a novel interdisciplinary field that is closely related to data mining, machine learning, and statistics. The commercial potential of text mining is estimated to be reasonably high, as most information is kept in the form of text (Kanakalakshimi and Chezian 2015). At the same time, currently, the largest source of information for text mining is thought to be the unstructured text data found on the internet (Kanakalakshimi and Chezian 2015). The most prominent issue when examining unstructured text data is performed. Humans can divide and apply linguistic forms into text. However, computers have performance issues in doing similar tasks, as they get less efficient when running complex algorithms on high volumes of data. Lately, the performance issues have improved thanks to technological developments, and it has become possible to use machine learning in summarizing, categorization, clustering, and visualization (Arumugam et al. 2016).

In the past three years, personalized user experience has taken over, as web content site users tend to have different habits of reading within pages and navigating through sites. Hence, the recommendation engines for the solution to this problem has become famous (Isinkaye et al. 2015). The recommendation engines that are not supported by text mining and machine learning methods, usually work by recommending contents that are from the same category. This is a fast method, but it does not meet the needs of news reading habits of today's internet users. Analyses on news reading habits suggest that users prefer to read different news on the same topic, rather than different news under the same category (An 2016).

There are multiple approaches in the literature regarding recommendation engines. The most common approaches are content-based filtering and collaborative filtering. Content-based filtering algorithms work by creating a unique profile for each user, from the first moment they enter the system. The goal of these algorithms is to produce user profiles and then recommend contents based on profiles (Schein and Popescul 2002).

In general, Content-Based Filtering approaches are based on information access and information filtering (Baeza and Ribeiro-Neto 1999). These algorithms take into account text-based documents, websites and news contents. Content-based systems detect levels of interests of active users on different contents (Balabanović and Shoham 1997). User profiles are created and updated according to user evaluation, demographic properties and previous choices of users.

The collaborative filtering method is based on the calculation of a probability for the content that the user has never read, over the content that has been read by a user before. These probabilities depend on the experience of other users in the user's group. The primary input in collaborative filtering algorithms is a matrix, where the rows represent different contents and columns represent different users. At the same time, content-content and user-user matrices are created and based on the values in these matrices, contents that the user might want to read at the next stage has been trying to predict.

Content-based and collaborative methods have certain advantages and disadvantages. The hybrid recommendation systems have been developed to eliminate the disadvantages (Resnick and Varian 1997). The details of hybrid methods will be discussed in the chapter "Approaches and Methods" section.

Users' levels of interest change through time. It is possible that the system's success might decrease over time. For instance, a user's calculated levels of interest might change from a year to another (Jannach 2004). Under these circumstances, information-based recommendation systems generally perform better than other ones. This type of information-based recommendation system is interactive, search-based or navigation-based (Chen and Pu 2010).

While the recommendation systems and content filtering approach work through users' past data, their data can be collected under 'social tags' (Puglisi et al. 2015). In the work which mentioned before (Puglisi et al. 2015), the tags of the content that the users read are also used in the suggestion system. Content tags are highly beneficial in categorization. These data are later used in the creation of the TF-IDF matrix. This issue will be discussed in the next in more detail.

Approaches and Methods

Recommendation engine algorithms are divided into three sub-methods. These are; collaborative filtering, content-based filtering and hybrid filtering (Bard 2007).

As a master plan in the recommendation engine algorithm that is adapted to the system uses a hybrid filtering algorithm supported with machine learning methods. As a backup plan, the system makes use of a content-based filtering algorithm that is supported with text mining methods (Isinkaye et al. 2015). Content-based filtering is used for solving the cold start problem, as well.

The dataset used in this study consists of 8308 Turkish contents. These contents include 11,164 different word roots and are read a total of 9,782,373 times by 5,488,973 users. The test set includes data from 100,000 unique users, 4289 unique contents read by these users and 9350-word roots. The data comes from contents from various categories written in Turkish.

Flow Chart of Recommendation System

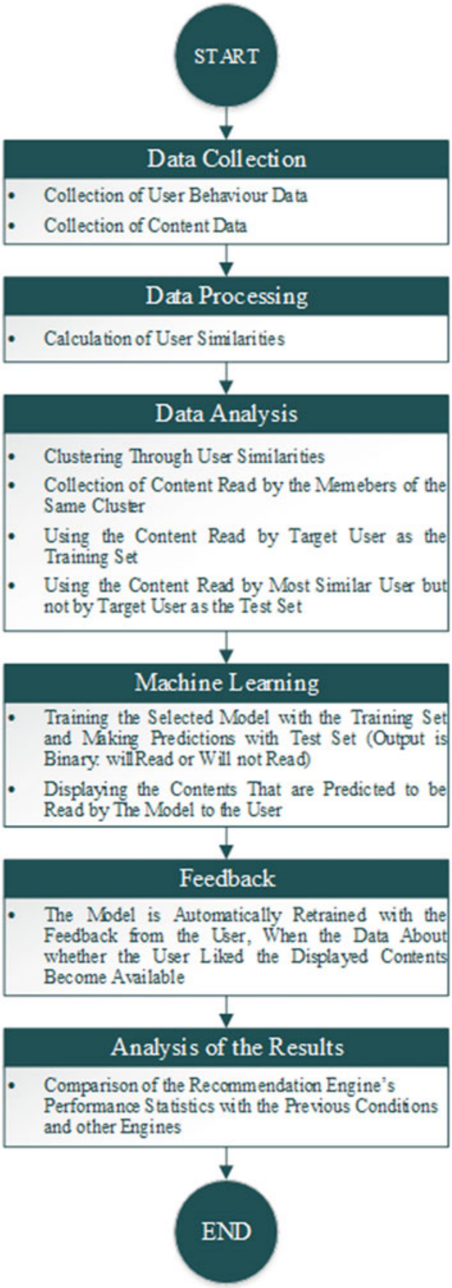
The process starts by loading the content data and records about users' past visits from the database. The commonness of the words from the tags, texts, and titles of the contents are checked to calculate similarities of contents. Here, tags provide the most information about the contents. Thus, they are added to the similarity calculation with the highest weight. Second highest weights are that of titles. Lastly, texts are added to the similarity calculation (Zhang et al. 2009). The similarity calculation is a costly procedure regarding time and memory (An 2016).

Later, users are clustered through the similarities of the contents they read. The clustering process is based on the similarity of the read contents with the method of calculating user similarities, and the clustering algorithms recommended in the literature are used in this method. During clustering, three algorithms found in the literature are tried: K-Means (WagStaff and Cardie 2001), Affinity Propagation (Dueck 2009), and Hierarchical Clustering (Fung et al. 2003) algorithms. The algorithm used in the application is K-Means, as determined by efficiency and performance tests.

After clustering, the similarity for the within-cluster user is recalculated for determining the contents that are to be displayed to the target user. The most similar user to the target user is found. Then the contents read by the most similar user but not the target user are used as the test set, and the contents read only by the target user are used as the training set.

For these contents in the training set, the model gives feedback on whether the target user will read the relevant content or not. For the recommendation, the contents that the model predicts to be read by the target user are selected. Flowchart of this recommendation system can be seen in Fig. 1.

Fig. 1 Flowchart for proposed system



Alternative Flow Chart of Recommendation System

This method consists of a content filtering algorithm (Bard 2007) supported by text mining methods. This method would be tried if the first method did not reach the desired result.

First, the text, title, and tags of the contents are collected and the collected components are divided into small parts based on words. In the separation process, it is a preferred option to divide by spaces. Alternatively, it is also possible to separate first at dots and then at whitespaces.

Later, words are passed through the pruning phase, distinctly for titles, tags, and texts (Xianke et al. 2014). During pruning; propositions, connective words, punctuation marks, and similar potentially unnecessary or harmful components are cleaned. This is because uncleaned components can negatively affect the similarity scores at later stages. However, it is important not to include numerical values in this cleaning procedure. Especially in financial contents, cleaning of numerical values can lead to wrong conclusions in making sense of the content.

In the next stage, the roots of the remaining words are found. This procedure is called 'stemming' and is another important aspect of text mining (Xianke et al. 2014).

After stemming, words are transformed into numerical values and are ready to be used by machine learning steps. In transformation into numerical values, the popular term frequency method is used (Vijayarani et al. 2015). TF-IDF matrices are created from the output of the term frequency method. TF-IDF matrices represent how often a word is seen in a given text. The remaining analyses are done at these TF-IDF matrices.

Next, separate similarity calculations are done for titles, texts, and tags through the TF-IDF matrices created at the previous stage. Cosine Similarity is used for this calculation, as suggested in the literature (WagStaff and Cardie 2001).

As a result, similarity scores are found separately for titles, tags, and texts. Thus, the similarity between the two contents is represented by three values at this stage. Similarities are weighted to represent similarity in a single score. For this process, multi-criteria decision-making methods are used; the weights for between-tag, between-title, and between-text similarities are consecutively 0.7, 0.2, and 0.1. These weights are selected as initiation values based on feedback received by editors. In the alternative flow is chosen, it will be possible to re-determine the weights using multi-criteria decision-making methods.

As a final step, by the similarity values calculated above, content that most closely resembles the content that the target user currently reads is recommended.

Approaches and Methods

Every headline, tag or text has its own specific importance while determining the category of the contents. Therefore, the first step is the separate the contents into its text, headline, and tags. After that operation, it is passed to the preprocessing step text mining.

During the preprocessing stage, the unnecessary components that won't be utilized to determine the category of the text are cleaned from the text. In the following step, the words must be reduced to their roots (Vijayarani et al. 2015). At this point, the Turkish text mining tools Zemberek (Akın and Akın 2007), İTÜ NLP (Yıldırım et al. 2014) and TRMorph (Çöltekin 2010) are tested. The performance values of these tools are presented in Table 1.

For these tests, a list of words with predefined roots has been introduced. Afterward, the roots returning from the tools are compared with the actual roots. Following this comparison, the success rates shown in the table has emerged.

In the light of the results from the table, the best performing tool concerning the localization of the roots for the Turkish test set is Zemberek. Thus, it is decided to continue with Zemberek.

The quantification process is applied to the text which had already been boiled down to its roots. Following that, the key term-document matrix is generated, afterward according to the frequency of the terms found in the text the term frequency-inverse document frequency Matrix (TF-IDF) has been generated. TF-IDF Matrices are constructed separately for each tag, headline, and text (Vijayarani et al. 2015). A section of the TF-IDF is shown in Table 2.

After that, using the TF-IDF matrices' contents, a similarity value is calculated for each tag, headline, and text. The similarity calculation between the contents is made using the Cosine Similarity method (Vijaymeena and Kavitha 2016). Following the calculations, as a result, three tables are generated, and a section of one is shown in Table 3.

On the next step the biggest similarity values for content, tag and headline are accepted.

After that the similarity calculation between the documents, the User-Based Filtering method is given the priority for the text content recommendation process. The soft spot of this method is the Cold Start problem. In the situations where this problem is confronted, the User-Based Filtering method is utilized (Sharma 2012). The recommendation is divided into two parts as User Based Recommendation and Content-Based Recommendation.

Table 1 Performance comparison of the text mining tools for Turkish

Tools	Success rate
Zemberek	0.7908
Tools NLP	0.7883
TRMorph	0.7734

Table 2 TF-IDF matrix section

Content ID	Word root				
	ağır	ajans	aksine	al	alan
10070	4.228	0	0	0	0
10468	0	0	4.459	0	0
10489	0	3.347	0	3.347	3.347
11042	0	0	0	0	0

Table 3 Table generated from the similarity calculations

Content ID	Compared content ID	Similarity
16611	15928	0.64
16491	13039	0.07
17396	17333	0.76
17382	17599	0.98
16464	14771	0

During the Content-Based Recommendation stage, using the Content Based Filtering method during the lecture of the user the content which has the highest-ranking similarity will be suggested. However, to obtain a better result, the similarity values of the content must be collated with the user information. The reason for this is that the recommendations made from the content similarity will mainly propose only the contents that are in the same category. However, users' fields of interest cannot be limited to one category. In the Cold Start problem where the user data is missing this method is utilized.

For the User-Based Content Recommendation stage as a start, the Term Document Matrices obtained from the previous step is used. The first step is the procurement of the Term Document Matrices from the database. The user data retrieved at this stage could be all the data read up to now or could be current data or data that could belong to a specific period.

A new column indicating whether the targeted user has read the recommended content or not has been added to the Term Document Matrix. A section of this matrix till now is given in Table 4.

As a result of the operations stated above, the recommended contents to the targeted users are taken as the basis. The contents that resemble the most of these contents, the Content Similarity Matrix given earlier is utilized to present a personalized content recommended.

Table 4 TF-IDF matrix for target user

Content ID	Word root					Read
	ağır	ajans	aksine	al	alan	
10070	4.228	0	0	0	0	0
10468	0	0	4.459	0	0	1
10489	0	3.347	0	3.347	3.347	0
11042	0	0	0	0	0	0

However, it is thought that the user should be fed by the other contents that are read by the users that are in the same category. In this respect, the User Group Based content recommendation methodology is deemed more suitable. During the development of this methodology the K-Means (WagStaff and Cardie 2001), Affinity Propagation (Dueck 2009) and Hierarchical Clustering (Fung et al. 2003) algorithms, from the Scikit-Learn library of Python programming language, are tested.

The cluster number for the K-Means and Hierarchical algorithms are taken as 3, 5 and 7. The clustering tests are realized on 100,000 users and the information of the concerned users. It is observed from the results that; the best outcome is obtained from the K-Means algorithm with 7 clusters user distribution according to the silhouette coefficient index. Comparison of clustering algorithms' silhouette coefficient index values is shown in Table 5.

Following the clustering operation based on the K-Means 7 Clusters, User Distribution method decisive word analyses are conducted for the contents of every cluster. The analyses show that the contents read from the users belonging to the same category possess some common and specific words in common. These are the keywords that enable us to figure out the category of the content.

After the clustering operation, in every cluster, a similarity calculation is conducted from the common contents that have been read. Finally, for a user that is not a newcomer (target user), the users that are in the same cluster are found and from these users, the users most similar to the target user have been identified. Afterward, for the contents that, these users read but the target user did not, the probability of the target user to read this content is calculated using the predictive methods. The results of the tests are shown in Table 6. These tests are performed by dividing the information into the training and test set after collecting the information that the user has read the recommended contents. In the running system, the same data is used as the training set, while the possible content read by the user is utilized as the test set.

In the course of selecting the most successful methods, methods are tested with small parts of our data set. The tests are done by taking a sample of 100,000 lines randomly from our data set.

Table 5 Comparison of clustering algorithms

Clustering types	Cluster count	Silhouette coefficient index
K-Means	3	0.577679969630
K-Means	5	0.579305490937
K-Means	7	0.599930273821
Hierarchical	3	0.557878372054
Hierarchical	5	0.540790175994
Hierarchical	7	0.517802662342

Table 6 Comparison of the machine learning algorithms

Algorithm	Accuracy
Naive Bayesian	%19.20
Decision Tree	%30.53
Random Forest	%31.78
K Nearest Neighbour	%21.12

In the methodology part, the most accurate methods for each step are used. These are; Zemberek for word stemming, K-Means 7 clustered method for clustering and Random Forest for predictions.

Discussion and Conclusion

With this Personalized Recommendation Engine, it has been tried to obtain economic gain by the advertisements that are displayed in the context of the content which is mostly read according to the increase of the user interaction on a content site. Since 30/09/2017, when the application was released, the readings of the proposed content have been improved to 32% of the level of 12%, yielding an efficiency in this area. This measurement is achieved by dividing the traffic on the site by two groups of 50% and by testing the performance of the related content that the editors specified by their workforce and the related content specified by the application were tested at the same time. Based on the power of machine learning algorithms, it is expected that the reading habits of users will be better analyzed depending on the cumulative amount of data accumulated each day and this efficiency ratio will be increased even more.

As the reading rate of the recommended content reaches 32%, the average number of content read per day is around 26,400. Therefore, an additional 3900 ads are displayed in response to the additional 3900 content read without advertising costs. On this basis, an additional profit of TL 741 per day and an average of TL 22,230 per month is started to be provided. However, this figure varies depending on the number of targeted ads shown each month and the exchange rate.

As a result, a technology product developed specifically for a small-sized company has been brought to a level where economic gain can be achieved and used for export purposes.

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A Customer Satisfaction Study in an Airline Company Centered in Turkey

Omer Faruk Gurcan, Omer Faruk Beyca, Abdullah Fatih Akcan and Selim Zaim

Abstract Airline industry has many challenges: decreasing costs, responding changeable demand, achieving high quality requirements as well trying to maintain superior services and satisfy customer needs. Turkish aviation industry presents a remarkable growth during the recent years. Besides the strategic role of the geographical position of Turkey, when the new airport started to service in İstanbul, Turkey's importance in the world aviation sector will increase further. Customer satisfaction is crucial to increasing the profitability of airline companies as the aviation industry grows. Turkey centered airplane companies have flight more than 120 countries and 300 cities around the world. Previous studies have investigated customers' perception of service quality and the effect of customer satisfaction levels on their future behavior, and various strategies for achieving customer satisfaction and customer loyalty. According to J.D. Power 2017 report, customer satisfaction with airlines has been rising for the past five years. So companies should understand customer satisfaction elements well to sustain their competitive advantage. This study looks at how online, cabin, flight services, and personnel characteristics could affect customer satisfaction of an airplane company centered in Turkey. Data were collected from the more than 1400 passengers, domestic and mainly international flights. Relations in the model is tested with Structural Equation Modelling using IBM SPSS Amos package.

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_31

Keywords Airline industry · Customer satisfaction · Structural equation modelling

Introduction

Aviation is a dynamic industry that continuously experiences a variety of market forces. The next years are likely to be more changeable because of technological changes and innovations in the aviation industry.

International Air Transport Association (IATA) 2017 report explains drivers of change for the aviation industry in 5 categories. Society includes such as urbanization and growth of megacities, global aging, new modes of consumption, shifting ethnic, political and religious identity. Technology includes such as cybersecurity, robotics, and automation, virtual and augmented reality, alternative fuels and energy sources, Internet(s) of Things. The environment is related to emissions and noise pollution, personal carbon quotas, extreme weather events, infectious disease, and pandemics. Some of economy category drivers are strength and volatility of global economy, price of oil, shift to knowledge-based economy, level of integration along air industry supply chain and lastly, politics is related to geopolitical (in)stability, strength of governance, shifting borders, boundaries, and sovereignty, trade protection, and open borders, rise of populist movements etc.

Worldwide traffic increased to 3.7 billion scheduled passengers and departures increased to about 35 million in 2016. Low-cost carriers had an essential role. Average petroleum prices (the largest cost item of airlines) were about €80 per barrel between 2011 and 2014. By the 2016 prices were an average of less than €42 helped increasing profits in the sector. Cheap fuel prices let low-cost carriers to be more competitive with full-service airlines (Url 1).

Year-over-year passenger travel growth for the past five years has averaged 6.2%. There has been significant airport investment in most regions of the world. For example, between now and the end of 2021, nearly $1 trillion will be invested in new and existing airports worldwide. Air travel has proven to be a resilient market, and robust growth is expected to continue in the future (Boing Report).

According to the International Civil Aviation Organization's Civil Aviation Statistics, more than 3.6 billion passengers were carried in 2016 in the world. From 1970 to 2016, numbers of passenger carried in the world is given in Fig. 1. IATA expects 7.8 billion passengers to travel in 2036.

Turkish aviation industry continues to grow and develop parallel with increasing infrastructure and fleet investments which offer more affordable ticket prices. Turkish aviation industry has grown by 13.7% annually and passenger penetration in the market has almost tripled in the period of 2013–2014 During the same period, the global aviation industry was grown 5.7% annually (Url 2). Total passenger traffic was about 174,153,146 in 2016 and 193,318,708 in 2017. Commercial aircraft traffic was 1,234,635 in 2016 and 1,290,549 in 2017 (Url 3). Flying population

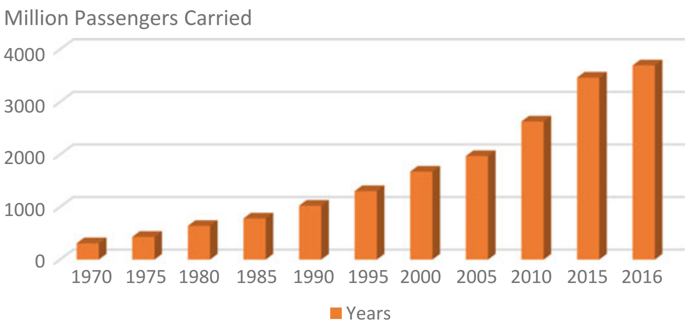


Fig. 1 Number of passenger carried in the world (International Civil Aviation Organization, Civil Aviation Statistics of the World and ICAO staff estimates)

Fig. 2 Monthly passenger traffic of Turkey (DHMI statistics)

change is estimated at 21% from 2014 to 2034. Monthly passenger traffic of 2017 is given in Fig. 2.

One of the World's most important airport construction projects is coming to life in Istanbul. New İstanbul Airport, after completion, will have an anticipated capacity for up to six runways serving 150 million passengers with extendable capacity up to 200 million. 150 airlines will operate from the airport, serving more than 350 international destinations. With the superior geographical location of Turkey and the added traffic that the new airport will bring to the region, it is obvious that Istanbul will be the most important international aviation (Turkish Airlines Annual Report 2014). Today leader airline company of Turkey has flights to more than 120 countries and 300 cities. IATA expects Turkey will enter the top ten world's largest aviation market (defined as traffic to, from and within the country) in 2036.

Customer Satisfaction in Aviation Industry and Hypothesis Development

Customer satisfaction is one of the mostly studied fields in marketing. It has become a baseline standard of performance (Hussain et al. 2015). Offering a high level of service quality became a marketing necessity for airline companies in the early 1990s. Service quality directly affects customer satisfaction. Customer satisfaction helps to companies to retain their customers so it is an essential element in marketing (David Mc A 2013).

Defining and analyzing relevant factors to increase customer satisfaction in the aviation industry which is strongly service-oriented industry, needs specific knowledge of its key antecedents from the customers' points of view (Ringle et al. 2011). Service quality can be defined as the gap between a customer's expectations about the service that he/she has perceived and actually received (Hapsari et al. 2016). In the literature, there is little research concerning customer satisfaction and the variables that affect it in the airline industry of Turkey.

Airline companies offer customers a variety of flights and destinations. Besides a number of destinations reachable with direct flights, the frequency of flights is the determinative factor. Flights are a competition parameter for airlines to maintain their market shares on specific routes or airports (Strobach 2008).

Determining sufficient frequencies of flights is a very important step for airplane companies. Flight frequency and departure times one of the most important variables that affect customers' decisions on choosing airplane company when there are several companies have flights to the same routes (Teodorovic 2017).

Chow (2014) investigated the on-time performance of scheduled flights on customer satisfaction by using a panel data set which is covering twelve large and small carriers. Curtis et al. (2012) investigated flight frequency issues and the differences between frequent and non-frequent passengers' levels of satisfaction and the importance attributed to overall airline service quality. The results indicate that the level of importance attributed to airline amenities increased with flight frequency. Milioti et al. (2015) frequent flyer program and schedule's effect on passenger decisions regarding airline choice. Basfirinci and Mitra (2015) analyzed frequent flight schedule importance in the study of airlines service quality through the integration of Servqual and the Kano model. Nagar (2013) observed flight schedule factors in the research among Indian passengers. Yang et al. (2012) investigated the flight schedule's effect on the intentions of passengers regarding low cost carriers.

In this study, questionnaire items of flight services are related to convenience of flight schedules, frequencies of flights and a sufficient number of non-stop flights. According to studies in the literature, the following hypothesis is formed:

H1 There is a positive relation between flight services offered by airline company and customer satisfaction

Some studies argue that personal is the key factor in customer satisfaction in the airline industry. Airline companies' personnel should understand and identify the passengers' needs/requests to increase their satisfaction in services (Koklic et al. 2017). Customer satisfaction is strongly affected by the interaction between customers and personal, examining employee behavior is important (David Mc A 2013). Suhartanto and Noor (2012) examined customer satisfaction in full-service and low-cost airlines. According to results, satisfaction with full-service and low-cost airline companies is strongly related to personal behavior, the accuracy of service, and price. Farooq et al. (2018) found personnel service (their attitude and behavior towards customer service, the responsiveness of aircraft crew members, helping attitude) have a positive on customer satisfaction in Malaysia Airlines. Koklic et al. (2017) found that personnel quality positively affects customer satisfaction with low-cost and full-service airline companies. Basfirinci and Mitra (2015) competent service staff in answering customer questions in the study of airlines service quality through the integration of Servqual and the Kano model. Milioti et al. (2015) friendly-helpful staff effect on passenger decisions regarding airline choice. Campbell and Vigar-Ellis (2013) investigated the efficiency of employees in the study with the South African domestic airline industry.

In this study, questionnaire items of personnel are related to behavior reliability of staff, the degree of kindness and friendship of staff, knowledge level and language skills of stuff. According to studies in the literature, the following hypothesis is formed:

H2 There is a positive relation between personnel properties of the airline company and customer satisfaction

Customers do not choose an airline just looking for the price. Some customers prefer their airplane company because of the comfort of the seats, interior design, the quality of in-flight food served, high standards of service above all else etc. (Messner 2016). Cabins are one of the most important parts of airline tangibles. Cabin tangibles such as cleanliness of interior cabins, quality of the catering and food, air-conditioning, design and comfort of seats, inflight entertainment facilities etc. affect passenger satisfaction (Suki 2014). Nadiri et al. (2008) found that the airline tangibles as the most significant factor affecting customer satisfaction. Farooq et al. (2018) also found airline tangibles have a positive on customer satisfaction in Malaysia Airlines. Hussain et al. (2015) identified tangibles as one of the most salient factors that describe airline service quality. Conde Nast and Frequent Flyer organization identified ten factors for overall airline satisfaction: on-time performance, schedule/flight accommodations, airport check-in, gate location, seating comfort, aircraft interior, flight attendants, food service, post-flight services, and frequent flyer programs (Curtis et al. 2012). Analyzing data collected from 3996 airline passengers, Messner (2016) found that perceptions of food quality are primarily affected by the quality of cabin staff service, followed by entertainment and seat quality. Milioti et al. (2015) investigated in-flight entertainment's effect on passenger decisions regarding airline choice. Archana and Subha (2012) found that personal entertainment is the most important dimension as perceived by airline passengers in inflight digital service quality. Liou et al. (2011) examined cabin service criteria and variety of newspapers and magazines in the study of improving service quality among domestic airlines in Taiwan.

In this study, questionnaire items of cabins are related to choices of catering and taste of food, in-flight entertainment, in-flight newspapers and magazines, on-board phone services and blanket and pillow services. According to studies in the literature, the following hypothesis is formed:

H3 There is a positive relation between cabin services offered by airline company and customer satisfaction

Internet environments can be evaluated from a variety of aspects such as usability, content, visibility. Especially, website usability is an important factor for firms which use marketing functions on websites commonly. Today, all firms have web sites and it is expected that these websites be suitable for marketing functions, effectively meet the customer expectations and constitute a positive attitude for the firm or the brand (Aktaş and Mutlu 2015). The airline industry's dependency on information and communication technology has increased since many of airline functions rely on them. One of the most popular functions for attracting more customers is to sell low-fare air tickets and ease boarding processes, such as e-ticketing and online check-in through companies' website (Elkhani et al. 2014). Elkhani et al. (2014) evaluated the effectiveness of airlines' websites from online customers who carry out e-ticketing via an airline website.

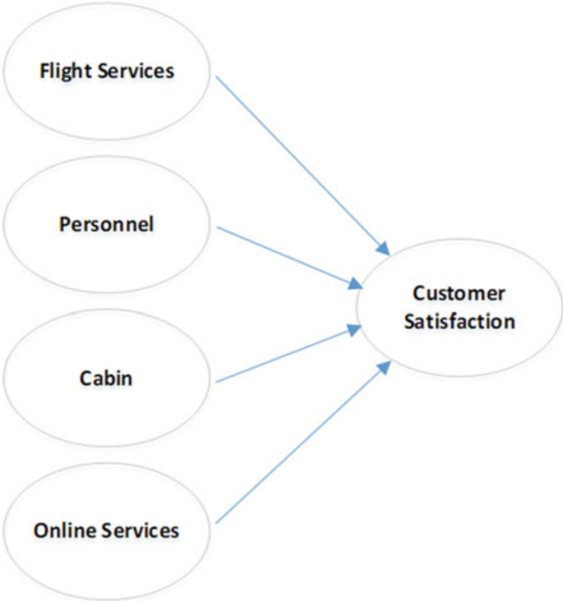
In this study, questionnaire items of cabins are related to usability of the website, contents of website and easiness of online check process. Following the hypothesis is formed:

H4 There is a positive relation between online services offered by airline company and customer satisfaction

The current research proposes a conceptual model showed in Fig. 3. The underlying premise is that customer satisfaction in the airline industry is positively influenced by flight services, personnel properties, cabin, and online services.

Previous studies compared airline types (low-cost and full-service) in terms of various variables which have varying degrees of influence on customer satisfaction such as airline tangibles, quality of services offered by personnel, price etc. (Koklic et al. 2017). Ringle et al. (2011) studied the travel purpose moderating effect between perceived safety and customer satisfaction. According to their study, safety's effect on the customer satisfaction is significantly different between passengers traveling for business rather than pleasure. In this study, Flight class's (business-economy) moderating effect is tested.

Fig. 3 Conceptual model



Sample and Data Collection

Survey data was collected from more than 1400 passengers who were chosen randomly from 71 flights to Western Europe, Eastern Europe, Africa, Middle East, Far East, and North America countries. According to the demographic data, 66.1% of participants are male, 33.9% of them are female. 43.6% of participants are Turkish and 56.4% of them are from other nationalities. The majority of respondents have undergraduate and higher degree (70.2%), 22.9% of them graduated from high school and 6.8% of them have primary education. 53.2% of participants fly less than once in a month, 21.4% of them fly once in a month and 25.3% of them fly more than once in a month. The majority of respondents flies for of business purpose (56%), 31% of them for vocation and 13% of them for another purpose. 21.3% of participants usually prefer business class and 78.7% of them usually prefer economy class.

Analysis and Results

Firstly, Exploratory Factor Analysis (EFA) with varimax rotation was performed on questionnaire items to define the dimensions of the construct. 4 factors were obtained and these factors were named as flights, personnel, cabin, and online services. The results of the EFA is given in Table 1. The standardized regression weights for all variables constituting each dimension were also found to be significant ($p < 0.001$), giving support to the convergent validity of the constructs, as shown in Table 1. The EFA showed a good fit. The χ^2 statistic was 286.568 (degrees of freedom = 82, $p < 0.05$), with the χ^2/df ratio having a value of 3.495. The goodness of fit index (GFI) was 0.973 and adjusted goodness of fit (AGFI) index was 0.961. The Comparative Fit Index (CFI) was 0.975, Tucker-Lewis coefficient (TLI) was 0.968. All indices are close to a value of 1.0 indicating that the measurement models provide good support for the factor structure determined through the EFA. The model parameters were estimated using the method of maximum likelihood.

Confirmatory Factor Analyses (CFA) were employed to confirm the reliability and validity of the measures before examining the structural relationship between constructs. This study used maximum likelihood for the estimation method as it provides a consistent approach to parameter estimation problems that can be developed for a large variety of estimation situations. First and second order CFA was tested using online services, cabin, personnel, flight services dimensions, and customer satisfaction variable. Table 2 summarizes standardized regression weights and Reliability Statistics. The second order CFA showed a good fit. The χ^2 statistic was 284.404 (degrees of freedom = 83, $p < 0.05$), with the χ^2/df ratio having a value of 3.427. GFI was 0.974 and AGFI index was 0.963. CFI was 0.975, TLI was 0.969. All indices are close to a value of 1.0 in CFA. Therefore, it can be said that each model showed a good fit when considered with related factors. The model parameters were calculated with the maximum likelihood method. For each variable, most of the indices are at an acceptable level. In addition, the significance

Table 1 EFA results

Factor	Sub-factors	Std. regression weights
Flights	A25: flight schedules	0.732
	A26: frequencies of flights	0.808
	A27: non-stop flights	0.674
Personnel	A1: reliability	0.718
	A2: politeness and friendly behavior	0.684
	A3: knowledge level	0.815
	A4: language skills	0.682
Cabin	A6: catering and food	0.541
	A7: in-flight entertainment	0.651
	A8: newspaper and magazines	0.642
	A9: on-board phone services	0.505
	A10: blanket and pillow services	0.598
Online services	A12: website usability	0.883
	A13: the content of the website	0.940
	A14: online check-in	0.602

Table 2 CFA results

Factor	Sub-factors	Std. regression weights
Flights (C. alpha = 0.777)	A25: flight schedules	0.735
	A26: frequencies of flights	0.807
	A27: non-stop flights	0.672
Personnel (C. alpha = 0.827)	A1: reliability	0.716
	A2: politeness and friendly behavior	0.683
	A3: knowledge level	0.818
	A4: language skills	0.683
Cabin (C. alpha = 0.722)	A6: catering and food	0.563
	A7: in-flight entertainment	0.649
	A8: newspaper and magazines	0.639
	A9: on-board phone services	0.535
	A10: blanket and pillow services	0.588
Online services (C. alpha = 0.841)	A12: website usability	0.883
	A13: the content of the website	0.941
	A14: online check-in	0.602

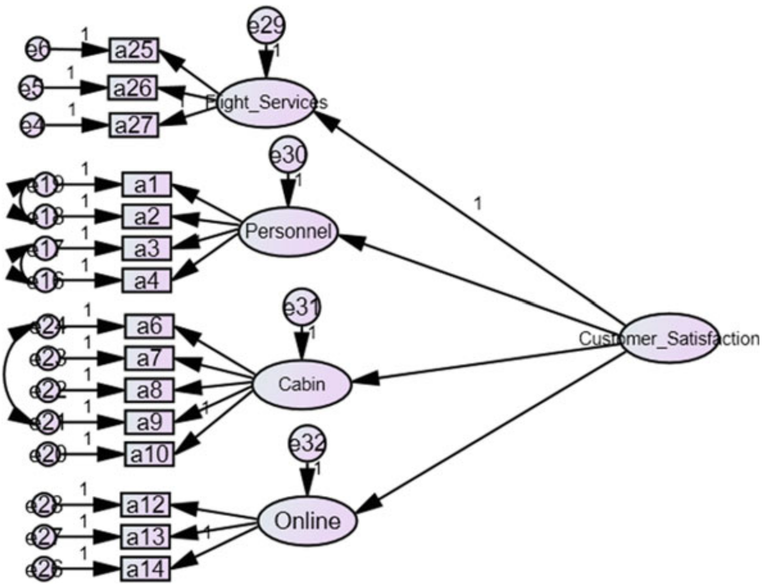


Fig. 4 Path model

Table 3 Results of path analysis

Hypothesis	Path		Estimate	*p*
H1	Flight services	C.S	0.725	0.00
H2	Personnel	C.S	0.661	0.00
H3	Cabin	C.S	0.898	0.00
H4	Online services	C.S	0.580	0.00

Table 4 Multi-group analysis

	Business class		Economy class		*z*-score
	Estimate	*p*	Estimate	*p*	
Personnel < customer satisfaction	0.614	0.00	0.913	0.00	2.343**
Cabin < customer satisfaction	1.052	0.00	1.137	0.00	0.460
Online services < customer satisfaction	0.708	0.00	0.739	0.00	0.250
Flight services < customer satisfaction	0.685	0.00	0.693	0.00	0.225

** means p_value < 0.001

levels of the factor loadings that belong to each component are investigated and, consequently, each of them is found to be statistically significant.

The effects of online services, cabin, personnel, flight services on customer satisfaction and the moderating effect of flight class were examined by using a covariance based SEM method. The standardized regression weights of path analysis and path model are given in Fig. 4 and Table 3. According to path analysis results, customer satisfaction is mostly affected by cabin services and it is followed by flight services, personnel, and online services respectively.

Moderating effect is tested with multi-group analysis. Flight class's moderating effect is tested. Table 4 shows the results. According to results, flight class (business-economy) has a moderating effect on the relation between personnel and customer satisfaction.

Conclusion

High competitives in the aviation sector makes the companies deliver high quality, distinct and differentiated services to passengers for the companies' profitability and sustained growth. Companies should understand what passengers expect from their services. Increase in levels of customer satisfaction enables consumer retention (Suki 2014). Researchers have paid much attention to understanding service quality related to customer satisfaction and loyalty (Koklic et al. 2017). When determining a preferred airline, prioritizing the expectations of airline customers is crucial. Misunderstanding of these expectations can reason serious problems in airlines' strategic decisions (Kurtulmuşoğlu et al. 2016).

This paper contributes to the understanding of customer satisfaction and its antecedents in the context of the airline industry. This contribution should be seen in the light of certain limitations. Despite the good fit of the customer satisfaction model identified in this research, the data collected concerned just one airline, raising questions about the generalizability of the results. Thus further research, including whether customer satisfaction plays either a mediating or a moderating role between an independent variable (e.g., service quality) and a dependent variable (e.g., brand loyalty) would be expedient. Some other variables can be added to the current model. Differentiating characteristics between the low-cost and full-service airline companies can be examined.

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Usability Measurement of Mobile Applications with System Usability Scale (SUS)

Aycan Kaya, Reha Ozturk and Cigdem Altin Gumussoy

Abstract The mobile application market is expanding with the diversity in mobile devices, and competition among the mobile application developers becomes fierce. Usability of the mobile applications is crucial to gain a competitive advantage under these circumstances. This study aims to reveal the difference in terms of usability of four of the commonly used mobile applications (WhatsApp, Facebook, YouTube, and Mail). Furthermore, this study investigates the difference in terms of usability between iOS and Android operating systems. To measure the usability of the mobile applications, a System Usability Scale (SUS) with an adjective rating scale is applied to the young 222 participants, using the applications on their mobile phones. The result of the study shows that usability of all applications is satisfactory and above the standards. The comparison of mobile applications with each other shows that, WhatsApp has the highest usability score, whereas Facebook has the lowest one. In addition, according to the results, there is no significant difference between operating systems in terms of the usability of mobile applications.

Keywords Usability · Mobile application · System usability scale (SUS) Operating system

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_32

Introduction

In the recent years, the mobile devices like smartphones and tablets are getting more and more popular. As of 2015, around 1.86 billion people use smartphones (Url 1), and approximately 1 billion people use tablet computers (Url 2). With the increasing rate of mobile device usage, mobile applications gain popularity. The leading mobile application market expands at an enormous rate. There were 2.2 million applications on Google Play Store and 2 million applications on the Apple App Store in July 2016 (Url 3). Although there are many mobile applications on Google Play and iStore, some of them have not been adopted by the people, and some of the adopters quit using the application due to its complex, inconsistent and difficult to use features. Therefore, usability is one of the most critical quality factors affecting the intention to use a system as well as the continued usage of mobile applications.

Usability is defined by ISO 9241-11 as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 1998). A usable system should be learnable, efficient and memorable. It should also satisfy the expectations and needs of the users with its physical and technical features. Companies that are aware of the importance of the usability try to design and develop more usable mobile applications. System Usability Scale (SUS) with an adjective scale rating is one of the most popular and easy to use the questionnaire to measure the usability level of any product. In the current study, we aim to explore the usability level differences in the most popular mobile applications such as Facebook, YouTube, WhatsApp, and Mail.

In addition, this study aims to reveal the difference in terms of mobile application usability between Android and iOS operating systems. iOS is a closed source operating system for mobile devices that are manufactured by Apple, Inc. Since no other device uses iOS, it is highly compatible with the Apple mobile phones and tablets. On the other hand, Android can be used in many models of mobile phones. It is an open source operating system for mobile phones. Since Android is used on different types of mobile phones, the integrity of the Android system for various mobile phones might not be at the same levels for every model.

This study is organised as follows: A review of the literature is presented in Section "Literature Review". The research methodology is discussed in Section "Methodology", and results are shown in Section "Results". In the last section, the results are discussed, and possible future studies are given.

Literature Review

There are three types of usability evaluation methodologies for mobile applications: laboratory experiments, field studies and hands-on measurement (Nayebi et al. 2012). In laboratory experiments, participants in a controlled lab environment, perform specific tasks related to mobile applications. The main idea is to control the environment that the users are conducting their tasks. It is useful because the participants perform all the tasks for the measurement of usability without any distractions. On the other hand, the main problem of laboratory experiments is that the real world conditions may be different from lab environments and the actual usability of the mobile applications may not be measured. In the literature, there are several studies using laboratory experiments (Biel et al. 2010; Masood and Thigambaram 2015) to measure the usability of different type of mobile applications. In field studies (Hoehle and Venkatesh 2015; Hoehle et al. 2016), the questionnaires are applied to ask the mobile application users about their experience. Field studies are not always the best evaluation method to test the user interface of mobile applications, because they are more time consuming than the lab test and need more preparation, pre-test and pilot applications (Kaikkonen et al. 2005). In hands-on measurements, to evaluate the usability, defined specifications of mobile applications are measured directly (Nayebi et al. 2012). The method of usability evaluation should be chosen carefully concerning the nature of the application and evaluation.

The features of mobile devices such as such, as small screen size, mobile context, connectivity, different display resolutions, limited processing capability and power, restrictive data entry methods etc. (Jacko 2011; Zhang and Adipat 2005) different from other computer systems influence the usability of mobile applications. In addition, the operating system for mobile devices may affect the usability of mobile applications. Kortum and Sorber (2015) use SUS to measure the usability of top ten mobile applications on iOS and Android platforms for smartphones and tablets. The results of their study show that mobile applications on the iOS platform are more user friendlier than Android-based applications.

Google's Android and Apple's iOS have their own user interface guidelines that developers must follow to release their mobile applications on Apple and Google store. In addition to these guidelines, in the literature, there are several mobile application usability guideline developed by researchers based on these type of user interface guidelines. Hoehle and Venkatesh (2015) develop 19 first-order constructs such as instant start, effort minimisation, concise language and 6-second-order constructs such as application design, user interface graphics etc. for mobile applications such as based on Apple general user guidelines. They validate their conceptualisation by applying survey to U.S. consumer using social media applications. The results of the study show that application design, application utility, and user interface graphics are the more important predictors of mobile application loyalty and continued intention to use. Hoehle et al. (2016) develop ten usability constructs for mobile applications such as aesthetic graphics, colour, fingertip-size controls and gestalt based on Microsoft mobile usability guidelines. They validate their constructs by applying a survey to German consumers using social media applications like Facebook, Twitter on their mobile phones. The results of the study show that gestalt, fingertip-size controls, and subtle animation are the most significant factors of continued intention to use. In addition, gestalt, fingertip-size controls, and control obviousness are essential factors of brand loyalty.

In the literature review, there is no similar study conducted in Turkey measuring mobile application usability. Therefore, this study aims to estimate the usability of popular mobile applications used by Turkish consumers and reveal the usability related problems by using SUS survey adapted with an adjective rating scale. The results of the study may help mobile application developers to design more user-friendly products.

Methodology

The methodology of this study consists of three steps. First, a questionnaire including SUS items added with an adjective rating scale is applied to Turkish participants using Facebook, YouTube, Mail and WhatsApp application on their mobile phones. Second, average SUS scores and adjective rating scales are calculated for each mobile application and operating systems. Third, statistical analysis is applied to find out if there is any significant difference between the mobile applications and operating systems in terms of usability. In addition, the correlation between SUS scores and adjective rating scales are calculated.

SUS (System Usability Scale)

John Brooke developed SUS in 1996. It contains ten basic and simple questions about the usability of a system. SUS is a useful tool to understand the problems of users facing while they are using the system.

The items in the SUS are (Brooke 1996):

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.

9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

SUS stands out with its wide range of usage area, simplicity, and quickness of use for both the practitioners and participants (Bangor et al. 2008). SUS provides a general overview of the usability of a product with the help of its understandable score calculation. Although it is a 100-point scale, it does not give an absolute judgment of the usability of a product. To deal with this situation, a seven-point adjective-anchored Likert scale is added as the eleventh question (Bangor et al. 2009). The question is: "Overall, I would rate the user-friendliness of this product as:" and the answer to this question ranges from "1: Worst imaginable" to "7: Best imaginable". The adjective rating scale could help to find an absolute judgement from the SUS questionnaire (Bangor et al. 2009).

To apply the modified SUS questionnaire, we choose most commonly used mobile applications. WhatsApp is a messaging application that enables sending text messages, pictures and videos to individuals or groups of people. It is #1 on the list "Top Free Applications" on App Store and Google Play Store (Url 5, Url 6). Facebook is a social media platform that people share their thoughts, photos, videos and news about themselves. It is #5 on the list "Top Free Applications" on the App Store and #3 on Google Play Store (Url 5, Url 6). YouTube is the biggest online video-sharing platform on the World Wide Web. It is #3 on the list "Top Free Applications" on App Store (Url 5). Both iOS and Android have a default e-mail application. For iOS, its name is Mail, and for Android, it is E-Mail.

Calculating Average SUS Scores and Adjective Rating Scales

The participants answer the questions of SUS with a scale between 1 (Strongly disagree) and 5 (Strongly agree). However, the outcome of these answers is evaluated in the range of 0–4 according to Brooke's scoring.

As can be seen in the SUS, the odd-numbered questions have positive meanings, and the even numbered questions have negative meanings. The scoring of positive questions is done as follows: The user's score is reduced by one point. For example, if the user's score is 4 for the question 5, then the outcome score will be 3. The scoring of negative questions is done as follows: The user's score is subtracted from 5. For example, if the user's score is 3 for the question 4, then the new score will be 2. After all the scores are determined, the sum of the scores is multiplied by 2.5 to make the range between 0 and 100. For each mobile application on Android and iOS, average SUS scores and adjective rating scales are calculated.

Statistical Analysis

To find out if there is any significant difference between mobile applications and operating systems in terms of usability, general linear model (GLM) univariate analysis is applied by using the SPSS program. GLM univariate analysis is applied to reveal the effect of multiple independent factors or variables on the means of various groupings of one dependent variable (Ho 2006). In addition, applying post hoc tests after an overall F test shows if there is any difference between specific means (Ho 2006). Furthermore, the correlation between SUS scores and adjective rating scales are calculated to show SUS adapted with an adjective rating scale gives meaningful results.

Results

The questionnaire is conducted with 222 Turkish participants in 2017. The participants evaluate the applications YouTube, Mail, Facebook, and WhatsApp in terms of usability based on their experience. Furthermore, participants who use more than one of these applications complete the survey for each application they use. Because of this, the number of surveys collected is 643. Demographic characteristics of the participants are shown in Table 1.

The average SUS scores and adjective rating scales of the mobile application for iOS and Android operating systems are calculated as shown in Table 2. The mean of average SUS scores for the four applications for iOS is 79.41 (ranging from 71.39 to 88.53), and the mean of average adjective scale scores is 5.21 (ranging from 4.73 to 5.89). The mean of average SUS scores for the four applications for Android is 81.2 (ranging from 75 to 86.1), and the mean of average adjective scale scores is 5.18 (ranging from 4.73 to 5.72). These results show that while compared the average SUS scores, Android has slightly better usability than iOS. On the other hand, according to the adjective rating scale, iOS has a better performance than

Table 1 Demographic characteristics of the participants

Gender (%)	Female Male	33.7 66.3
Age	Max Min Mean	46 18 22.85
Operating system usage (%)	Android iOS	42.7 57.3
Application usage (%)	YouTube Mail Facebook WhatsApp	91.4 86 81.9 95.5

Table 2 Average SUS scores and adjective rating scales of the mobile apps

	SUS			Adjective rating scale		
	iOS	Android	Average	iOS	Android	Average
WhatsApp	88.53	86.1	87.32	5.89	5.72	5.81
Facebook	71.39	75	73.19	4.73	4.73	4.73
Mail	74.72	78.7	76.72	4.78	4.88	4.82
YouTube	83.00	85.03	84.02	5.43	5.39	5.41
Average	79.41	81.2	80.63	5.21	5.18	5.23

Android. Average SUS scores of each application for iOS and Android are higher than 70, and they are all acceptable in terms of usability (Bangor et al. 2009).

According to the average SUS scores and an adjective rating scale, for both operating systems, Facebook has the lowest scores, and WhatsApp has the highest scores compared with the other applications. Although these average values roughly indicate the usability of the applications and operating systems, the further statistical analysis is needed to get more understanding. Therefore, GLM univariate analysis is applied to show if there is any difference between the applications and operating systems in terms of usability.

According to Levene's test results, error variances of SUS scores of operating systems are homogenous ($\alpha = 0.971 > 0.05$). Since the homogeneity assumption is met, Tukey test is applied for post hoc test. The results show that operating systems have no significant effect on SUS scores and there is no difference between iOS and Android operating system in terms of usability (mean difference = −1.649, std. error = 1.349, $\alpha = 0.222 > 0.05$). Furthermore, the same tests are applied by taking into consideration average adjective rating scales of operating systems and mobile applications. Error variances of adjective rating scores of operating systems are homogenous ($\alpha = 0.725 > 0.05$) according to Levene's test results. Operating systems have no significant effect on adjective rating scores, and there is no difference between iOS and Android operating system in terms of usability (mean difference = 0.037, std. error = 0.081, $\alpha = 0.649 > 0.05$).

According to Levene's test results, error variances of SUS scores of mobile applications are not homogenous ($\alpha = 0.000 < 0.05$). Due to inhomogeneous variances of mobile applications, Dunnett test is applied for post hoc tests. The results of the Dunnett test are shown in Table 3. The results of the Dunnett test

Table 3 Post hoc test results of mobile applications in terms of SUS scores

(I)	(J)	Mean difference (I−J)	Std. error	Sig.
YouTube	WhatsApp	−3.7134	1.52134	0.087
	Mail	7.5149	1.68893	0.000
	Facebook	10.9442	1.80224	0.000
WhatsApp	Mail	11.2282	1.83604	0.000
	Facebook	14.6576	1.94077	0.000
Mail	Facebook	3.4293	2.07476	0.465

Table 4 Post hoc test results of mobile applications in terms of adjective rating scores

(I)	(J)	Mean difference (I−J)	Std. error	Sig.
YouTube	WhatsApp	−0.4133	0.08410	0.000
	Mail	0.5930	0.09912	0.000
	Facebook	0.6806	0.10531	0.000
WhatsApp	Mail	1.0063	0.10337	0.000
	Facebook	1.0940	0.10931	0.000
Mail	Facebook	0.0876	0.12125	0.978

show that there is no difference between the average SUS scores of YouTube and WhatsApp ($\alpha = 0.087 > 0.05$) and Mail and Facebook ($\alpha = 0.465 > 0.05$). In other words, the usability of YouTube and WhatsApp is at the same level and better than the usability of Mail and Facebook by taking into consideration their average SUS scores. In addition, the same steps are followed, taking into consideration adjective rating scales. Error variances of adjective rating scores of mobile applications are not homogenous ($\alpha = 0.000 < 0.05$) according to Levene's test results. Due to inhomogeneous variances of mobile applications, Dunnett test is applied for post hoc tests. The results of the Dunnett test are shown in Table 4. The results of the Dunnett test show that there is no difference between the average adjective rating scores of Mail and Facebook ($\alpha = 0.978 > 0.05$). On the contrary, the results based on SUS scores, YouTube and WhatsApp have a different usability level ($\alpha = 0.000 < 0.05$) in terms of adjective rating scores. While comparing their average adjective rating scales, WhatsApp is better than the other applications. In addition, YouTube has better usability than Facebook and Mail.

We also made an item-based evaluation by using GLM univariate analysis. First, if there is any difference between the IOS and Android is checked, and the results show that these two operating systems are different in only two questions "S5—I found the various functions in this system were well integrated" ($\alpha_1 = 0.018 < 0.05$) and "S9—I felt very confident using the system" ($\alpha_2 = 0.044 < 0.05$). While comparing their average scores for S5 and S9, Android is more confident and well integrated than iOS. For all questions, there is no effect of the operating system on the usability of mobile applications. For example, there is no difference between the usability of YouTube working on iOS or Android.

Furthermore, the same kind of analysis is conducted to make an item based evaluation of the usability of mobile applications. For "S1—I think that I would like to use this system frequently", WhatsApp is better than the other applications, Facebook is the worst. There is no difference between Mail and YouTube ($\alpha = 0.32 > 0.05$). For "S2—I found the system unnecessarily complex." Facebook and Mail are unnecessarily complex than WhatsApp and YouTube. There is no difference between Facebook and Mail ($\alpha = 0.96 > 0.05$) and YouTube and WhatsApp ($\alpha = 0.96 > 0.05$). For "S3—I thought the system was easy to use." WhatsApp is more easy to use than the other applications; YouTube is better than Facebook and Mail. Facebook and Mail are at the same level in terms of easiness

($\alpha = 0.99 > 0.05$). For "S4—I think that I would need the support of a technical person to be able to use this system", for all applications, there is no need for additional support. For "S5—I found the various functions in this system were well integrated." WhatsApp is the most integrated application. Mail and Facebook are not well integrated like the others, and there is no difference between them ($\alpha = 0.99 > 0.05$). For "S6—I thought there was too much inconsistency in this system." WhatsApp and YouTube are more consistent than Mail and Facebook. There is no difference between WhatsApp and YouTube ($\alpha = 0.073 > 0.05$), and Facebook and Mail ($\alpha = 0.569 > 0.05$). For "S7—I would imagine that most people would learn to use this system very quickly." WhatsApp is easier to learn, Mail and Facebook are more difficult to learn ($\alpha = 0.575 > 0.05$). For "S8—I found the system very cumbersome to use." all applications are not cumbersome to use. For "S9—I felt very confident using the system." Facebook is less confident, and there is no difference between WhatsApp, YouTube, and Mail. For "S10—I needed to learn a lot of things before I could get going with this system." there is no difference between the application, there is no need to learn many things to use these mobile applications.

Discussion and Conclusion

In this study, we determined usability scores of the four most used mobile applications Facebook, WhatsApp, YouTube, and Mail by using SUS adapted with an adjective rating scale. The applications used in this study are highly popular among people. Therefore, it is not a surprising result that the SUS scores of these applications are acceptable (over 70). In addition, their average SUS score is relatively high (80.63). While comparing the usability of mobile applications with each other, the results show that WhatsApp has the highest usability scores because of its easier to use, less complicated and well-integrated structure. On the other hand, Facebook has the lowest usability scores due to its complex structure and privacy concerns of the users. In addition, the usability of YouTube is less than WhatsApp but better than Mail and Facebook. The result showing that YouTube is better than Facebook in terms of usability is consistent with the study of Kortum and Sorber (2015). In addition, the results related to the usability of Facebook are consistent with the studies in the literature (Hart et al. 2008). The results of the study also correlate with the rankings on the lists "Top Free Applications" on the Apple Store and Google Play Store.

The results show that privacy is an essential aspect of usability and users find Facebook less confident than the other applications. To reduce the privacy concerns of users, Facebook should strengthen their security system against cyber-attacks and guide their users to improve their security against profile hacks. In addition, they should review their privacy and data use policy. Privacy is not just an important issue that Facebook should deal with all mobile application developers should be sensitive to privacy issues if they want to increase the brand loyalty of their users. Furthermore, the results show that all mobile applications are easy to learn, and there is no need for additional support to use these applications. Mobile application developers should also give importance to the complexity, consistency and integration issues, which are also important, issues affecting the usability of mobile applications.

The other aim of this study is to investigate the effect of operating systems on the usability of mobile applications, and the results show that there is no significant difference between the usability scores of mobile applications working on iOS and Android systems. This result is not consistent with the study of Kortum and Sorber (2015) which show that mobile applications on the iOS platform are more user-friendly than Android-based applications. This inconsistency should be raised from the use of different number and type of mobile applications. They conducted their study by using more applications with more participation compared with our study.

In addition, a correlation analysis is conducted to reveal how well SUS scores match with the adjective rating scales. SUS scores correlate well with adjective rating scales ($r = 0.674$, $\alpha < 0.01$). This result is compatible with the study of Bangor et al. (2009). On the other hand, in the study of Bangor et al. (2009), the correlation between SUS scores and adjective rating scale is $r = 0.822$ ($\alpha < 0.01$). Our correlation rate is less than the correlation rate of Bangor et al. (2009). The difference between the correlations may be due to the several reasons such as the different demographics of the participants, different usability measurement methodologies for a different type of products. Bangor et al. (2009) prefer user testing method after participants performed several tasks for the products such as TV, web, cell phones etc., they completed the surveys. Our study only focuses on the mobile applications and conducts surveys based on the user experience without making any user testing.

This study is crucial because mostly young people (average of 22) participated in the questionnaire. According to the statistics, young people aged 18–24 years spend more time than other age groups and usage time decline with age (Url 7). Therefore, the results reveal the opinions of young people about the usability of mobile applications and the study shows the general aspects of development to get more user-friendly mobile applications. On the other hand, this situation is also a limitation of this study. While usability dimensions such as learnability and complexity of the mobile applications may not be a problem for young people, for the users who are older and disabled, these features could be severe problems. In addition, this study only focuses on mostly used four mobile applications, which owned by the high tech companies such as Google and Facebook. Most of the usability problems that could exist in any ordinary mobile applications are already solved in these mobile applications. Because of this, as a future study, a different type of mobile applications should be investigated to understand the usability of mobile applications in detail with more participants having different demographics.

This study uses SUS adapted with adjective rating scale to measure usability of the mobile applications. SUS is developed for measuring the usability of any products or software; it is not a specific scale for mobile applications. Although it is straightforward to use and quickly applicable, it could only detect general usability problems and give a general overview. To identify more usability problems specific to mobile applications, there is a need for a comprehensive study using a scale, checklist or a usability guideline specific to mobile applications to provide more insights and understanding of usability of mobile applications.

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Factors Affecting Intention to Use Big Data Tools: An Extended Technology Acceptance Model

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Abstract The purpose of this study is to examine the factors affecting the intention to use big data tools, using an extended technology acceptance model. The model includes job relevance, big data dimensions, compatibility, self-efficacy, complexity, and anxiety. The study was conducted on a Turkish airline company, and data were gathered from its employees through an online survey. A total of 252 questionnaires were collected. The results show that behavioral intention to use big data technology is explained by perceived usefulness and perceived ease of use. Of these, perceived usefulness has a higher direct influence on behavioral intention to use big data tools. Another result of this study is that perceived usefulness is explained by perceived ease of use, job relevance, compatibility, and big data dimensions, where big data dimensions have a higher direct influence on perceived usefulness. The final result is that perceived ease of use is explained by self-efficacy and anxiety. Of these two factors, self-efficacy has a higher direct impact on the perceived ease of use.

Keywords Technology acceptance model · Big data tools · Adoption
Big data dimensions

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_33

Introduction

Big data undoubtedly represents a rising trend and a topic of interest in the business world. It refers to a set of very large and complex data and the advanced analytical techniques that are required to store, manage, and analyze these data (Chen et al. 2012). It is reported that 2.5 quintillion bytes of data are generated on the planet daily and that 90% of the data in the world today has been generated in the last two years (URL 1). This vast amount of data creates challenges and opportunities for both small and large enterprises all over the world, particularly in the airline industry. These complex and concurrent data sets create enormous technical and human challenges in collecting and sorting aviation databases, and recently, these databases have exceeded the capabilities of desktop computing (Larsen 2013). In order to deal with these challenges and complexity, big data should be used as a competitive asset to reduce uncertainty in decision making and to improve competitive positioning for the airline industry.

For a better understanding of the individual acceptance of information technologies, Davis et al. (1989) proposed the technology acceptance model (TAM). TAM is a powerful, robust, and commonly applied model for predicting and explaining user behavior and IT usage (Agarwal and Prasad 1999; Davis 1989; Legris et al. 2003). It is determined by perceived ease of use, perceived usefulness, attitude toward use, behavioral intention to use, and system usage. Perceived usefulness and perceived ease of use are the most important determinants of intention to use and of system usage (Wu and Wang 2005).

Our research model extends the TAM using the factors of job relevance, big data dimensions, compatibility, self-efficacy, complexity, and anxiety in order to measure the implementation of a big data system in a Turkish airline company. This study provides evidence for the direct influence of these five factors on perceived usefulness and perceived ease of use, and their indirect effects on intention to use big data tools. There are other studies in the literature that have researched the impact of certain factors on the acceptance of data mining tools. In the study of Esteves and Curto (2013), the actual adoption of big data was examined using the decomposed theory of planned behavior and TAM. The authors included the dimensions of big data, compatibility, self-efficacy and facilitating conditions into their models, and also assessed the intention to adopt big data using the perception of risks and benefits. In the study of Huang et al. (2012), the intention to use data mining tools was investigated using TAM. This model included factors in four categories: the task-oriented dimension (job relevance, output quality, result demonstrability, response time and format), control beliefs (computer self-efficacy and perceptions of external control), emotion (computer anxiety) and intrinsic motivation (computer playfulness).

This paper discusses the research model and the hypotheses used in the methodology and analysis of these surveys. The results of these surveys are presented, and this paper concludes with a discussion of the findings and of future studies.

Research Model and Hypotheses

The research model tested in this study is illustrated in Fig. 1. The following hypotheses were developed based on the findings of previous research on this subject.

Behavioral Intention to Use

Behavior is influenced by motivational effects that are components of behavioral intention. These effects are indicators of how individuals are willing to act and how much energy they are willing to use to perform the behavior. Behavior is determined by behavioral intention as long as an individual agrees to perform a behavior (Ajzen 1991). Therefore, behavioral intention to use is a determinant of the possibility that an individual will become involved in a certain behavior (Ajzen and Fishbein 1980). People intend to use a given technology before they use it. Hence, the direct factor of actual use can be determined as the behavioral intention to use (Mathieson 1991). The more a person is willing to use a system, the higher is his or her likelihood of using it (Ajzen and Madden 1986).

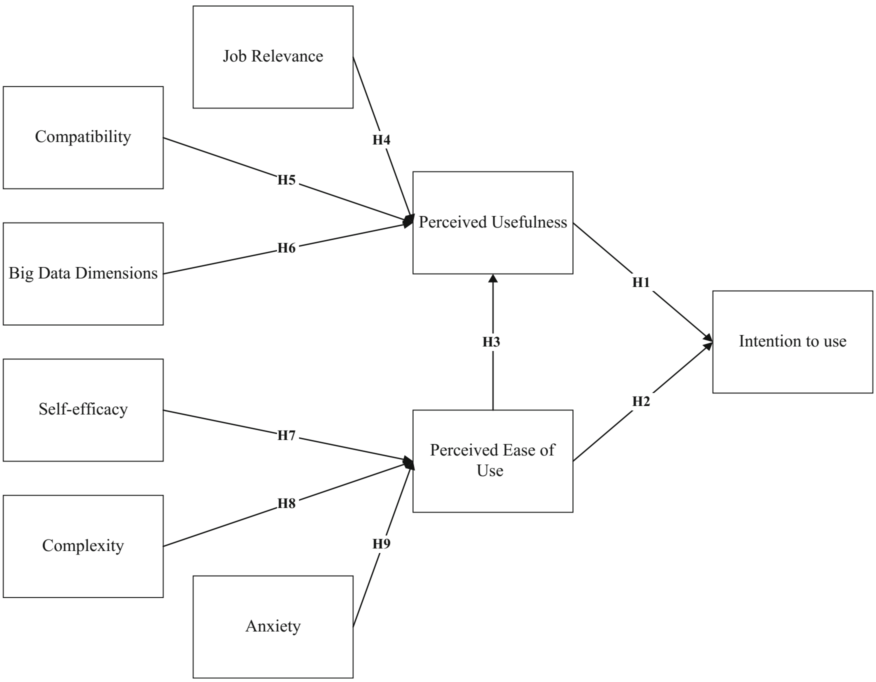

Fig. 1 Proposed research model

Perceived Usefulness

Perceived usefulness is defined as the "degree to which a person believes that using a particular system would enhance his or her performance" (Davis 1989; Saadé and Bahli 2005). In the original technology acceptance model, perceived usefulness is a key determinant of behavioral intention to use (Davis et al. 1989). Extensive research in various areas confirms the significant impact of perceived usefulness on the behavioral intention to use (Chang and Tung 2008; Fu et al. 2006; Gallego et al. 2008; Horst et al. 2007; Khalifa and Ning Shen 2008; Lee 2006; Liao et al. 2007; Tung and Chang 2008b; Agarwal and Prasad 1999; Davis 1989; Hu et al. 1999; Venkatesh 2000; Venkatesh and Morris 2000; Gefen 2003; Guriting and Oly Ndubisi 2006). Thus, in addition to various application areas, the perceived usefulness of big data tools may be critical for the intention to use. We, therefore, hypothesize as follows:

H1 Perceived usefulness will have a positive effect on behavioral intention to use big data tools.

Perceived Ease of Use

Perceived ease of use is defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989). The relationship between perceived ease of use and behavioral intention to use is confirmed by TAM. After perceived usefulness, it is the second key determinant of behavioral intention to use in the original TAM (Davis et al. 1989). People prefer to reduce the effort required for their actions (Venkatesh 2000). If the use of big data tools requires a high level of effort, then employees may not start to use or may even give up using the tool. Many research studies have verified the significant relationships between perceived ease of use and behavioral intention to use (Chang and Tung 2008; Fusilier and Durlabhji 2005; Gallego et al. 2008; Hong and Tam 2006; Lee 2006; Lee et al. 2006; Tung and Chang 2008b; Tung et al. 2008). Thus, we hypothesize as follows:

H2 Perceived ease of use will have a positive effect on behavioral intention to use big data tools.

If all other factors are held constant, the easier the system and the higher the user's job performance. Users may not feel confident with a new system since they do not have the necessary skills and comfort. Nevertheless, after gaining a certain amount of knowledge and being more familiar with it, their perception of its ease of use may change (Hackbarth et al. 2003). In other words, if other aspects are equal, then the easier the system is to use, the more useful it can be (Davis 1993; Venkatesh and Davis 2000). If using big data tools is easy, employees do not have to devote a great deal of time to learn how to use them, which may affect the user's performance. Research in various fields has confirmed the significant relationships between perceived ease of use and perceived usefulness (Anandarajan et al. 2000; Calisir and Calisir 2004; Chan and Lu 2004; Fu et al. 2006; Gallego et al. 2008; Igbaria et al. 1995; Kleijnen et al. 2004; Lee 2006; Liker and Sindi 1997; Lin 2007; Oh et al. 2003; Tung et al. 2008; Venkatesh and Davis 2000; Yi et al. 2006). Thus, we hypothesize as follows:

H3 Perceived ease of use will have a positive effect on the perceived usefulness of big data tools.

Job Relevance

Users have different perceptions of the results they expect to obtain from a new system due to the diverse nature of their jobs. Moreover, they are exposed to external information that might affect their selection of the tool they need. Job relevance can be defined as a user's perception regarding the degree to which the system is applicable to his or her job. In their revised version of TAM, Venkatesh and Davis (2000) propose that job relevance is a cognitive instrumental process. Users of big data tools employ a mental representation to relate their primary work goals to the results of using these tools. This cognitive relationship forms the basis for making decisions about whether the tool is useful. Several studies confirm that job relevance is found to be a significant predictor of perceived usefulness (Chismar and Wiley-Patton 2003; Liang et al. 2003; Venkatesh and Davis 2000). Moreover, the positive moderating effects of job relevance on perceived usefulness have also been studied (Bhattacherjee and Sanford 2006; Kim 2008). Thus, we hypothesize as follows:

H4 Job relevance will have a positive effect on the perceived usefulness of big data tools.

Compatibility

Compatibility is accepted as one of the five major constructs that determine innovation adoption (Tornatzky and Klein 1982). It is defined as "the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters" (Rogers 1995). According to Moore and Benbasat (1991), there is a significant relationship between compatibility and perceived advantage, which is equivalent to perceived usefulness in the context of TAM. Moreover, Chau and Hu (2001) propose that compatibility is a significant determinant of perceived usefulness but not of perceived ease of use. They state that the incompatibility of a system may require a long learning process that results in a decline in the perception of ease of use. Previous research in various areas confirm the significant relationships between compatibility and perceived usefulness

(Fu et al. 2006; Oh et al. 2003; Chang and Tung 2008; Tung and Chang 2008a, b; Tung et al. 2008; Chen et al. 2004). Thus, we hypothesize as follows:

H5 Compatibility will have a positive effect on the perceived usefulness of big data tools.

Big Data Dimensions

Big data is characterized as a new generation of technologies, intended to extract value economically from very large volumes of a wide variety of data by allowing high velocity capture and analysis (Woo et al. 2011). Consistent with this view, the early descriptions of big data used the '3Vs' model to describe the three dimensions of volume, velocity, and variety. Volume refers to the amount of data that contains information of value to an organization; variety represents the combination of different types of data from different sources; and velocity refers to the input and output speed of data (Naumann 2014). Recent research has verified the relationship between big data dimensions and perceived usefulness (Esteves and Curto 2013; Shin 2016). Thus, we hypothesize as follows:

H6 Big data dimensions will have a positive effect on the perceived usefulness of big data tools.

Self-efficacy

Self-efficacy, rooted in social cognitive theory, is the insight and assurance of individuals regarding their ability to accomplish and conduct the specific activities needed to succeed in particular types of tasks (Bandura 1986; Huffman et al. 2013). It has an impact on which activities people prefer to perform, the amount of effort they are ready to use, and the amount of time for which they will continue this effort to overcome obstacles (Bandura 1982, 1986). Bandura's theory states that people with high self-efficacy are more likely to assess difficult tasks as something to be become skilled at, rather than something to be avoided. The importance of perceived ease of use is supported by Bandura's (1982) extensive research on self-efficacy (Davis 1989). It is therefore expected that employees with high self-efficacy towards the use of big data tools are more likely to view this as easy, rather than complicated. Several studies in various areas have examined the relationship between self-efficacy and perceived ease of use (Igbaria and Iivari 1995; Venkatesh 2000; Yi and Hwang 2003; Ozturk et al. 2016; Alalwan et al. 2016). Thus, we hypothesize as follows:

H7 Self-efficacy will have a positive effect on the perceived ease of use of big data tools.

Complexity

Complexity is defined as "the degree to which an innovation is perceived as relatively difficult to understand and use" (Rogers and Shoemaker 1971; Thompson et al. 1991). Technological complexity represents a situation where a new technology is more difficult for the users than the prior technology utilized for the same task, where there is an increase in the number of tasks the user has to carry out in the same amount of time. Similar to other new technological tools, big data tools are often perceived as very complex and difficult to implement. The higher the complexity, the higher mental workload and stress (Sokol 1994). The complexity of big data tools may negatively affect the perceived ease of use. In the literature, several studies link complexity and perceived ease of use (Thompson et al. 1991; Venkatesh and Davis 1996; Rajan and Baral 2015). Thus, we hypothesize as follows:

H8 Complexity will have a negative effect on the perceived ease of use of big data tools.

Anxiety

Anxiety is described as "anxious or emotional reactions when it comes to performing a behavior" (Venkatesh et al. 2003). According to Van Raaij and Schepers (2008), anxiety is a personal characteristic, and negatively affects the acceptance of the technology. Therefore, an employee's discomfort towards a technology or big data tools may create a perception of them as more difficult and complex. Likewise, employees who are less anxious are more likely to work effectively with big data tools than employees who are more anxious. Several studies in the literature have observed the negative significant relationship between anxiety and perceived ease of use (Chatzoglou et al. 2009; Van Raaij and Schepers 2008; Venkatesh 2000; Karaali et al. 2011; Calisir et al. 2014). We, therefore, hypothesize as follows:

H9 Anxiety will have a negative effect on the perceived ease of use of big data tools.

Methodology

A survey methodology was used to gather data for this study. The target population was Turkish airline company employees.

The questionnaire was formed of two main parts. The first part consisted of demographic questions designed to solicit information about age, gender, job description, department and work experience within the airline company. A total of 290 questionnaires were sent to the airline company employees in June 2015, and the response rate was 86.89%. A summary of the demographic profiles of the participants is given in Table 1.

The second part consisted of items measuring continuance intention (Agarwal and Karahanna 2000), perceived usefulness (Davis 1989), perceived ease of use (Davis 1989), job relevance (Davis et al. 1992), compatibility (Moore and Benbasat 1991), big data dimensions (Sahoo and Yajnik 2014), self-efficacy (Venkatesh et al. 2003), anxiety (Venkatesh et al. 2003) and complexity (Thompson et al. 1991). The items for these constructs can be seen in Table 2.

The items were modified to make them relevant to big data use. A five-point Likert-type scale was used to measure the items, where one represents "strongly disagree" and five represents "strongly agree."

Results

Cronbach's alpha was used to measure the internal consistency or reliability of each factor (Bayraktar et al. 2017). Robinson et al. (1991) suggest that 0.70 is acceptable as a lower limit for the value of Cronbach's alpha, and this is used to show that a factor has good internal consistency. The results of the reliability analysis show that all the variables have a Cronbach's alpha of over 0.70. The values of Cronbach's alpha for the constructs can be seen in Table 3.

Stepwise regression analyses were conducted to test the proposed hypotheses of the research model. The value of R2 indicates that the percentage of the total variance of the dependent variable is explained by independent variables in the regression model, and the F value indicates whether the overall model is statistically significant in explaining the independent variable. In the first equation, the effect on intention to use of the perceived usefulness and perceived ease of use are investigated. Eighty percent of the total variance of intention to use big data tools is explained by the perceived usefulness and perceived ease of use (F (2; 249) = 498.583, $p < 0.001$). This result

Table 1 Demographic profiles of the respondents

Age (years)		
Max: 55	Min: 18	Average: 27
Gender (%)		
Female: 35.65	Male: 64.35	
Job description (%)		
Specialist: 46.29	Engineer: 26.85	Chief: 10.18
Clerk: 4.16	Analyst programmer: 2.77	Business analyst: 2.31
Project manager: 2.31	Controller: 1.85	Others: 3.28
Work experience within the airline company (%)		
0–3 years: 29.63	3–7 years: 37.96	7–10 years: 13.89
>10 years: 18.52		

Table 2 Construct and items

Construct	Code	Items
Intention to use	INT1	I plan to use big data tools in the future
	INT2	I intend to continue using big data tools in the future
	INT3	I expect my use of big data tools to continue in the future
Perceived usefulness	PU1	Using big data tools in my job would enable me to accomplish tasks more quickly
	PU2	Using big data tools would make it easier to do my job
	PU3	Using big data tools in my job would improve my productivity
	PU4	Using big data tools would improve my job performance
	PU5	I would find big data tools useful in my job
	PU6	Using big data tools would enhance my effectiveness in my job
Perceived ease of use	PEU1	It would be easy for me to become skillful in using big data tools
	PEU2	I would find big data tools easy to use
	PEU3	I would find it easy to get big data tools to do what I want them to do
	PEU4	Learning to use big data tools would be easy for me
	PEU5	My interaction with big data tools would be clear and understandable
	PEU6	I would find big data tools to be flexible to interact with
Job relevance	JR1	In my job, usage of big data tools is important
	JR2	In my job, usage of big data tools is relevant
	JR3	The use of big data tools is pertinent to various tasks related to my job
Compatibility	CMP1	Using big data tools is compatible with all aspects of my work
	CMP2	Using big data tools is completely compatible with my current situation
	CMP3	I believe that using big data tools fits well with the way I like to work
	CMP4	Using big data tools fits into my working style
Big data dimensions	BGD1	I use big data tools because they help in processing huge volumes of data, which is not possible using traditional systems Traditional system
	BGD2	I use big data tools because they help in processing various types of data, such as unstructured, structured, and semi-structured data Structured, semi structured
	BGD3	I use big data tools because they help in processing data faster than traditional approaches
Self-efficacy	SE1	If there was no one around to tell me what to do as I go along, I could complete the job using big data tools
	SE2	If I could call someone for help if I got stuck, I could complete the a job using big data tools
	SE3	If I had a lot of time to complete a job for which software was provided, I could complete the job using big data tools
	SE4	If I had only the built-in help facility for assistance, I could complete the job using big data tools

(continued)

Table 2 (continued)

Construct	Code	Items
Complexity	CX1	Using big data tools takes too much time away from my normal duties
	CX2	Working with big data tools is so complicated, it is difficult to understand what is going on
	CX3	Using big data tools involves too much time doing mechanical operations (e.g. data input)
	CX4	It takes too long to learn how to use the system to make it worth the effort
Anxiety	ANX1	I feel apprehensive about using big data tools
	ANX2	It scares me to think that I could lose a lot of information when using the big data tools by hitting the wrong key
	ANX3	I hesitate to use big data tools for fear of making mistakes I cannot correct
	ANX4	Big data tools are somewhat intimidating for me

Table 3 Values of Cronbach's alpha for all variables

Variable	Cronbach's alpha
INT	0.879
PU	0.954
POEU	0.911
JR	0.938
CMP	0.928
BGD	0.915
SE	0.906
CX	0.818
ANX	0.857

indicates that perceived usefulness ($\beta = 0.643$, $t = 12.513$, $p < 0.01$) and perceived ease of use ($\beta = 0.285$, $t = 5.551$, $p < 0.001$) are significant predictors of intention to use big data tools.

In the second equation, 94.3% of the total variance of perceived usefulness is explained by perceived ease of use, job relevance, compatibility, and big data dimensions (F (4; 247) = 491.733, $p < 0.001$). This result suggests that perceived ease of use ($\beta = -0.149$, $t = 3.717$, $p < 0.001$), job relevance ($\beta = 0.261$, $t = 4.836$, $p < 0.001$), compatibility ($\beta = 0.284$, $t = 6.039$, $p < 0.001$), and big data dimensions ($\beta = 0.302$, $t = 6.039$, $p < 0.001$) are significantly associated with perceived usefulness.

In the third equation, 74.2% of the total variance of perceived ease of use is explained by self-efficacy and anxiety (F (2; 249) = 357.188, $p < 0.001$).

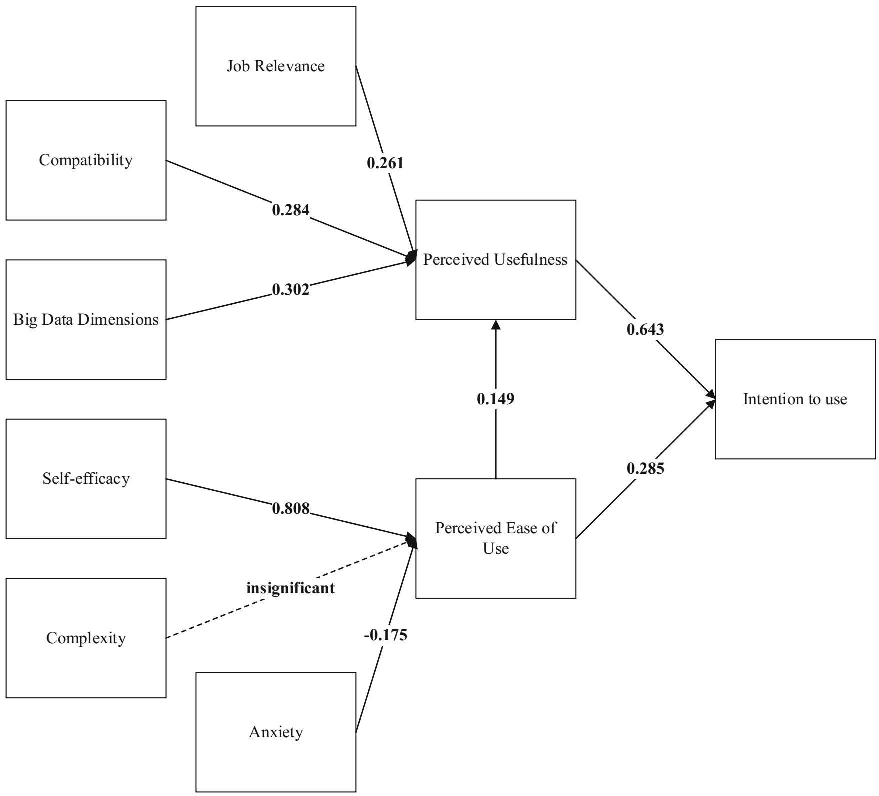

Fig. 2 Findings of the proposed research model

This result suggests that self-efficacy (β = −0.808, t = 24.572, $p < 0.001$) and anxiety (β = −0.175, t = −5.319, $p < 0.001$) are significant determinants of perceived ease of use, whereas complexity is found to be an insignificant predictor (t = −0.625, $p < 0.10$). A graphical summary of these findings can be seen in Fig. 2.

Discussion and Conclusion

The aim of this study is to examine the intention to use big data tools, using an extended TAM. A survey methodology was used in this study, where data were collected from employees of a Turkish airline company. A total of 252 questionnaires were collected.

The results also show that behavioral intention to use big data technology is explained by perceived usefulness and perceived ease of use. Of these, perceived usefulness has a higher direct influence on behavioral intention to use big data tools. If employees find big data efficient and perceive beneficial outcomes for themselves, they will be motivated to use big data tools in their work.

Employees need to understand the benefits of using big data tools, which include better job performance and productivity. Top management should use a range of methods to convey the importance of using this technology in increasing employees' job performance. Company management should also choose the most user-friendly big data technology available so that employees are not demotivated by the technical difficulties of using the software.

A further result of this study is that perceived usefulness is explained by perceived ease of use, job relevance, compatibility, and big data dimensions. Of these factors, big data dimensions have the highest direct influence on perceived usefulness. The three attributes of volume, velocity, and variety are the key elements in the perception of the usefulness of big data tools. The ability to "extract value from very large volumes of a wide variety of data by enabling high velocity capture" (Gantz and Reinsel 2011) may shape employees' perceptions of using big data tools.

Another result of this study is that the perceived ease of use is explained by self-efficacy and anxiety. Of these, self-efficacy has a higher direct impact on the perceived ease of use. If an employee has confidence in his/her ability to use big data tools and has enough knowledge regarding that technology, the perception of the ease of use of big data technology will be improved, and this improved perception of ease of use may alter employees' intention to use it.

The company's management should determine the ability and knowledge of users of big data tools, since the degree of perception about the necessary skills for and knowledge of the use of big data tools is important. The company should, therefore, arrange training programs for the use of the software and encourage and motivate their employees to use this technology.

The findings of this study provide a better understanding of the factors affecting the intention to use big data tools, but several limitations should also be considered. Firstly, only 80% of intention to use, 94.3% of perceived usefulness, and 74.2% of perceived ease of use are explained in the model. Thus, a considerable percentage of these variables remains unexplained, suggesting the need for future studies to explain user behaviors. Some additional factors may be required, such as perceived risks (Esteves and Curto 2013), perceived benefits (Esteves and Curto 2013), facilitating conditions (Esteves and Curto 2013), output quality (Huang et al. 2012) and result demonstrability (Huang et al. 2012).

Secondly, the effects of demographic attributes on the adoption of big data tools were not analyzed in this study. A similar study that includes demographic characteristics such as the extent of computer use, experience, age and gender of the respondents may be a subject for future research. Thirdly, by increasing the size of the data collected, differences between airline companies and companies from different sectors may be analyzed for the further study.

Finally, this study may be combined with qualitative analysis to understand and interpret the intention to use big data tools, since qualitative and quantitative aspects may complement each other to offer a better understanding.

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The Moderating Effect of Indulgence on the Relationships Among Global Innovation Index Indicators

Basak Cetinguc, Eyup Calik and Fethi Calisir

Abstract National level innovation has been studied prominently. Global indices are utilized while evaluating country level innovation. Global Innovation Index (GII) is one of the most commonly used indices in this context. Moreover, cultural dynamics also affect innovation level. Hofstede's Cultural Dimensions (HCD) is one of the outstanding guidelines on cultural dynamics of countries. In this study, infrastructure, institutions, and human capital and research are designated input indicators of GII while knowledge and technology output and creativity output are chosen output indicators of GII. Moreover, indulgence is considered as a moderator variable from HCD. Our main aim is to examine the relationships among global innovation index factors and investigate the moderating effect of indulgence on these relationships. For this purpose, we proposed a conceptual model to explore these relationships. Structural Equation Modeling (SEM) was employed in order to conduct path analysis with data from official web sites. The results show that all hypotheses related to GII factors are supported, and a moderating effect of indulgence is observed on some of the relationships. These findings indicate that countries with sufficient innovation input make the transformation to innovation outputs. Furthermore, innovation leaders should be aware of societies have more indulgent score moderate several relationships.

Keywords Global innovation index · Hofstede cultural dimensions
Structural equation modeling · Moderating · Relationships · Factors

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_34

Introduction

Innovation is one of the prominent dynamics for economic and business growth at not only firm level but also country level. From a strategic point of view, companies and economies should innovate in order to strength and sustain their position (Moonen 2017). Country level innovation is considered a national innovation system. National Innovation Systems (NIS) introduced by Freeman (1987) and later on discussed by Lundvall (1992) and Nelson (1993), examine the relationships among government, research institutions and industry in terms of development and usage of innovations. A proper definition of national innovative capacity is expressed by Edquist as "all important economic, political, social, organizational, institutional and other factors that influence the development, diffusion and the use of innovations or as a country's economic and political potential as directly related to the development, diffusion, and use of innovations" (1997). Moreover, Furman and his colleagues claimed that the strength of national innovation is relevant to innovation infrastructure, which is the factors that contribute to the economy, the innovation environment of industrial clusters, and the links between infrastructure and innovation environment (2002). Additionally, Furman and Hayes pointed out that the research regarding national innovation system not only based on economic or technological developments but also focuses on assemblages of organizations, policies that contribute to innovations, national approaches to innovation (2004). Analyzing the innovativeness of countries is not easy, on account of the complex structure of national innovation systems. Many global organizations have created indices to evaluate countries in order to compare their innovativeness. Well-known examples of these indices are the Innovation Union Scoreboard (IUS), the European Innovation Scoreboard (EIS), the World Economic Forum (WEF), and the Global Innovation Index (GII). The main aim of these indices is to evaluate and compare countries based on predefined factors. Among them, addressing countries from all around the world, including input and output indicators of innovation, GII comes into prominence at first sight. The first GII was conceived in 2007 by INSEAD as a tool to sort out how countries cope with the challenge of innovation ("The Global Innovation Index" 2017). After the first edition, nine more editions were published. The last four editions were presented by a partnership of INSEAD, Johnson Cornell University and the World Intellectual Property Organization (WIPO). Every year, GII embrace a new theme related latest research on innovation. Moreover, since the dynamics of innovation environment changes, in order to be up to date GII needs to evolve measurement tools by available data and trending concepts. Thus, GII measures innovativeness of countries with evolving indicators based on environment needs. For instance, GII 2014 includes 143 economies and 81 indicators, GII 2015 covers 141 economies around the world using 79 indicators, whereas GII 2016 includes 128 economies and 82 indicators. This year, there are 127 countries and 109 indicators in GII 2017 report. The GII consists of two sub-indices: the Innovation Input Sub-Index and the Innovation Output Sub Index. The Input Sub-Index score is the simple average of the first five pillars: institutions, human capital, and research, (HCR) infrastructure, market sophistication and business sophistication. Additionally, the Innovation Output Sub-Index is the simple average of the last two pillars: knowledge and technology outputs (KTO) and creative outputs. Each sub-index score ranges between 0 and 100, and the final index score is gained by the simple average of sub-index scores ("The Global Innovation Index" 2017). In this study, five of these pillars are utilized in accordance with the aim of our research. Infrastructure, institutions, human capital and research, creative output and knowledge and technology outputs are determined as the factors while market sophistication and business sophistication are not taken into consideration in our study.

Furthermore, there is a factor that should not be ignored while exploring innovativeness of countries: national cultures. Since humans are the main element of societies, the movements and decisions are affected by the background of their culture. Hofstede and colleagues define culture as "the collective programming of the mind that distinguishes the members of one group or category of people from others" and claims that it is the unwritten rules of the social game (2010, p. 6). Hofstede proposed a four-dimensional national culture model with four dimensions based on his research in IBM (Hofstede 1984). These dimensions are individualism versus collectivism, large versus small power distance, strong versus weak uncertainty avoidance, and masculinity versus femininity. Afterwards, Hofstede introduced a fifth dimension called long-term orientation versus short-term orientation as the outcome of his studies with Michael Bond from the Chinese University of Hong Kong in 1991 (Minkov and Hofstede 2011). Finally, Hofstede's cultural dimension model attained the latest version with the sixth dimension by the contribution of Minkov (Minkov and Hofstede 2011). The sixth dimension is indulgence versus restraint regarding happiness degree of countries (Minkov 2009). Although there are other researchers studied cultural dimensions (i.e. House et al. 2004; Schwartz 1994; Trompenaars and Hampden-Turner 2011), Hofstede's framework is adopted more than other studies mentioned above (Beugelsdijk et al. 2015). Besides, scores of Hofstede's cultural dimension (HCD) range between 0 and 120 and preferred to use normalized values between 0 and 100. At the same time, each country has its own scores for each dimension and all dimensions are evaluated separately; no integration is needed in HCD.

In this paper, we examined if the input factors transform into innovations or not? Additionally, another curiosity was if happy countries are more successful at transforming innovation input into innovation outputs or not. Thus, the main purpose of this study is analyzing the relationships among selected factors of GII and examining the moderating effect of indulgence on these relationships. This paper contributes to the literature by investigating the relationships among input and output pillars (factors) of GII and to explore the moderating effect of indulgence on these factors of GII. Managers, innovation leaders, and policy makers can utilize findings while making decisions regarding national wide innovations.

The organization of this paper is as follows. In Section "Conceptual Background and Model Development", the conceptual background and model development is given. Section "Data and Methodology" introduces data and methodology. Later on, analyses and results are expressed in Section "Analyses and Results". Finally, findings and conclusion are presented in the last section.

Conceptual Background and Model Development

In this part of the study, factors are defined, and hypotheses are proposed based on the relationships among these factors. As mentioned above, innovation input sub-index consists of five different factors, and innovation output sub-index includes two different factors. In this study, institutions, human capital and research and infrastructure are taken from innovation input sub-index, also knowledge and technology outputs and creative outputs from innovation output sub-index are contemplated. Institutions factor includes political environment, regulatory environment, and business environment. Moreover, human capital and research consists of three sub-factors: education, tertiary education, research and development. Finally, infrastructure factor comprises of information and communication technologies (ICTs), general infrastructure and ecological sustainability. Besides, knowledge and technology outputs are based on creation, impact, and diffusion of knowledge, while creative outputs incorporate with intangible assets, creative goods and services, and online creativity.

Furthermore, indulgence is the degree of satisfaction of human natural basics related to enjoying life and having fun (Hofstede et al. 2010). Creator of this dimension, Minkov formulates this dimension by three items: happiness, life control and importance of leisure. Happiness is the level of a person's feels about his/her life while considering all things together. Additionally, life control is the degree of a person's free choice of control over his/her life, and the importance of leisure is a person's perception of the importance of leisure time. Minkov found that these three items are mutually correlated, and figured out that this dimension has two poles. One pole is specified with persons who become happy when they spend money, do activities fun-related, comfort their selves with leisure activities, on the other pole, perceived social norms and taboos restrain persons from having joy and give the idea of indulgence is wrong (Hofstede 2011).

Sohn and his colleagues proposed a model consisting of seven pillars of GII as latent variables and investigated the relationships among them (2016). According to their results, infrastructure has a positive strong effect on human capital and research. Also, the relationship between infrastructure and institutions occurs positively. They found a long-term potential indirect relationship between infrastructure and creative outputs. Besides, human capital and research has a positive effect on knowledge and technology outputs, while institutions positively affect knowledge and technology outputs. Although they proposed that creative output has a direct positive effect on knowledge and technology outputs, the results indicated that there is no relationship between these two factors. On the light of Sohn and his friends' work, we proposed the following hypotheses that are shown by 'a' index of a hypothesis (i.e. H1a, H2a etc.). At the same time, Hofstede et al.

found that there is a positive relationship between indulgence and national wealth (Hofstede 2011). In this study, one of the main aims is to analyze the moderating effect of indulgence over relationships of innovation input and output factors. Hypotheses with ‘b’ index also include moderating effect on given relationships.

H1a The infrastructure has a positive effect on human capital and research.

H1b Indulgence has a moderating effect on the relationship between infrastructure and human capital and research.

H2a The infrastructure has a positive effect on institutions.

H2b Indulgence has a moderating effect on the relationship between infrastructure and institutions.

H3a The infrastructure has a positive effect on creative output.

H3b Indulgence has a moderating effect on the relationship between infrastructure and creative output.

H4a The human capital and research have a positive effect on knowledge and technology outputs.

H4b Indulgence has a moderating effect on the relationship between human capital and research and knowledge and technology outputs.

H5a The institution has a positive effect on knowledge and technology outputs.

H5b Indulgence has a moderating effect on the relationship between institutions and knowledge and technology outputs.

H6a The knowledge and technology output has a positive effect on creative outputs.

H6b Indulgence has a moderating effect on the relationship between knowledge and technology outputs and creative outputs.

The sole difference in our study is formulating a hypothesis regarding the relationship between creative output and knowledge and technology outputs. We postulated that knowledge and technology outputs have a positive direct effect on creative outputs. Research model with hypotheses can be seen in Fig. 1.

Data and Methodology

In this study, we used secondary data gathered from the Global Innovation Index and Hofstede’s Cultural Dimensions. Moreover, GII factor scores range between 0 and 100, and these factor scores are gained by the average of sub-factors. Similarly, indulgence factor of HCD ranges the same interval. Factor scores gained from indices are used to analyze the relationships among factors. Furthermore, since a different number of countries is handled in these indices, a matching step is needed.

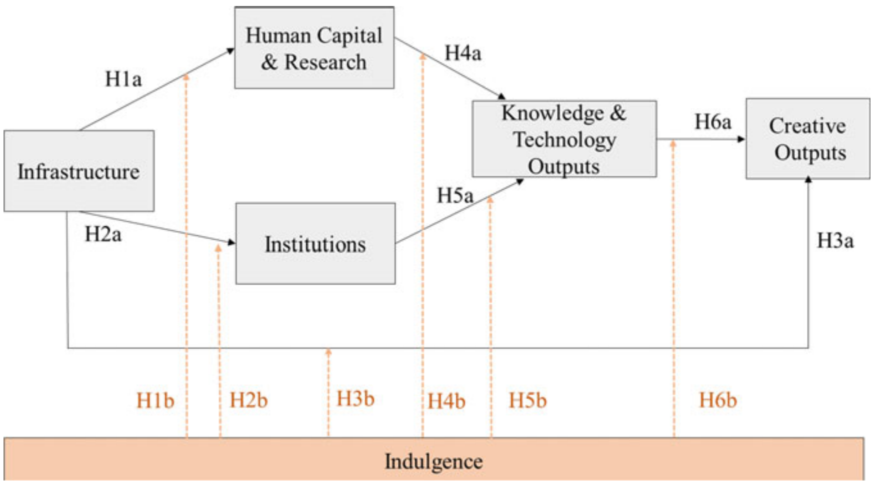

Fig. 1 Proposed model

Countries that are included in only GII or HCD are eliminated. After this process, remained number of countries is 88, and all analyses were conducted based on these countries. Besides, path analysis was conducted by employing SEM methodology via AMOS software to calculate the coefficients, GoF values, and other relevant results. Moreover, the GoF index helps to understand the acceptability of any SEM model, and a number of various GoF measures can be used by researchers (Hair et al. 2010). We will present most widely the GoF indices reported by AMOS users such as χ^2/df, GFI, AGFI, and CFI. Moreover, moderator analysis was conducted by using "Stats Tools Package" developed by James Gaskin (Gaskin, n.d.).

Analyses and Results

A path model was built based on the relationships previously mentioned. After running the model by using AMOS, we obtain coefficients of relationships and *p* values are shown in Table 1. All hypotheses regarding relationships (H1a, H2a, H3a, H4a, H5a, and H6a) are supported, and it indicates that there are positive relationships among factors of GII. Moreover, GoF measures found in our analysis are (χ^2/df = 2.241; GFI = 0.958; AGFI = 0.842; CFI = 0.989) greater than cut-off values, and indicate that the model fit is appropriate (Hair et al. 2010).

Besides, while performing moderation analysis, the data was divided into two level categories as low level and high level by taking the average value of indulgence scores of countries into consideration as a threshold. By using "Stats Tools Package", group differences were utilized to explore the moderating effect of indulgence on the relationships among factors mentioned above. Table 2 indicates

Table 1 Coefficients and *p* values

Relationships			Estimate	S.E.	*p*
HCR	←	Infrastructure	1.087	0.078	***
Institutions	←	Infrastructure	1.189	0.073	***
Creative outputs	←	Infrastructure	0.631	0.089	***
KTO	←	HCR	0.48	0.078	***
KTO	←	Institutions	0.255	0.075	***
Creative outputs	←	KTO	0.395	0.079	***

Note ****p*-value < 0.01

Table 2 Results of moderating effects

			Low		High		z-score
			Estimate	*p*	Estimate	*p*	
HCR	←	Infrastructure	0.860	0.000	1.293	0.000	2.851***
Institutions	←	Infrastructure	1.011	0.000	1.346	0.000	2.279**
Creative outputs	←	Infrastructure	0.541	0.000	0.699	0.000	0.837
KTO	←	HCR	0.591	0.000	0.253	0.057	−2.065**
KTO	←	Institutions	0.093	0.311	0.552	0.000	2.944***
Creative outputs	←	KTO	0.451	0.000	0.337	0.004	−0.726

Note ****p*-value < 0.01; ***p*-value < 0.05

that the moderator effect is occurred on the proposed relationships except for the relationships between KTO and creative outputs, the relationships between infrastructure and creative outputs contrary to our expectations. In other words, H1b, H2b, H4b, and H5b are supported while H3b and H6b are not supported.

Findings and Conclusion

This study aims at exploring the relationships among selected factors of GII and investigating the moderating effect of indulgence on these relationships. Several researchers have studied the relationships among GII factors, but we did not come across indulgence as a moderator on these relationships. Our study contributes to the literature by proposing and validating a conceptual model that consists of a moderating effect of indulgence in order to fill the gap. According to the results, all proposed hypotheses regarding GII factors' relationships are supported. It illustrates that the countries have sufficient innovation inputs are able to transform innovation outputs in order to sustain national innovation capacity. Moderating effects of indulgence on the relationships between infrastructure and human capital and research; infrastructure and institutions; human capital and research and knowledge and technology outputs, also institutions and knowledge and technology outputs are maintained. Additionally, there are strong positive relationships between infrastructure and human capital and research, infrastructure and institutions, also institutions and knowledge and technology outputs in the countries that have a high level of indulgence. On the contrary, human capital and research has a strong positive relationship in the countries that have a low level of indulgence. Moreover, there is no moderating effect between the level of indulgence on the relationships between KTO and creative outputs, and between infrastructure and creative output. These findings give a perspective to policy makers while developing national strategies. They should be aware of the national innovation system should be taken into consideration in order to gain/sustain competitive advantage without compromising cultures.

Due to the fact that our study contributes to the literature by proposing a validated model consists of cultural dynamics as a moderator, it has several limitations. First of all, only 88 countries are utilized in accordance with the available exact data on both GII and HCD. Secondly, data employed is peculiar to given year; hence although these results give an idea for the whole picture, they may not be interpreted for coming years due to changing conditions. Even though these limitations are acknowledged, research findings provide a basis for future research. For instance, other dimensions of GII can be added to the research model to explore comprehensive effect. Moreover, other dimensions of Hofstede can be used as a moderator variable in these relationships. Furthermore, the model may be validated by analyzing the data for each accessible year.

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Part III
Healthcare Systems Engineering and Management

Mobile Health (mHealth) Applications and Self Healthcare Management: Willingness of Female Patients Living in Rural Areas to Static Mobile Apps

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Abstract The objective of this research is to assess the attitudes and preferences of female patients living in rural areas regarding various functionalities a mobile app can play. I classified mobile app functionalities into two major categories of static and dynamic. Static functionalities are those with whom a patient develops one-way, top-down interactions, such as receiving drug information from hospital staffs. Interactive functionalities develop mutual and engaging interactions among patients, physicians, and health staffs. This is a descriptive, cross-sectional study collected data from 460 female patients visited rural "Health Houses" in provinces of Ardabil and Isfahan. The respondents were selected randomly. The data collection tool is a questionnaire designed by the author. Validity (content and form) and reliability (Spearman–Brown with r = 0.83) includes two categories of questions: background and questions regarding the role of mobile information-communication apps. Data were analyzed by SPSS software. This research shows that the patients prefer a mobile health app that develops a static interaction between themselves and their physician or other health staffs. In general, patients have medium trust to mobile apps, and they prefer to use mobile apps developed and run by a clinic or a hospital so that they can receive health information, medical bills and the results of their medical tests. They showed little tendency to interact with other patients, physicians, and health staffs through a mobile app. They prefer face to face interactions.

Keywords mHealth applications · Self-healthcare management
Telemedicine in rural areas · Static mobile apps · Dynamic mobile apps

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_35

Introduction

There is no doubt that mobile technology has an enormous impact on patients' health care management. Mobile technology was adopted within the healthcare industry for several reasons. For instance, one of the major challenges is that many patients have little engagement with the management of their health. This situation is aggravated in developing countries in which hospitals and clinics have established one-way and non-interactive communication with their patients. Of the other challenges is that many patients in rural areas lack having a solid system of knowledge regarding their health issues. Patients blindly follow the instruction of their physicians and health care staffs without knowing the science and rationality behind their prescriptions. One of the other challenges in rural areas is that patients lack on-time access to medical and educational centers. As a result of various health challenges, mobile technology can service as a tool to facilitate the better management of healthcare, especially in rural areas.

Before the advent of mobile technology, in order to solve healthcare challenges in rural areas, the Iranian government established health centers called "Health Houses" to serve as a major medical and educational center for multiple villages that are geographically adjacent to each other. In a health house, Behvarz or health workers were in charge of running the Health Houses. A Behvarz with a minimum degree of high school diploma provides basic health care to rural patients. In the case of critical and emergency health situations, the Health House refers patients to Rural Health Centers. These centers have two physicians and several health technicians.

The advent of mobile technologies is a promising event since they are ubiquitous not only among the urban population but also among rural people in both developed and developing countries. International reports mentions to the ubiquitous use of mobile technologies among underprivileged populations, and these reports mention that mobile technology is a ubiquitous technology in rural areas of developing countries. In another example, the report of the UNCIEF shows that while only 2% of African households have a landline, "cellphones are as common in Nigeria and South Africa as they are in the United States, with about 90% of adults owning mobile phones" (UNICEF 2015). International organizations, such as WHO confirms the tendency of low and middle-income countries to mhealth "as a complementary strategy for strengthening health systems and achieving the health-related Millennium Development Goals" (Kay et al. 2011).

In Iran, for instance, around 40 million own a smartphone (Trend.az 2015) with myriads of apps that can be downloaded on these devices. Studies confirm that deficiencies in the quality of health care services mainly result from knowledge gaps and inappropriate use of existing technologies (Murray and Frenk 2000). Mobile technologies are accessible anytime and anywhere. Since they are the very personal belonging of a person, developers are aware that the contents of mobile apps can be personalized with the personal preferences of users. One proper use of mobile technologies within the health sector is developing personalized contents and functionalities.

Statistics show the mushrooming development of mobile apps, both with static and dynamic contents and environments. While in the beginning, mobile technology was only offering one-way and static information, mainly in the form of SMS, these days, mobile apps are geared toward developing interactive and engaging environments and contents. The report by the Patient View Co shows that patients, who were affected by five diseases of diabetes, cancer, arthritis, mental health, and rare diseases, expected the following functions from a mobile health app:

1. To understand their condition and treatment choices (61%)
2. To provide a way to communicate with their doctor or nurse (45%)
3. To raise public awareness of conditions important for the public (38%)

The WHO Global Observatory for eHealth also published a report identifying areas that mobile technologies have greatly transformed within the realm of health care. These areas are as follows:

Health call centers, emergency toll-free telephone services, managing emergencies and disasters, mobile telemedicine, appointment reminders, community mobilization and health promotion, treatment compliance, mobile patient records, information access, patient monitoring, health surveys, and data collection, surveillance, health awareness raising, and decision support systems.

Some of the other technological solutions offered by mobile technologies can be divided into the following categories:

- Computer-based patient records: This solution creates a digitized set of all clinical and administrative information regarding a patient's health status.
- Data warehousing: This solution stores a great amount of information, such as clinical, financial, and operational, in an integrated decision support databases, which are immediately accessible.
- Document imaging: This solution scans and stores images of paper based forms in order to make them sharable and accessible to clinicians and administrators across various scales.
- Internet solution: This solution aids integrating clinical and financial data from disparate sources.
- Telemedicine: This solution utilizes ICT to deliver medical services and information anywhere.

The goal of this research is to understand the preferences and attitudes of female patients living in rural areas toward an effective mHealth app and to understand desirable functionalities that a mobile app can play. Do patients prefer a dynamic app to have interactive and engaging interactions with the physicians and healthcare staffs or they prefer a passive app to receive only information and data? In other word, do patients expect a mobile app to provide an interactive and engaging platform? Theoretically this study extends the literature on mobile health management by studying the preferences of women in rural areas regarding mobile health apps. Practically, this paper can service as a guideline for technology developers and policy-maker on how to design and develop a health mobile app that can better service the needs of women in rural areas.

Literature Review

One of the recent concepts in the e-health literature is the concept of Patient 2.0 and patient empowerment. In this concept, telecare plays a major role (ibid), specifically with fast recent developments in mobile phone applications. Research on patients' interest and willingness to use mobile technologies for health management is not a new topic. As the studies show, there is a positive overall attitude among patients with various diseases and illnesses to use mobile health technologies for the management of their health and wellbeing.

The following studies, which are also shown in Table 1 confirm that patients from various contexts and backgrounds, and with different diseases are willing to use mobile technology for better management of their diseases:

1. Ramirez et al. (2016) explain that despite their lower socioeconomic status, patients of this status use their mobile phones for both managing chronic diseases and improving their overall health. Their study shows that patients find the mobile health apps most useful for nutrition, exercise, and obtaining general information on medical conditions.
2. Seto et al. (2010) in their study of the attitude of heart failure patients toward mobile phone based remote monitoring conclude that patients prefer to use mobile phone-based remote monitoring.
3. McGillicuddy et al. (2013) study of the kidney transplant recipients' attitudes toward mobile phone-based health monitoring also shows that these patients have a positive overall attitude toward mobile health.
4. Price et al. (2013) also study Hispanic farm workers' attitudes toward mobile phone-based telehealth for the management of chronic health conditions. Their study shows the willingness of the farmers to use mobile health devices.
5. Jayashri and Rory (2014) also studied the willingness of the US rural patients to receive mobile-based health services and conclude that the rural patients have an overall positive willingness.
6. Liu et al. (2016) in their study of the feasibility and acceptability of mobile apps for seizure self-management in China, conclude that people with epilepsy have a positive attitude toward using epilepsy apps.
7. Hwabamungu and Williams (2010) also studied the adoption of mobile health from patients' perspectives. Their study shows that both patients and caregivers adopt mobile phone based applications for HIV/AIDS care.

Table 1 A summary of the literature on the impact of various mobile functionalities on patients' attitudes

Author	Disease	Mobile functionality	Patients' attitudes
Ramirez et al. (2016)	Patients with lower socioeconomic status and with chronic disease	Mobile phone and app	"Substantial interest among our patients in using mobile health technology to both manage chronic disease and improve overall health"
Liu et al. (2016)	Chinese patients with epilepsy	Smartphone apps for seizure self-management	"There is a positive attitude toward using epilepsy apps among patients with epilepsy"
Sieverdes et al. (2015)	Patients on the kidney transplant waiting list	Personalized mobile health programs—delivered physical activity programs	"High interest (95%) for using mHealth to promote physical activity was found"
Price et al. (2013)	Hispanic migrant farm workers with a chronic health condition	Mobile phone-based telehealth for management of chronic health conditions	Most participants (65/80, 81%) were receptive to using mHealth technology and felt it would be helpful in enhancing medication adherence, self-monitoring health conditions, and receiving quicker medication changes from their doctors
McGillicuddy et al. (2013)	Kidney transplant recipients	Mobile phone based remote monitoring of medication adherence and physiological parameters	Kidney transplant recipients have a positive overall attitude toward mobile phone based health technology (mHealth)
Seto et al. (2010)	Heart failure patients	Mobile phone-based remote patient monitoring systems	Patients and clinicians want to use mobile phone-based remote monitoring and believe that they would be able to use the technology

8. Pfeifer Vardoulakis et al. (2012) studied the benefits and challenges of using the mobile phone as an information display from the perspectives of the patients. Their study shows that mHealth is a promising approach to improving patient awareness.

In regard to the role of mobile technology in health care management, many studies were conducted to understand if SMS has played a positive or negative impact on self-healthcare management. Most of the studies have confirmed the positive impact of short-message service (SMS) on healthcare. In the following, we briefly describe some of these studies:

In order to evaluate the feasibility of using SMS for asthmatic diary data collection, Anhøj and Møldrup (2004) conclude that SMS may be a tool for supporting self-management of asthma and possibly the other chronic diseases.

Wangberg et al. (2006) also tested the feasibility of using mobile SMS for sending information to people with diabetes. Their study shows that parents of children with diabetes were positive about this system and expressed their desire to continue to use it.

The studies of Rodgers et al. (2005) confirm that SMS has caused a significant and positive change in smoking cessation. In another study, Hurling et al. (2007) demonstrate that in regard to the management of patients' physical activity, SMS has caused positive significant change. Joo and Kim (2007) also conclude that in regard to anti-obesity behavior modification, SMS has caused a significant positive impact on weight reduction. Leong et al. (2006) also argue that compared to the mobile phone call, a text messaging reminder was effective in improving attendance in primary care compared with a no-reminder control.

The role of mobile applications for reporting test results (Menon-Johansson et al. 2006; Dhar et al. 2006) and the role of mobile apps for collecting data between appointments are the other topics that scholars have studied (Freedman et al. 2006; Collins et al. 2003). These studies all show the positive role of mobile phones in self-healthcare management of patients.

Of the other scholarly topics, we can mention the role of mobile phones as an educational and informative tool. Castaño et al. (2012) investigated the use of mobile phone as an educational and informative tool on oral contraceptive dosing reminders and educational messages. In another study, Perry et al. (2012) researched the effective role of text messaging for efficient delivery of educational informational health messages especially for culturally sensitive topics like sexual health to teenagers.

One of the other inquires in the literature is the use of mobile medical apps for increasing patients' adherence to medication. As the adherence cause matrix table, Table 2 shows, one of the patient-related factors that may refrain a patient from taking his/her medication is informational. The lack of comprehending the disease, misunderstanding the prescription, and treatment instruction are the other factors refraining a patient from taking medication.

Table 2 Impact of socio-economic factors on patients' health belief

Socio-economic factors such as	Patient health belief	Knowledge and informational
Lack of family and social support	Denial of diagnosis	Lack of comprehension of disease and treatment
Family financial support	Negative attitude to medication	Situational operational knowledge
Family emotional support	Belief in self-efficacy for taking medication	Misunderstanding of the prescription and treatment instruction

As this table shows, other factors affecting a patient's adherence is the patient-related demographic and social-economic factors (e.g. Costello et al. 2008; Lanouette et al. 2009; Julius et al. 2009) and the other domain is related to the patient's health belief (Munro et al. 2007). The last domain is knowledge and informational factors (Karamanidou et al. 2008; Vreeman et al. 2008; Jindel et al. 2003).

Studies by Lester et al. (2010) and Pop-Eleteches (2013) also confirm that in a developing country, such as Kenya, patients who received mobile messages through SMS had a significant adherence; so they conclude that "mobile phones might be effective tools to improve patient outcome in resource-limited settings" (ibid).

In another similar study of 16 kidney transplant recipients, Israni et al. (2016) conclude that all of the patients were interested in using a mobile app to remind them to take their medications.

Methodology

This is a quantitative study of the preferences of female patients visited the Health Houses and Rural Health Centers of Ardabil and Isfahan provinces from November 2015 until February 2016. The questionnaires were administered between these dates. The questionnaires were distributed among 461 patients. The sample size was 434 based on the formula of d = 0.4, Q = 0.5, p = 0.5 and a = %5. In order to determine the required sample size for each section, the determined sample size (434) was calculated with the number of admitted patients in the previous year at the same section. After rounding the number to its higher number, the number of required sample size was 461 patients.

The samples were selected systematically randomly regardless of the type of disease. The other eligibility criteria was not being admitted for psychiatric diseases. During their usual clinic visit, all patients who met the inclusion criteria were asked if they were willing to participate in the study. All patients who were approached for the interviews agreed to participate except 10 patients who declined to participate in the survey. A questionnaire was used to collect data. The questionnaire was designed by the authors based on the past studies and comments from other experts. The questionnaire was designed in two sections: some of the questions addressed patients' background and the other questions were yes or no answers or selecting an item based on a 4 scale multiple choice.

In order to assess the reliability of the questionnaire, the Spearman-Brown was used. The questions were divided into odd and even questions and the correlations between the two groups were calculated. The correlation was 38.0. The validity of the questionnaire was determined through surveys with faculty researchers. Data analysis was performed through descriptive statistics by using the SPSS software.

Results

Most of the respondents were between 20 and 30 years old (around 79%), and 80% of them were living in Tehran Province and 40% of them were not employed. In regard to their education, 30% had a diploma and 40% had not recieved diploma.

This research assessed the level of trust in a mobile health care app based on the perspective of female patients. Of 460, 50% of the respondents have high trust to a health mobile app, 33% have a medium level trust, and 7% responded they have low trust while 9% believed that they could not trust a mobile app as a health care tool. 4% did not express any opinion.

Of the four options of increasing health literacy, increasing interaction with a doctor, increasing interaction with a physician, increasing interaction with a health staff, 92% of the patients believed that a mobile app is a good tool to increase health literacy.

The other inquiry was how a mobile app can help a patient to increase their adherence to medication. 85% believed that receiving information regarding their "personal" diet and diseases through a mobile app by health staffs and physicians would increase their adherence to medication; 55% believed receiving alerts to take their medication, and 56% believed receiving "general" information on proper use of drugs would increase their adherence to medication.

The other inquiry was if a patient prefers a mobile app that would enable her to add comments regarding physicians and healthcare staffs. Only 24% expressed their positive attitude toward this functionality. 74% of the patients preferred to interact face to face interactions. Some of them believed that the comments of "strangers may be biased".

88% of patients preferred to set their appointments through a mobile app, with a condition that the app is owned and run by a clinic and not a third party. Also, 40% of the patients showed a tendency to virtually meet their physicians and receive

Table 3 Summary of the results of the questionnaire

Functionality	The mobile app as a tool to	Result %
Dynamic functionality		
Online reviews	Write comments online on a mobile app regarding physicians and other health related topics	24
Virtual meetings with the physicians	Have virtual visits and consultation with physicians through mobile apps	30
Virtual visits with health staffs	Have virtual visits and consultation with health staffs through mobile apps	20
Virtual visits with patients	Have virtual visits and consultation with other patients through mobile apps	35
Networking	Attend a network of adjacent health houses and centers	21
Knowledge	Attend online and interactive educational classes	45
Static functionality		
Medical records	Receive medical test results	85
Set an appointment	Set an appointment	88
Referrals	Receive referral letters	79
Knowledge	Use for increasing health literacy through documents	92
Methods of adherence to medication	To receive personal information on their diet and diseases	85
	Receive alerts to take medication	55
	Receive general information on proper use of drugs	56
Financial	Receive bills	79
	Pay medical bills	80

consultation through a mobile app. 79% of respondents preferred to receive their referrals through a mobile app.

In regard to using a mobile app to access and store their medical records, around 85% of the patients preferred to receive the results of medical tests and images on their mobile app “as access to them will be fast and they are available anytime and anywhere”.

In regard to the financial functions of a mobile app, 79% prefer to receive their bills through a mobile app, and 80% also prefer to pay their medical bills through a secure mobile app (Table 3).

Discussion and Conclusion

The results of this study show that female patients living in rural regions have a generally positive attitude toward using mobile apps for better managing and monitoring of their health. However, their willingness is toward static and top-down interaction. The patients do not assume a mobile health app as a platform to network; and to have interactive and virtual interactions.

This study suggests that apps can be easily integrated into personal life of patients if they are developed in accordance with their needs. The flexibility of mobile apps in terms of their functions is a key driver of their adoption among patients. While patients expressed a strong and high preference for static functions, they expressed a low tendency toward more engaging and virtual ones. Patients have a tendency to use mobile apps to recieve information and documents. Instead of picking up physical documents, they prefer to receive the healthcare related documents and information through mobile apps, such as receiving medical records or referrals.

In regard to adherence to medication, patients have a desire to know more about their specific health issues and to receive customized health information regarding their medicine and diet. This means the patients prefer to increase their own engagement on their health and lifestyle management.

To conclude, the possibility that female patients in rural areas accept telemedicine systems, such as mobile health apps are high due to restrictions and limitations that a villager face, such as time, weather, place and etc. On the other hand, since mobile as a telemedicine service is going to deliver health services through the most private tool a patient owns, its mobile phone, it is necessary that mobile apps offer health services that are in compatible with a patient's needs.

This study demands further investigations, such as what are the differences between developed and developing countries in regard to the functionalities of mobile health apps? What causes female patients in rural areas to refrain from virtual visits or another kind of interactive and engaging interaction with other stakeholders?

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Humanitarian Supply Chain Management: Extended Literature Review

Busra Gulnihan Dascioglu, Ozalp Vayvay and Zeynep Tugce Kalender

Abstract Humanitarian supply chain management (HSCM) has gained popularity in recent years in research fields. The aim of this paper is to review the literature on humanitarian operations and crisis/disaster management from 2010 to the latest researches, in order to identify the current research and to provide direction for future research in this growing field. Studies are classified considering the research publication year and research fields. Articles from humanitarian supply chain management were reviewed, and keywords were identified within a disaster management lifecycle framework. Research gaps are identified for future research areas.

Keywords Humanitarian supply chain management · Relief operations
Disaster

Introduction

Disasters are generally classified into two kinds, namely natural disasters such as floods, earthquakes, or hurricanes; and manmade disasters such as wars. These disasters can cause a significant degree of damage when they occur, a significant number of people are killed or die in these disasters. Humanitarian organizations are focused on delivering the demands and needs in such disaster situations, for helping

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Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_36

and saving as many people as possible. The more efficient the supply chain is, the more resources are available. However humanitarian organizations are still lack of the resources and tools for delivering to aid more effectively. To solve such problems that may occur and to help even more people the researchers in the last decade mostly focused on humanitarian organizations. The main researchers were made to make a connection between the donations and humanitarian organizations to deliver people in need when a disaster occurs. A disaster is defined by Centre for Research on Epidemiological Disasters (CRED) as a "situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (CRED http://www.cred.be). The disaster management is divided into two phases: the pre- and post-disaster phase. Activities belonging to the pre-disaster phase are dealing with the strengthening of vulnerable networks or the pre-positioning of relief items before the occurrence of a disaster. In the post-disaster phase, the distribution of first aid supply and the transportation of injured persons are of primary importance. Since the collaboration and organization in these disaster process are hard for communities and non-governmental organizations most researchers focused on defining and identifying key chains and key success factors in HSC. Pateman et al. (2013), made an extended literature review challenges in collaboration and coordination in disasters. Logistics and supply chain management directly effect humanitarian organizations since it is urgent to respond to a disaster (Leiras et al. 2014). The researchers have aimed to improve humanitarian operations and disaster management since the tragic loss of life and devastation associated with recent large-scale disasters (Goldschmidt and Kumar 2016). When a disaster occurs another important factor is the funding system. For supplying goods and services to the people in disaster areas, humanitarian organizations use funds from donors. In humanitarian supply chain management problems, it is a challenge to predict and make time-the dependent decisions since the natural disasters occur unpredictably. Researchers in this field model the uncertainties by two-stage stochastic programming approach. Grass and Fischer (2016), examined, classified and compared the two-stage stochastic models in HSCM and presented an extended literature survey for future researches. Burkart et al. (2017), had an extended literature survey at this limited but important and growing field. Analysed the funds and identified a promising area for future researches. Figure 1 shows the number of studies for each year.

The paper is organized as follows: Articles are classified by the scope of researches as in Fig. 2 and will be presented in Section "Humanitarian Supply Chain". Section "Conclusion and Discussion" describes a number of potential further research directions and concludes the paper.

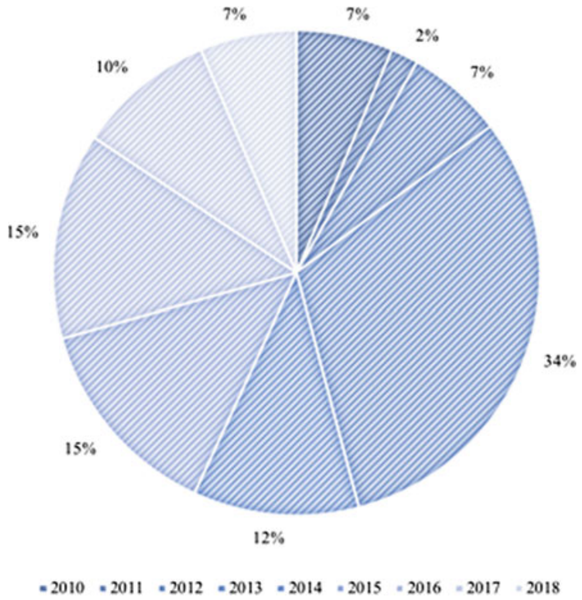

Fig. 1 Number of studies each year

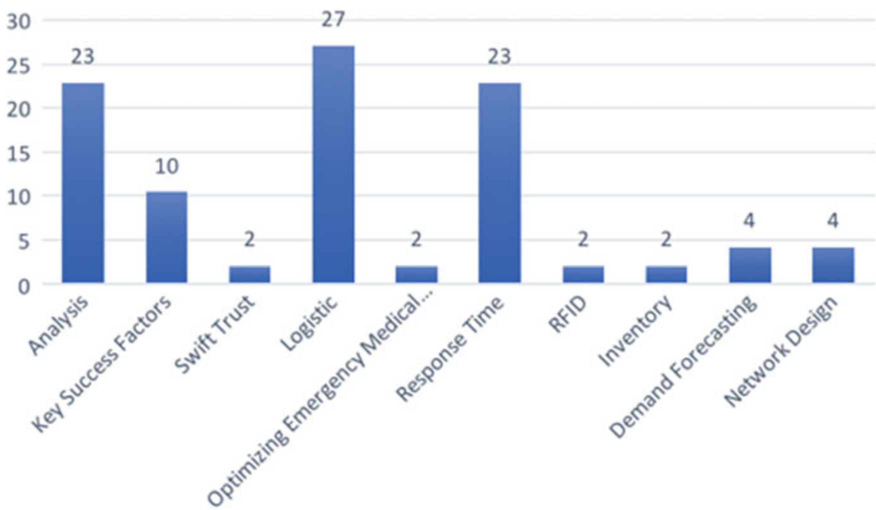

Fig. 2 Percentage of scopes

Humanitarian Supply Chain

Key Success Factors

Oloruntoba (2010), had researched about Cyclone Larry in Australia, which has been with effective emergency cyclone response in the history of northern Australia. He first collected data about the disaster and identified and analysed the key success factors in the emergency relief chain. The researcher aims to describe the disaster by impact, physical, social and economic characteristics and identifies the key success factors, so these factors can be learnt and implied in future disasters. The research that has been made by Roh et al. (2013), considers finding the critical key factors for selecting humanitarian relief warehouse locations as criteria of the developed analytical hierarchical process model. Researchers claim that national stability, cost, logistic opportunities, and location are the most important factors when selecting a warehouse for the humanitarian supply chain. For the first phase of the research, the researchers used the multi-criteria decision making method to consider and find the most important criteria for locating humanitarian supply chain warehouses. The study used and summarized results of the analytical hierarchy process to determine the weights of evaluation criteria. Scarpina and Silvab (2014), identified the critical factors of humanitarian logistics by using Balcik's theoretic model. The proposed Balcik's model considers factors such as availability, access, and security when making a decision. They aimed to clarify the roles of the chain such as suppliers, donors, beneficiaries, and distribution center. All connections between these factors in post-disaster had been explained. After explaining these factors, a case study in Blumenau-Brazil environmental disaster had been implemented and discussed. By implementing a theoretical model to a case study, this research proved the applicability of the model. Kabra et al. (2015), defined categories and criteria of coordination in humanitarian supply chain management. And implemented a fuzzy analytical hierarchical process and implied this model on Uttarakhand, India disaster as a case study. The research was divided into three phases. An extended literature review has been made and brainstorming sessions with experts had been made. Then the barriers to coordination had been found and grouped into 5 categories such as management, technological etc. barriers. Then a survey questionnaire was implemented, tested and refined and implied in Uttarakhand, India disaster. Then in the last phase fuzzy-AHP had been implemented and developed in the case study. The main aim of the research was to remove coordination barriers. The results were submitted. In West Africa 2014 Ebola outbreak was the largest outbreak in history, the disease had been affected several countries. Yadav and Barve (2015), after making a review of literature and consultation with experts had identified 12 critical success factor for the effective responsive humanitarian supply chain. After identifying factors the authors had implemented Interpretive Structural Modeling approach to interpret the interdependency among these selected critical success factors. Also, Cross-impact matrix multiplication applied classification had been used for analysing and illustrating the relative dependence power among selected factors. The authors claimed that government policies and organizational structure are the most dominating factor. The results had been summarized and explained as a conclusion.

Logistic in HSCM

Argollo da Costa et al. (2012), presented an analysis of the logistic procedures of emergency reliefs in four major international disasters; India 2004, Pakistan 2005, Brazil 2011, Japan 2011. The authors, claim that efficient in logistic is a key success factor since it ensures the efficient and quick flow of services and needs in the humanitarian supply chain. Based on the analysis some guidelines are identified and discussed in research, to support developing models in humanitarian logistics. Özdamar and Onur (2012), had considered solving a capacitated network flow model of humanitarian supply chain logistics network. The authors extended the definition of the UNDP's Disaster Management Program, Balcik et al. (2008) definition of the last mile distribution problem as "the last mile delivery and pickup problem" by including both delivery and pickup functions. The Disaster Coordination Center (DCC), provides air surveys over affected areas and coordinates the information flow in a post-disaster situation. DCC also provides aid materials to the survivors. The main problem considered in this research is requested demands often surpass the available capacity of transportation capacity, so the vehicles depart from warehouses to the hospitals with a full load. The goal of the research is to minimize the total travel time of vehicles and to promote efficient resource utilization while considering vehicle and supply availability restrictions. A hierarchical optimization procedure called "cluster first route second" had been considered. A mathematical model and heuristic approach had proposed for solving the proposed problem. Scenarios up to 1000 nodes are tested by proposed models and results are discussed. In another article, the authors aimed to propose a methodology to build an efficient and reliable routing and scheduling model. By developing the model the authors considered a fleet of vehicles with reliability considerations in the humanitarian response planning. First, the methodology was developed as a mathematical model for routing and scheduling humanitarian supply transportation. To apply the methodology for real and larger models a genetic algorithm based heuristic is proposed. A test had been implied to compare the performance of the mathematical optimization model and the heuristic algorithm. The multi-objective routing algorithm minimizes both the travel time and reliability cost. For small networks, an optimal solution can be provided by solving the mathematical model. A heuristic is proposed to deal with the large size problems. The results of both algorithms are compared by a statistical test (Hamedi et al. 2012). Balcik et al. (2012), analyzed and implemented a last-mile delivery problem model. For small instances, the problem was solved by MILP algorithm and for bigger problem types a heuristic approach was presented.

Ke and Feng (2013), has proposed a two-phase metaheuristic algorithm. This algorithm starts with a solution and at each iteration different local search operators are used by two independent phases and aims to improve the solution. This proposed algorithm is used for cumulative capacitated vehicle routing problem in this research. At the first phase, the algorithm finds potential customers and by that time the second phase focuses on minimizing the cumulative routing time. The results of this proposed two-phase algorithm are compared with the results of existing algorithms. The authors claim that this algorithm gives better solutions than existing algorithms. Taniguchi and Thompson (2013), proposed a multi-objective optimisation model of the distribution of relief supplies to displaced people in disasters. The model minimizes the penalty of a total shortage of supply and fuel consumption. The model was tested in the case of the Tohoku disasters in Ishinomaki city, 2011. Kusumastuti et al. (2013), considered information about the relief logistic network in Indonesia through interviews and focus group discussions from organizations in disaster management in Indonesia. The objective function of the proposed model's aim is to maximize the expected number of victims that can be covered by village level facilities during the considered periods of time. Two models were developed, the first model decides the facility locations at the village level and the second model determines the facility locations at the district level. Models were applied on 2007 Jakarta flood. In another research, the authors presented some military logistic dimensions of humanitarian relief organizations. The relationship between military and non-military organizations are discussed and logistic problems and planning factors in humanitarian relief are considered. New mathematical models were proposed for scheduling humanitarian relief distribution in a disaster relief operation. Air and land modes of transportation were considered in the planning and distribution of multiple classes of supplies to demand points in a disaster area (Sebbah et al. 2013). Rachaniotis et al. (2013), aimed to model the last mile distribution fleet management problem. To locate vehicle's hubs, allocate demand areas and vehicles, scheduling and routing in the case of development programs a stochastic model is proposed by the authors. The aim of the stochastic model is to minimize travel time. Bastos et al. (2014), focused on logistic operation in the humanitarian supply chain. The authors claim that logistic is the key factor in disaster response operations and to achieve efficient and effective logistics operations analysed seven documents focused on the logistics concepts, identified a set of logistic processes and applied these findings in disaster response operations in Brazil. In another article, the authors presented a three-stage mixed-integer stochastic programming model. The aim of the model was to plan the response of disaster, to open local distribution facilities, a preliminary allocation of supplies, and last mile distribution of aid. Stochastic elements of paper are presented as available vehicles for transportation, infrastructure state, and potential beneficiaries' demands. The model had been implied to Haiti's earthquake disaster and results were presented and analysed as result research (Rennemo et al. 2014). In their research Comes et al. (2015), had present a research which is based in Ghana and Liberia field research. The main aim of the research is to understand the decision-making and coordination of logistic processes and planning them. By implementing a model to case study some expert support a need and data collection process are based on these field research with experts. The disease was analysed and explained in this research. Moreno et al. (2016), developed and proposed two stochastic mixed-integer programming models. The models integrate and coordinate facility location, transportation and fleet sizing decisions in a multi-period, multi-commodity, and multi-modal context under uncertainty. The models also consider a first-stage fixed cost for each vehicle and one of the model considers the option of reusing vehicles to cover extra routes within the same time period. The authors developed a relaxed-and-fix and fix-and-optimize decomposition heuristic to solve the NP-hard problem of the mega disaster in the Mountain Region of the Rio de Janeiro. EVPI and VSS analysis were used to analyse considered scenarios. Another article focuses on supply chain disruptions and humanitarian logistics and aims to examine the response and recovery phases in post-disaster operations. The authors presented a goal programming based multiple-objective integrated response and recovery model. Model investigates strategic supply distribution and early-stage network restoration decisions. The model was implemented on Hazus-generated regional case studies, South Carolina and California. The developed goal programming model finds a solution by using soft constraints by usage of these soft constraints, it gets harder to gain a solution, but soft constraints are more likely to describe user requirements in a real scenario. In this research, the methodology was investigated and by the conclusion of that some key factors had been developed. Some of these key factors are summarized as a solution method, objective function formulation, and degree of compromise. The results of Hazus-generated earthquake scenarios were investigated by these factors and methodology and the results were analysed (Ransikarbum and Mason 2016). Fahimnia et al. (2017), presented a stochastic bi-objective blood supply chain model in disaster situations. A hybrid solution approach to the ε-constraint and Lagrangian relaxation methods is developed to solve the proposed model. The model minimizes cost and delivery time in the supply of blood. he authors presented a realist and relatively complex blood supply network, which considers the chains of which include blood donors, mobile blood facilities, local blood centers, regional blood centers, and hospitals. Numerical examples are implied and discussed as a conclusion.

Optimizing Response Time

Ertem and Buyurgan (2013), presented a procurement method for humanitarian logistic considering auctions. The auction model focuses on unique characteristics and restrictions of disaster relief environments by using a single round sealed-bid auction. By considering the supplier location in the procurement operations in humanitarian logistic also some perspectives on the timing of the procurement is discussed in the research. Simoes-Marques and Nunes (2013), presented an application of the Integrated System for Priority Management and Resource

Assignment. The model was developed to dynamically manage priorities, considering situational parameters and selecting adequate resources by considering emergency situations. The model implemented in the management of critical incidents resulting from emergency on board navy ships. The other implementation was made on complex infrastructures such as industrial facilities. The results were discussed as a conclusion. Granberg (2013), introduced the quantitative preparedness measures concept and proposes a methodology for constructing such measures. The researchers presented two case studies to illustrate how can the proposed methodology be used in practice. The first case study concerns hurricane disasters and the second concerns emergency medical services during routine emergencies. Other research focuses on hurricanes which are natural disaster and researchers claim that they are possible to plan and efficiency of post-disaster is possible. The research develops a mathematical model which prepositions supply in preparation for disasters where the destruction of stored supplies is allowed and developed several theoretical properties such as when only one of the facilities is destroyed, none of them is destroyed and both of them are destroyed. These tests have statistical dependence. Then performed some computational tests which demands are considered as stochastic to prove the applicability of developmental models. The computerized test was made in Katherina's Hurricane disaster. Since the mathematical model can't capable of solving large problems a clustering methodology had been proposed. The sensitivity tests are applied to the results. The results and conclusion explain the contribution of the article and present the results (Galindo and Batta 2013a, b). Kumar and Havey (2013), aimed to build a structure which can support the network authority for organizing the efficient humanitarian supply chain. The study emphasized to evaluate a social and infrastructure system which can function well prior, during and after a disaster. The authors used the fault tree method for analysing and building short, middle and long-term response times. Short-term response is providing initial requirements such as food, water, medical care, and shelter. Middle-term response time provides cleanup of debris and a small level of rebuilding. And the long-term focus on rebuilding. The fault tree will be used to develop and integrate efficient and effective framework for the Japanese Tsunami disaster in March 2011. The developed model can be integrated and used with possible future Tsunami disasters. Chakravarty (2014), had proposed two stage decision making model, identify and analyse demand/inventory quantity and response time before and after a disaster occurs. The disasters intensity, strike probability, infrastructure disruption, and the actual damage make coordination in a human chain complex because of the uncertainties. In this research, proactive as a stage before a disaster occurs and reactive as after a disaster occurs has been explored. The main aim of the research is to categorize disaster intensity into a rapid response and large relief quantity in each range, to adjust the response quantity and time, to find a relationship between the effectiveness of the relief strategy and disaster intensity. The results of the decision making model are summarized and explained. Lassiter et al. (2015), aimed to minimize the cumulative unmet demand and maximize volunteers' preference after a disaster. In order to achieve the goals, the authors had developed a flexible optimization framework to allocate volunteers dynamically. A robust optimization was used to handle uncertainty in task demands in the considered scenarios. By considering the maximization of volunteers' preference to enable decision makers to derive Pareto optimality and allocation decisions for any degree of conservativeness a constraint had presented in the model. The authors claimed that their proposed model was shown to be tractable for a wide variety of problem sizes that humanitarian supply chains may face. Dufour et al. (2017), focused on analysing the potential cost benefits of adding a regional distribution center in Kampala, Uganda, to the existing network of the United Nations The Humanitarian Response Depot in order to better respond to humanitarian crises in East Africa. In this research, the authors used fieldwork, simulation, network optimization, and statistical analyses. The study aimed to assess the costs of repositioning high-demand non-food items in Kampala and to propose a robust stocking solution. The researchers analysed field studies in Italy, the UAR and Uganda, collected data and defined the problem. Then the network flow model was developed. Several demand scenarios for East African delivery points had created, the results were compared and discussed by sensitivity analysis. Sahebjamnia et al. (2017), proposed a hybrid decision support system which contains three level humanitarian relief chain; consisting of a simulator, a rule-based inference engine, and a knowledge-based system. The coverage, total cost and response time are considered as three main performance measures of the system. In this research, the simulator calculates the performance measures of the different structures of the humanitarian relief chain under different disaster scenarios. Then, a rule-based inference engine builds the best configuration of the humanitarian relief chain includes facilities' locations, relief items' allocation and distribution plan of the scenario based on the calculated performance measures. The best configuration for each scenario is stored in the knowledge-based system. The results of a case study in Tehran are developed and analysed.

Demand Forecasting and Inventory Management

Rekik et al. (2013), considered and modelled the situation faced by decision makers in the first hours after disaster discussed the network design and humanitarian aid distribution problem and proposed a solving approach which solves both the network design problem and the distribution problem. For network design problem, researchers used three models to determine the number and the location of humanitarian aid centers and their resource allocation. And for the distribution problem to determine transportation routes a distribution model was proposed. For discussing different alternative solutions, a multi-criteria analysis based on TOPSIS method was used. As a conclusion, researchers proposed these solution approaches as a Decision Support System and claimed that this system can be used in emergency situations. Díaz-Delgado and Iniestra (2014), did a detailed research on flood risk assessment and its relationship with the humanitarian logistic process design. The timing and size of the flood are estimated by using a forecasting model while these data are essential for prediction. Once this information is known the authors provide two models; for defining humanitarian aid and evacuation plans, including processes and metrics of the network. These both models had implied on flood disaster in Tabasco, Mexico, which occurred on 2012. The results were analysed as the conclusion of the research. Laan et al. (2016), since that humanitarian aid organizations are short-term emergency relief demand planning can be challenging by forecasting methods. Data of the standardized consumption data of the Operational Center Amsterdam of Me decins Sans Frontie res (MSF-OCA) regarding their nineteen longer-term aid projects and over 2000 medical items consumed in 2013 had been collected for analysing the proposed analysis. Several internal and external factors influence forecasts and order planning performance. Therefore the authors had implemented insight into the demand planning and distribution operations, through a case study at MSF-OCA. Then a statistical analysis of monthly consumption and forecasting data over 2000 medical items had been empirically explored among the impact of internal and external factors on forecasting and order planning performance. Then the opportunities for further improvements are identified based on case study and in humanitarian logistics organizations in general. Cao et al. (2018), aimed to maximize the lowest disaster victims' satisfaction of relief operations and minimize the deviation of victims' satisfaction for their demand and sub-phases by proposed multi-objective mixed-integer nonlinear programming model and genetic algorithm for larger problems. The models were tested in the Wenchuan earthquake and results were compared respectively.

Network Design

Gunnec and Salman (2011), considered an earthquake in Istanbul. The researchers considered Istanbul highway network utilized a Monte Carlo Simulation algorithm and compared the related and not-related links by analyzing the performance of the proposed algorithm. Florez et al. (2015) had aimed to design a humanitarian coherent network. While designing the network the authors claim to guarantee good performance levels of efficiency and resilience. The researchers developed a stochastic multi-scenarios program. After developing, the model had been used to design, humanitarian supply chain in Peru as a real-life application case. In conclusion, the authors had discussed the benefits and limits of the result. Kabra et al. (2015), identified ten critical factors in the use of Information Technology in HSC in the Indian context through a literature survey and by gathering expert opinion. A cause-effect relationship diagram was developed by decision-making trial and evaluation laboratory (DEMATEL) method for identifying the critical factors. Tofighi et al. (2016), proposed a two-echelon humanitarian logistics network design problem involving multiple central warehouses and local distribution centers and developed a novel two-stage scenario-based possibilistic-stochastic programming approach. The research was tested with the case study of Tehran for potential earthquakes in pre- and post-disaster situations. The authors determined the central warehouses' and local distribution centers' locations by inventory levels for the relief supplies. The model considers the availability level of the transportation network's routes after an earthquake and uncertainties in supply and demand data. Then the proposed model, minimizes total distribution time, the maximum weighted distribution time for the critical items, the total cost of unused inventories and weighted cost of unmet demands. A hybrid uncertainty programming approach is developed to cope with a range of uncertainties when designing a humanitarian relief chain.

Others

Tatham and Kovács (2010), aimed to understand the swift trust in hastily formed networks since trust is one of the most important factors of a humanitarian supply chain. Since trust increases the team motivation and performance. The authors first determined and analysed disaster relief in hastily formed networks and developed different routes to them. The swift trust model has been presented and they claimed to suggest new ways to set swift trust in hastily formed networks. In another article, the authors aimed to illustrate how to design optimal supply chains, how to implement this designed supply chain into uncertain, risky humanitarian logistics. The authors examined the International Federation of the Red Cross' process through a 10-year retrospective. Then the decentralized humanitarian supply chain's performance during the Yogyakarta earthquake in 2006 had evaluated (Gatignon et al. 2010). McLay et al. (2012) used zero-inflated Poisson regression, multiple linear regression, and logistic regression models to characterize the volume and nature of emergency medical service (EMS). By usage of these models, an effective EMS response system aimed to be built. The authors point that almost all models allocate EMS resources to focus on normal operating condition however, EMS systems must work effectively during every condition to respond patients. The researchers consider the weather events effect on the volume and nature of EMS by applying a three regression models. This analysis was implemented on a data set from Hanover County, Virginia and the results were compared to find more efficient regression model.

Özgüven and Özbay (2013), proposed an extensive methodology for real-time tracking for emergency supplies and demands by using RFID technology integrated multi-commodity stochastic humanitarian inventory management model. By aiming the minimum cost the multi-commodity stochastic humanitarian inventory management model based on the Hungarian Inventory Control Model which was presented by Prékopa (2006), determines the optimal emergency inventory levels. Also, a simultaneous perturbation stochastic approximation has been used which is based on-line function approximator for controlling the highly stochastic and uncertain conditions during the extreme events. By implementing these two methods a model-free closed loop feedback based inventory control strategy was developed so even in uncertain conditions the models would work effectively. For real data that this model-free feedback strategy requires the RFID based tracking system to keep track of dynamic changes. A sensitivity analysis with pLEPs algorithm had been made to prove the contributions of study. Agostinho (2013), focused on improving humanitarian chains main problems such as defining internal operational factors and determining the best order for implementing these factors. An algorithm had been proposed to identify and classify these problems. Galindo and Batta (2013a, b), extended a previous review from Altay and Green (2006). Both studies are about how to evaluate OR/MS in HSC. The researchers covered articles from after 2006 and extended the identified gaps in previous research. A comparative analysis was presented about the common assumptions in recent OR/MS literature in HSC. Haavisto and Kovács (2015), aimed to develop a framework for cascading innovation in HSC, evaluated innovative public procurement. The researchers then discussed the implications of innovation in humanitarian supply chain. In another article, the author considers five different cases related to kites. The aim of the authors' research was to manage the capabilities of a large humanitarian organization to help support kit management. The method was used in a multiple case study on activities managed by a UNICEF (Vaillancourt 2016). Noham and Tzur (2018), developed a mathematical model and a Tabu-search method for improving supply chain performance in post-disaster decisions. The authors used data from the Geophysical Institute of Israel and measured the applicability. Rahmani et al. (2018), presented a robust model for cope with the facility disruptions after an earthquake. A Lagrangian relaxation model was proposed and the performance of methodology is tested in Tehran.

Conclusion and Discussion

Table 1 shows the methods used for solving problems presented below. Mostly mixed-integer linear programming and stochastic programming methods are used for solving problems in the humanitarian supply chain management area.

This paper has presented a review of the recent papers on humanitarian supply chain management. A total of 50 papers was presented. By classifying the studies in terms of scopes and solution methods, this paper not only serves as a guideline for researchers and practitioners that are not familiar with this area, but it also aims to help researchers in the field of the humanitarian supply chain to detect research gaps in this body of literature.

With the increase in the number of disasters the number and variety of problems related to saving human lives expected to increase. This requires that the researchers working in this area be aware of prior work over different problem types and across disciplines, for which this paper aims to serve as a starting point. We found that in HSCM swift trust, RFID, network design, inventory management, and demand forecasting areas are not much studied areas and there is a gap in these areas.

Table 1 Methods

Article	Exact solution methods				Metaheuristic methods		Heuristic methods	
	MILP	Regression	Stochastic programming	MCDM	Genetic algorithm	Tabu search	Heuristic methods	Fuzzy MCDM
Gunnec and Salman (2011)							✓	
Balcik et al. (2012)	✓						✓	
Özdamar and Onur (2012)	✓*				✓			
Hamedi et al. (2012)	✓*				✓			
McLay et al. (2012)		✓*						
Agostinho (2013)							✓	
Kumar and Havey (2013)							✓	
Ertem and Buyurgan (2013)	✓*							
Özgüven and Özbay (2013)			✓					
Galindo and Batta (2013a, b)	✓*							
Granberg (2013)	✓*							
Ke and Feng (2013)	✓*							
Kusumastuti et al. (2013)							✓	
Rachaniotis et al. (2013)			✓					
Rekik et al. (2013)			✓					
Roh et al. (2013)				✓				
Sebbah et al. (2013)	✓*							
Simoes-Marques and Nunes (2013)				✓				
Taniguchi and Thompson (2013)	✓*							
Chakravarty (2014)				✓				

(continued)

Table 1 (continued)

Article	Exact solution methods				Metaheuristic methods		Heuristic methods	
	MILP	Regression	Stochastic programming	MCDM	Genetic algorithm	Tabu search	Heuristic methods	Fuzzy MCDM
Rennemo et al. (2014)			✓					
Scarpina and Silvab (2014)	✓*							
Florez et al. (2015)			✓				✓	
Kabra et al. (2015)			✓					✓
Yadav and Barve (2015)	✓							
Lassiter et al. (2015)	✓							
Kabra et al. (2015)								✓
Laan et al. (2016)	✓*							
Moreno et al. (2016)			✓				✓	
Tofighi et al. (2016)			✓					
Ransikarbum and Mason (2016)	✓*		✓					
Fahimnia et al. (2017)	✓*							
Cao et al. (2018)	✓*				✓			
Noham and Tzur (2018)	✓*					✓		
Rahmani et al. (2018)							✓	

*Mixed-integer linear programming and regression is regression analysis

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Green Hospital Together with a Lean Healthcare System

Hatice Camgoz Akdag and Tugce Beldek

Abstract Green hospitals and Lean Healthcare Systems are both dealing with increasing efficiency and effectiveness by decreasing waste/non-value added activities and cost in healthcare institutions. When both of the issues are used and applied, it can be seen that green hospitals will encourage more effective and efficient usage of energy, water and material currently used, ensure the prevention of any kind of waste, perform environmentally sensible and eco-friendly building design and be environmentally friendly in the process of service provision. In addition, lean heathcare will decrease waste, costs, non-value added activities, increase patient, doctor, nurse, and staff satisfaction, decrease waiting times, increase performance and finally increase revenues. The aim of this study is to give information about the concept of the green hospital with a lean healthcare system when applied jointly. It demonstrates the applicability of the concept of green hospitals in the healthcare sector together with lean management. The study examines the contribution of these two concepts to healthcare institutions as well as to the environment. For this purpose, in this study, the concept of green, green healthcare, lean management, and lean healthcare is defined and the joint application of green and lean healthcare is presented as a suggestion. The implementation of environmentally friendly green strategies, together with lean strategies to healthcare within the framework of social responsibility and in this respect extended employees, patient and community awareness can be suggested to both public, university and private hospital managers for developing and improving the sustainable lean healthcare systems.

Keywords Green hospital · Green building · Lean management
Lean healthcare · Sustainability

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_37

Introduction

Today growing industries are causing pollution that affect our lives directly. It gives harm to our health and is a big threat to the next generation. In this case, green products and services are becoming more popular. Production systems are being customer focused to meet their requirements on time, with high quality. Even in the construction industry, it is important to manage every step, beginning with the building design to the demolition. The consideration must not just be with the aesthetics or the usage of the building the resource efficiency must also be reached. As a solution, green building design reduces usage of raw materials at the initial stage, which will result in a higher percentage of recyclable materials for a sustainable structure. If the design phase considered, architectures and civil engineers are the only ones who have a role in making a building "green".

Another important topic is to provide customer needs on time and in a turely manner. This goal can be reached by some calculations in a production line but it is more difficult for a service sector. Especially in healthcare systems, it is more important to give a high quality service to the patients. When the human life is considered, it is vital to start the treatment quickly. Waiting is the biggest problem at the hospital, which increases the risk of exacerbation of the disease. Even at the beginning of the healthcare system, patients try to get an appointment at the hospital and wait for long periods, sometimes for months, to see the doctor.

This kind of delays leads to the integration of lean management and healthcare systems. Lean management aims to eliminate actions, which do not add any value to the process that is defined as "waste". Elimination of non-value added tasks shortens the lead-time of the process, which means to reach customer more quickly. Some lean management tools can provide the current state of hospitals departments. It will be more efficient to integrate green principles with lean thinking to a hospital. With the usage of "green" materials and making the building sustainable with its every kind of energy usage, eliminating "waste" types at a medical service line will completely fit each other to satisfy patient on time with a high quality of treatment.

The aim of this study is to give information about the concept of the green hospital with a lean healthcare system when applied jointly. It demonstrates the applicability of the concept of green hospitals in the healthcare sector together with lean management. The study examines the contribution of these two concepts to healthcare institutions as well as to the environment. For this purpose, in this study, the concept of green, green healthcare, lean management, and lean healthcare is defined and the joint application of green and lean healthcare is presented as a suggestion. Lean management and its principles will be defined in the following section and then green building definition will be extended to green hospital design. As a result, the integration of lean in healthcare systems and green hospitals will be discussed.

Literature Review

Lean Management

Lean Manufacturing, which is also named as "Toyota Production System (TPS)" was a new process-driven production system for the industry, founded by Japanese leaders (Abdulmalek and Rajgopal 2007). The main aim of lean manufacturing is to get rid of the "waste" while increasing the quality of the product (Sundar et al. 2014). Kilpatrick (2003), classified waste types in eight different ways: producing more than the need, inventory, defects, waiting, transportation, extra motions, non-value added activities and the unused human ability. These waste cost nearly 95% of the whole production cost which is mentioned by Taiichi Ohno who is one of the leaders of TPS (Kilpatrick 2003). Lean principles mainly aim to make a sustainable production line while eliminating non-value added activities. This line has to work with customer orders which means a pull system (Sundar et al. 2014).

In August 1997, a non-profit organization "Lean Enterprise Institute, Inc." was founded by Womack (2000). He aimed to explain lean thinking in accordance with the Toyota system which is being used by many different sectors spread wide (URL 1). The Lean Enterprise Institute website gives detailed information about lean principles which is summarized in Fig. 1.

Not only in manufacturing but also service industry uses lean principles in spite of the application of mentioned ones are certainly different. The difference is that many service area works with a pull system, which means the customers' needs trigger the production of the service. If the system has problems in terms of the process, then waiting periods will be longer (Maleyeff 2006).

Fig. 1 Lean principles (https://www.lean.org/WhatsLean/Principles.cfm, retrieved 05.03.2018)

Lean in Healthcare

In a production line, lean manufacturing aims to create a high quality product and an on-time shipment to the customer. In Canada, these lean principles are concerned for healthcare systems because of the excess patient amount (Ng et al. 2010). Recovery of the patient is the total of the value created in the medical service. For this reason, as mentioned for the production line, also in the healthcare sector, the process has to be customer-based, that means patient-based at a hospital (Kujala et al. 2006).

In a healthcare system, to reach a "perfect" medical experience, delays, waiting times in a queue, unnecessary repeating actions, and false applications should be eliminated or at least minimized. When lean principles are adapted to health care systems to create value, some issues have to be considered such as patients, tax-payers and service providers' equality and the legal issues for costing while reaching the required pleasant level for patients. Even tough every process in a production line is known by its standards, in a service line especially at a hospital, patients' road is not clear due to different examination results. This uncertainty causes more complicated systems to be analyzed (Young et al. 2004).

Waste definition differs from sector to sector so that when health care systems are considered, mostly documentation is accepted as "waste". Also, the whole process flows and the hardware of the hospital can yield non-value added activities (Campbell 2009). These non-value added activities corresponds to following waste types in a healthcare system:

– Doing diagnostic tests more than needed,
– Patient, personnel, equipment, document, etc. transportation,
– On hand inventory of both medical and non-medical equipment,
– Documentation more than needed or duplicated,
– Waiting,
– Errors,
– Unnecessary motions (Machado Guimarães and Crespo de Carvalho 2013).

Dammand et al. (2014) studied at Denmark hospitals to find out effects of lean management in healthcare systems. Data gathered from a university hospital showed that lean principles increase patient satisfaction and performance of medical services. These increases were reached by eliminating non-value added activities such as waiting times of patients, unnecessary movements of personnel and documentation via using lean tools such as value stream mapping and Kaizen applications (Dammand et al. 2014).

Green Building Design

Like any other industries, green production is very popular today at construction sites. At the design phase, architectures are considering different types of shapes and materials to provide energy saving. Green building design provides savings in different scopes: nearly 30% energy, 35% carbon, 30–50% water usage, 50–90% waste cost savings will be reached (Council 2001). The main reasons for constructing green buildings at the U.S. are given in Fig. 2.

There are different definitions of green building in literature. A green building is better designed than a traditional building in case of its effect on the environment. Another definition is the building that provides an important development and innovation within its environment. Green building is not only the consumer but also a manufacturer of energy and water. During its life cycle, it presents the healthiest environment while using water, energy and land sources efficiently (Terekli et al. 2013). The growth of the green building market at the U.S. is shown in Fig. 3.

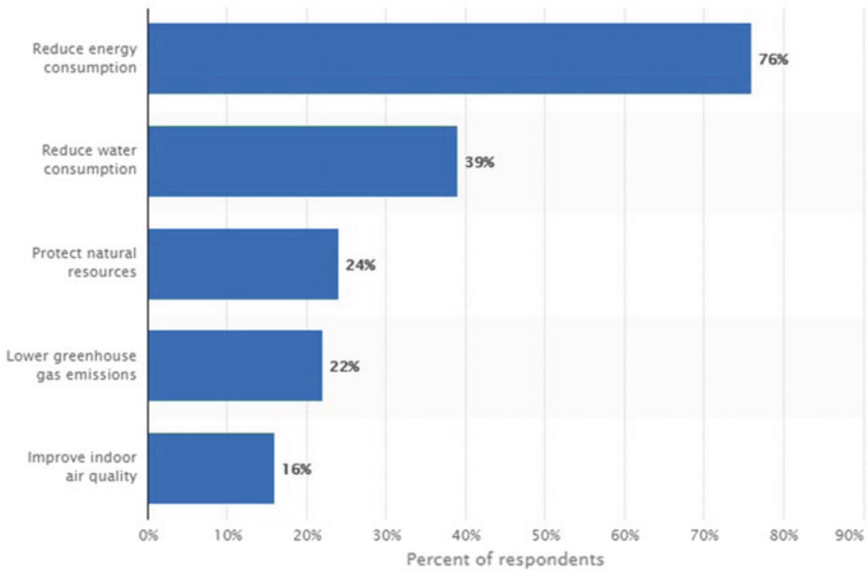

Fig. 2 Main reasons to construct green buildings at the U.S. by 2015 (https://www.statista.com/statistics/616594/top-environmental-reasons-driving-green-building-activity-future-in-the-us/, retrieved 21.03.2018)

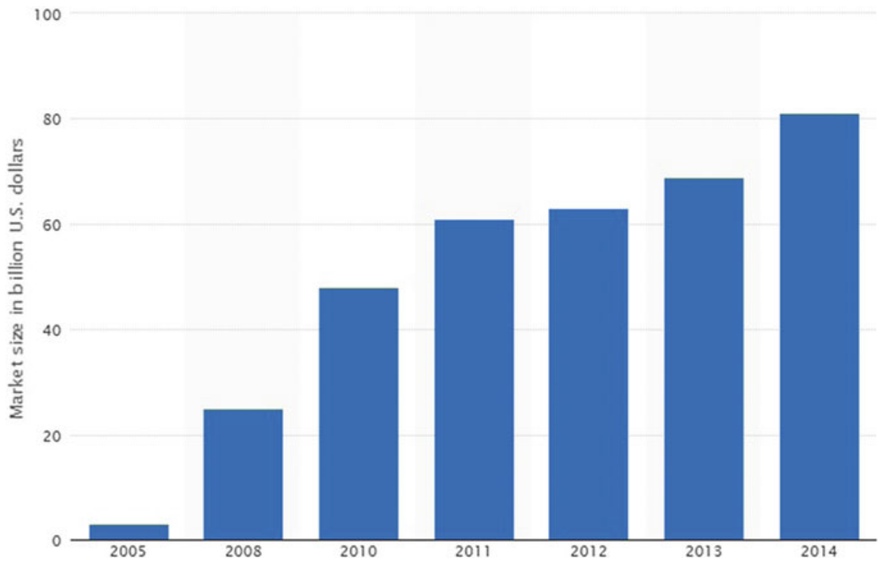

Fig. 3 The growth of green building market at the U.S. (in billion U.S. dollars) (https://www.statista.com/statistics/248060/value-of-us-green-building-market/, retrieved 21.03.2018)

Green Hospital and Its Key Elements

The Green Hospital is defined as a hospital that has taken the initiative to do the one or more of the following: choose an environmentally friendly site, utilizes sustainable and efficient designs, uses green building materials and products, thinks green during construction and keeps the greening process going. A Green Hospital is constructed around a facility that recycles, reuses materials, reduces waste, and produces cleaner air (URL 3). In 2002, the American Society for Healthcare Engineering (ASHE) published the Green Healthcare Construction Guidance Statement, the first sustainable design guidance document emphasizing a health based approach (ASHE 2002).

The Green Guide for Health Care, the healthcare industry's first best-practices, voluntary green building tool, modeled with permission after the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) rating system, was initiated in 2002, followed by periodic updates and the registering of pilot projects to bolster participation (Anderson et al. 2004). While emphasizing the importance of integrated design, the Green Guide is organized in two sections—construction and operations—to facilitate its use. Using the Green Guide for Health Care as a foundational reference document, the LEED for Healthcare Application Guide development process began in 2004. With its release anticipated in 2007, LEED-Healthcare will represent the first third-party green building certification tool customized for the healthcare sector. The rapid market uptake of these tools and resources is manifested today in more than 40 million ft^2 of green healthcare facilities, representing about 180 healthcare projects. These include more than 100 Green Guide pilots, six LEED certified projects, and about eighty LEED-registered projects. By embracing a life-cycle view of human health and environmental stewardship as strategic definers of success, this new generation of healthcare tools—and the buildings they guide—is poised to accelerate the adoption of health-based green building standards in other sectors (Guenther 2016).

A network "Global Green and Healthy Hospitals" gives ten goals to reach required sustainable health care systems (URL 4):

1. Give importance to the environmental health,
2. Find substitutional materials instead of harmful ones,
3. Minimize healthcare waste, and or dispose of them in a proper way,
4. Use renewable energy systems,
5. Use potable water and minimize the water consumption,
6. Develop new transportation systems for both patients and personnel,
7. Provide healthy food,
8. Manage medical products in a safe manner,
9. Support green building design and construction,
10. Purchase sustainable materials.

Green building operations are vital for both the environment and people. The growing trend of environmental awareness and practice in management (especially supply chain) systems has had its effect on many sectors, including healthcare and hospitals. Having touched upon Green supply chain and Green management in general, turning towards Green practices in hospitals, starting with the, again the US focused—Hospitals 2020 initiative, which aims—to accelerate the development, use, and diffusion of environmentally preferable products, practices, and construction of Green buildings in hospitals and medical practices worldwide. The seven key elements include hospitals' food, water, and (alternative) energy consumption, waste production, and related factors of building design, energy efficiency, and transportation in and around the hospital. World Health Organizations seven key elements for the green hospital are as follows (URL 2):

1. With efficiency measures, reducing cost and energy consumption
2. Building to reduce resource and energy demand and being sensitive to climate conditions
3. Producing/consuming clean, renewable energy
4. Make personnel and people coming to the hospital prefer walking and cycling
5. Sustainability of producing/consuming green food for personnel and patients
6. Reducing waste and using alternative disposal techniques
7. Finding safe alternatives to save water instead of bottled ones

In the United States, different certification types are owned by hospitals. The most qualified types of LEED certification, gold, and platinum are owned by nearly 28 hospitals (URL 5). Indian Green Building Council also have members who have

LEED certification. Kohinoor Hospital is the first in Asia and second in the World as a platinum LEED certification owner, which has 150 beds and placed in Mumbai (Rich et al. 2013).

Integration of Lean Management and Green Hospital

It is hard to implement a new system for a whole project. For this reason, architectures should think of the green building principles at the beginning of the design phase. Both green building design and lean principles will result in the economic and social benefits (Camgöz-Akdağ et al. 2016). Lean management will decrease patient waiting times, queue length and especially it will provide a standardized application in the whole medical treatment system. An example is shown in Fig. 4 to implement lean and green together for a hospital supply chain system.

Integration of lean principles both with the goals of the green building leads to a more efficient healthcare system for patients. This integration includes all internal management structure to ease the adaption in every step of the medical care (Zhu et al. 2018).

Continuous improvement and efficiency increase at every step of healthcare services can be provided by implementing both lean and green at the same time. An example from New Jersey, Capital Health Replacement Hospital, shows the results of getting a LEED silver certification and planning its facility according to lean principles. Even patient rooms were designed very same for medical staff to

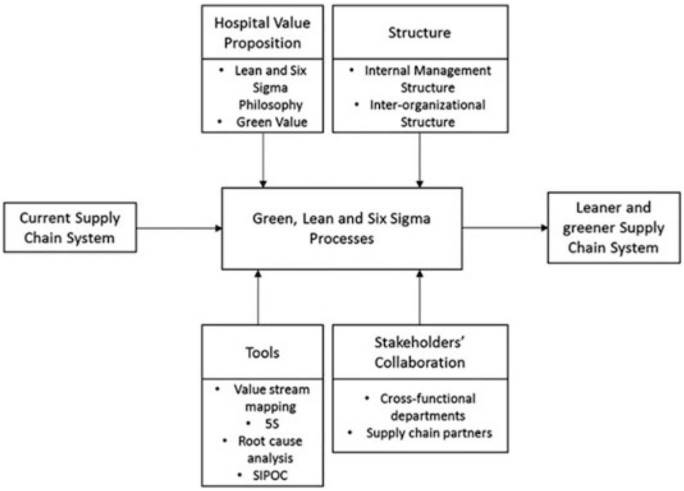

Fig. 4 Integration of lean and green to a hospital supply chain system (https://www.tandfonline.com/doi/full/10.1080/16258312.2018.1426339?scroll=top&needAccess=true, retrieved 23.03.2018) (Zhu et al. 2018)

increase their efficiency during treatments. The equipment in every room is placed in the same area and the whole corridors are designed to clearly see every patient who needs help emergently (URL 6).

Conclusion

The aim of this study is to give information about the concept of the green hospital with a lean healthcare system when applied jointly. It demonstrates the applicability of the concept of green hospitals in the healthcare sector together with lean management. The study examines the contribution of these two concepts to healthcare institutions as well as to the environment. For this purpose, in this study, the concept of green, green healthcare, lean management, and lean healthcare was defined and the joint application of green and lean healthcare was presented as a suggestion.

In conclusion, it is obvious that green and lean thinking is very integrated into the definition. They have so many common topics to make the related system sustainable. With green principles, the whole construction of the hospital will be considered as environmental-friendly. "Green" building will provide energy, water and any kind of consumption efficiency. When thinking about a hospital, it is vital to use safe systems for patients in terms of "healthy environment". With the lean principles application, the process of every kind of medical experience inside the hospital will create value for the patients' health. Useless, unnecessary and non-value added tasks will be eliminated and the lead time for leaving the hospital will be minimized.

Both green and lean principles are patient oriented so their moral will also raise while getting the treatment on their way inside the hospital. It is clear that green building completion with lean management principles will result in a healthy and sustainable environment.

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The Relationship Between Risk Management and Patient Safety Incidents in Acute Hospitals in NHS England

Gulsum Kubra Kaya

Abstract In healthcare, a number of applications have been applied from high-risk industries to minimise the risk of harm. However, there is little formal evidence to demonstrate the relationships between those applications and their contributions to patient safety. In this study, a correlation analysis was conducted to explore the link between risk management and patient safety incidents in hospitals in NHS England. Findings revealed that hospitals with the highest risk management level report more incidents and demonstrate a statistically significant relationship between risk management and patient safety incidents data. In contrast, hospitals with lower risk management levels do not demonstrate any statistically significant relationships. This study concludes that reporting a higher number of incidents is likely to be as a result of having a better risk management in hospitals, which indicates that a higher number of incidents reported refers to having a better incident reporting culture.

Keywords Risk management · Patient safety · Acute hospitals

Introduction

Patient safety has been a primary goal in healthcare (Vincent and Amalberti 2016). To ensure patient safety, healthcare organisations have been encouraged to learn from safety-critical industries (Sujan et al. 2016). Risk management, for instance, has been undertaken in hospitals, in which incident investigation and risk assessment are essential parts of it (DoH 2015; Dückers et al. 2009; Agnew et al. 2006). Incident investigation considers 'what went wrong?', and risk assessment investigates 'what could go wrong?' to ensure patient safety in hospitals (Wreathall and Nemeth 2004; Ward et al. 2010). In turn, risk management considers both before

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_38

and after an undesired event as well as ensures a number of activities such as communication, documentation, and monitoring.

National Health Service (NHS) England has made considerable efforts to undertake effective risk management in hospitals. Healthcare staff have been encouraged to report incidents and risks (Sujan et al. 2017); a number of reports have been published to guide both incident investigation and risk assessment (NPSA 2008, 2009); and a number of organisations have been established to support and investigate hospitals on their risk management activities. For instance, the National Reporting and Learning System (NRLS) was established to create a central patient safety incident reporting database and share lessons learnt, and the National Health Service Litigation Authority (NHSLA) was established to investigate risk management. Both organisations are now under the umbrella of NHS Improvement (NHS Improvement 2016). Regardless of these efforts, there is little evidence to demonstrate the significant contribution of risk management to patient safety (Sujan et al. 2016; Hudson et al. 2012). In fact, measuring safety in healthcare itself is challenging, and it is not solely about measuring harm (Vincent et al. 2013). However, since risk management considers an adverse event in the form of before (as a risk) and after (as an incident), effective risk management should contribute to patient safety.

In this study, we aimed to explore the relationship between risk management and the number of patient safety incidents experienced in acute hospitals in NHS England.

Methodology

Assumptions

In this study, there were three assumptions made. First, the level of risk management was determined by the use of NHSLA investigation reports on the assessment of hospitals' risk management practices. The NHSLA used to assess hospitals' risk management levels on a scale of 1–3 (NHSLA 2013). Level 1 assessment was seeking whether the hospital describes and documents the process for managing risks; Level 2 whether the process for managing risks, as described in Level 1, is in use; and Level 3 whether the process is described, used, monitored and necessary changes have been made. All three levels of the assessments were undertaken by considering hospitals' capability of meeting 50 predetermined requirements. It is, therefore, the hospitals achieved Level 1 were called as hospitals with the 'lowest risk management level'; Level 2 as the 'moderate risk management level'; and Level 3 as the 'highest risk management level'.

Second, this study assumed that there is a logical relationship between the elements of risk management and how they might help improve safety (see Fig. 1).

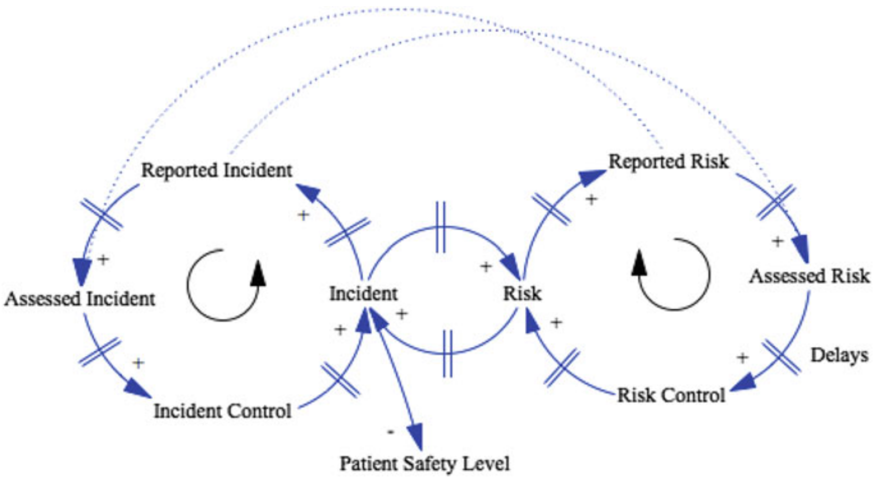

Fig. 1 The relationship between incident investigation and risk assessment

A greater level of risk would lead to a higher possibility of incidents as well as a higher number of risks reported and, in turn, more to be assessed and controlled. Similarly, a higher number of incidents would increase the number of incidents reported and, therefore, assessed and controlled. After controlling the risks and incidents, fewer incidents are expected to occur in the future, and thus an increased level of safety. However, multiple other factors might delay or reduce the influences of these relationships such as legal, cultural, regulatory and financial factors from an individual, organisational and society perspectives (Barach and Small 2000; Illingworth 2015; Berwick 2002; Hutchinson et al. 2009). This study, therefore, assumed that fewer incidents should occur in hospitals having good risk management practice, and tested this assumption through a correlation analysis of real-life data.

Third, this study assumed that the data collected in this study is reliable to be analysed since the data were collected from NHS organisations.

Data Collection

This study collected risk management and patient safety incident data from all acute hospitals in NHS England (n = 160) to explore the relationship between risk management and the number of patient safety incidents. The number of patient safety incident data were collected from the NRLS website for a six month period (between 1st April 2014 and 30th Sept 2015) (NRLS 2014), and the level of risk management data was obtained from the NHSLA website (NHSLA 2015).

Table 1 A list of variables used for the correlation analysis

Data source/Type	Variables (V)
Data from the NRLS	
Incidents	V1: The total number of incidents
The degree of harm	V2: The number of incidents resulting in severe harm
	V3: The number of incidents resulting in death
Incident categories	V4: The number of access, admission, transfer and discharge-related incidents V5: The number of clinical assessment-related incidents V6: The number of consent, communication, confidentiality-related incidents V7: The number of documentation and records-related incidents
	V8: The number of implementation of care and ongoing monitoring/review-related incidents
	V9: The number of infrastructures (including staffing, facilities, environment)-related incidents V10: The number of medical device/equipment-related incidents
	V11: The number of medication-related incidents
	V12: The number of patient accident-related incidents V13: The number of treatment and procedure-related incidents
Data from the NHSLA	
The assessment of risk management	V14: The total number of requirements met (out of 50 requirements) for the assessment of risk management levels (i.e. 1, 2, and 3)

In total, 14 variables were described for the analysis, of which 13 are in relation to incident data, and 1 to risk management as shown in Table 1.

Analysis of Data

A total of 157 out of 160 acute hospitals' data were analysed due to the missing values in some of the variables. The collected data were divided into 3 groups depending on the hospitals' risk management levels. 72 hospitals were at the lowest risk management level; 41 hospitals in the moderate risk management level; and 44 hospitals in the highest risk management level. Following that, a correlation analysis was conducted to observe relationships between the variables.

The statistical Package for the Social Sciences (SPSS) software version 22 was used to conduct statistical analysis. As almost all data were abnormally distributed, bivariate correlations analysis was used for Spearman Correlation Coefficient and p values. Two-sided statistical tests were used in correlation analysis, and a significance level of $p < 0.05$ was used.

Results

The Trend in Incident Reporting Based on Risk Management Levels of Hospitals

Figure 2 shows the trend of incident reporting based on risk management levels. Hospitals with the lowest risk management level reported an average of 3751 (standard deviation: 2344) incidents in a six month period, while those with the moderate level reported 3863 (SD: 1607), and those with the highest level reported 4209 (SD: 2779).

Results demonstrated that the average number of incidents reported slightly increase when hospitals have a higher risk management level.

The Relationship Between Risk Management and Patient Safety Incidents

There was statistically non-significant correlation found between risk management and incident data (13 variables) for hospitals with the lowest and moderate risk management levels. However, hospitals with the highest risk management level established moderate correlations between their incident and risk management data. Table 2 shows the results of correlation analysis for those with a significant level of $p < 0.05$.

Hospitals with the highest risk management level confirmed a statistically significant relationship between the number of incidents reported and risk management data ($p = 0.005$, correlation coefficient 0.413). Additionally, some incident types

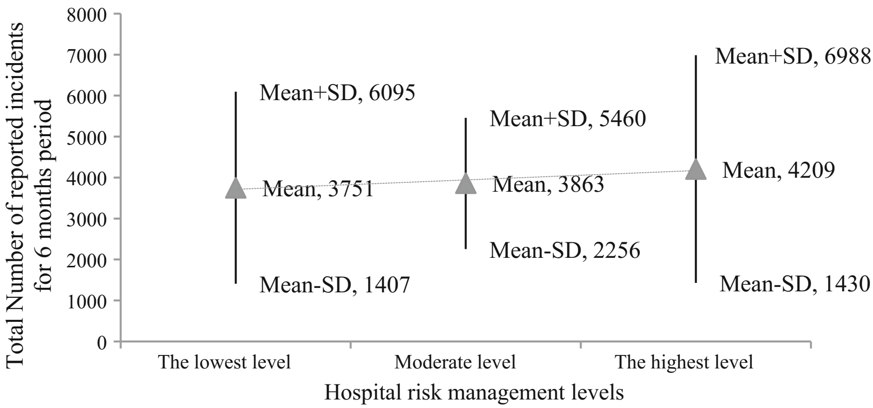

Fig. 2 The total number of incidents reported for 6 months period based on hospitals' risk management levels

Table 2 Incident reporting data relationship to risk management data

Risk man. data	Incident reporting data							
	Number of incidents reported	Incident categories						
		Access, admission, transfer and discharge	Consent, communication, and confidentiality	Documentation and records	Infrastructure	Medical device	Patient accidents	Treatment and procedure
Hospitals with the highest risk management level (N = 44)	$p = 0.005$, $r = 0.413$**	$p = 0.015$, r = 0.366*	$p = 0.029$, r = 0.33*	$p = 0.002$, r = 0.462**	$p = 0.044$, r = 0.305*	$p = 0.014$, r = 0.369*	$p = 0.004$, r = 0.43**	$p = 0.017$, r = 0.358*

*Significance 0.05, **Significance 0.01

demonstrated a correlation with the achievement of the highest risk management level. The strongest positive correlation was observed between documentation and records-related incidents and risk management data (p = 0.002, correlation coefficient 0.462). This means that reporting the documentation and records related incidents has a positive influence on the achievement of the highest risk management level. However, no statistically significant correlation was found between the degree of harm and risk management data.

Discussion and Conclusion

The findings of this study revealed that a higher risk management level in hospital leads to a higher number of incidents reported as well as the better correlation between the risk management and patient safety incident data.

In contrast to high-risk industries, reporting incidents is claimed to be as a result of a mature reporting culture (Barach and Small 2000; Vincent 2006; Francis 2015; Hutchinson et al. 2009). Therefore, the findings indicate that hospitals with a higher risk management level have a better safety culture in, and refute the assumption made earlier “fewer incidents should occur in hospitals having good risk management practice”. Since risk management has been applied to improve safety in healthcare, this also refutes the general understanding of “safety is measured by the number of incidents occurred”. Indeed, the incident reporting rate is claimed not to be a strong evidence to measure the level of safety (Howell et al. 2015).

In healthcare, the measurement of safety is a very challenging issue, and it is difficult to demonstrate the significant contribution of risk management to safety. Measuring safety should not only consider past harm, but also reliability, sensitivity to operations, anticipation and preparedness, and integration and learning (Vincent et al. 2013). Similarly, effective risk management should have some considerations in all these aspects. It is due to likely that only data from hospitals with a higher risk management level demonstrated statistically significant results.

However, the results of this study should be viewed in light of some limitations. The reliability of the data may also be arguable on the grounds of data quality and validity. The NHSLA assessment may not reveal the quality of hospitals actual risk management practice, but still, the assessment should reflect their standard practice. In addition, the NHSLA encourages all hospitals to involve in the assessment by providing a financial incentive in case of their achievements at an upper level (Hutchinson et al. 2009). Similarly, the NRLS patient safety incident reporting data might not reflect the actual number of incidents experienced in hospitals. In the literature, it was also claimed that the incident is being under-reported in hospitals (Shojania and Dixon-Woods 2016). However, it is mandatory to report all serious patient safety incidents in hospitals in NHS England (NHS 2015), and this study also used such data to correlate risk management and incident data.

Overall, this study showed that hospitals with a higher risk management level report more incidents due to having a better incident reporting culture. This indicates that reporting more incidents does not mean that the hospital is less safe.

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The Problem with Traditional Accident Models to Investigate Patient Safety Incidents in Healthcare

Gulsum Kubra Kaya and Halime Tuba Canbaz

Abstract In healthcare, a number of patients experience incidents, where accident models have been used to understand such incidents. However, it has been often traditional accident models used to understand how incidents might occur and how future incidents can be prevented. While other industries also use traditional accident models and built incident investigation techniques based on the traditional models, such models and techniques have been criticised to be insufficient to understand and investigate incidents in complex systems. This paper provides insight into the understanding of patient safety incidents by highlighting the problems with traditional accident models to investigate patient safety incidents, and gives a number of recommendations. We hope that this paper would trigger further discussions on the fundamental concept of the incident investigations in healthcare.

Keywords Accident models · Incident investigation · Patient safety

Introduction

In healthcare, the incident rate is estimated to be between 6 and 25% of the patient admissions (Baker 2004; Landgrigan et al. 2010). Incidents not only lead to patient harm, but also to financial loss, psychological harm to healthcare staff, reputational damage and so on (Davies 2014; Barach and Small 2000). It is, therefore, considerable efforts have been made to minimise the occurrence of incidents in

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_39

healthcare (Hayes et al. 2014; Vincent and Amalberti 2016; Sujan et al. 2015). For instance, hospitals adopted incident reporting system from aviation (Mitchell et al. 2016), and used a range of techniques to investigate incidents (NHS England 2015; Woodward et al. 2004; House of Commons 2015; Center for Chemical Process Safety 2010). However, such efforts have not demonstrated significant contribution to preventing incidents, and criticised due to underreporting rates, the quality of the reports, inadequate use of techniques and insufficient investigations (Sari et al. 2007; NHS 2015; Vincent 2007; Macrae 2016; Lawton and Parker 2002; Barach and Small 2000). Indeed, researchers discussed problems with incident investigations with often focusing on the use of Root Cause Analysis (Peerally et al. 2016; Card 2017). However, there is little evidence to highlight the problems with the accident models, where such techniques were built on (Perneger 2005; Reason et al. 2006).

Accident Models

Accident models have been developed to understand incidents, and so to prevent similar ones. Hollnagel (2004) divides these models into three categories, sequential (e.g. domino model) (Heinrich 1931), epidemiological (e.g. Swiss Cheese Model) (Reason 1997a, b) and systemic (e.g. FRAM and STAMP) (Hollnagel 2004; Leveson 2004). Figure 1 shows representative examples of their use when investigating the wrong medication incident in a hospital.

Sequential models imply that accidents transpire as a result of sequential events occurring in a specific order (Hollnagel 2004). A specific type of accident potentially follows the same route and series of events (Huang et al. 2004). The domino model is the first model for this way of thinking. Based on the domino model, all accidents result from the social environment leading to a fault of the person, which results in unsafe acts, which lead to an accident and, in turn, an injury (Heinrich 1931). The domino model suggests that accidents can be prevented by removing one of these five blocks so that the domino effect is interrupted (Hollnagel 2004). Among these five blocks, Heinrich focused on the removal of the fault of the person. His study found that 88% of preventable accidents result from the unsafe acts of persons, 10% result from the unsafe machines and 2% are unavoidable (Heinrich 1931). Thus, this model considers humans as the main reason for the accident.

The principles behind the sequential models have been used to built incident investigation techniques, including 5 Whys, Root Cause Analysis, Bow-Tie or Barrier Analysis and Fault Tree Analysis (Mullai and Paulsson 2011; Hollnagel 2004). While these techniques have been successfully applied in a range of industries, the sequential models have still been criticised to be insufficient to explain incidents in complex systems. Epidemiological models were, therefore, developed to understand and investigate incidents more sufficiently.

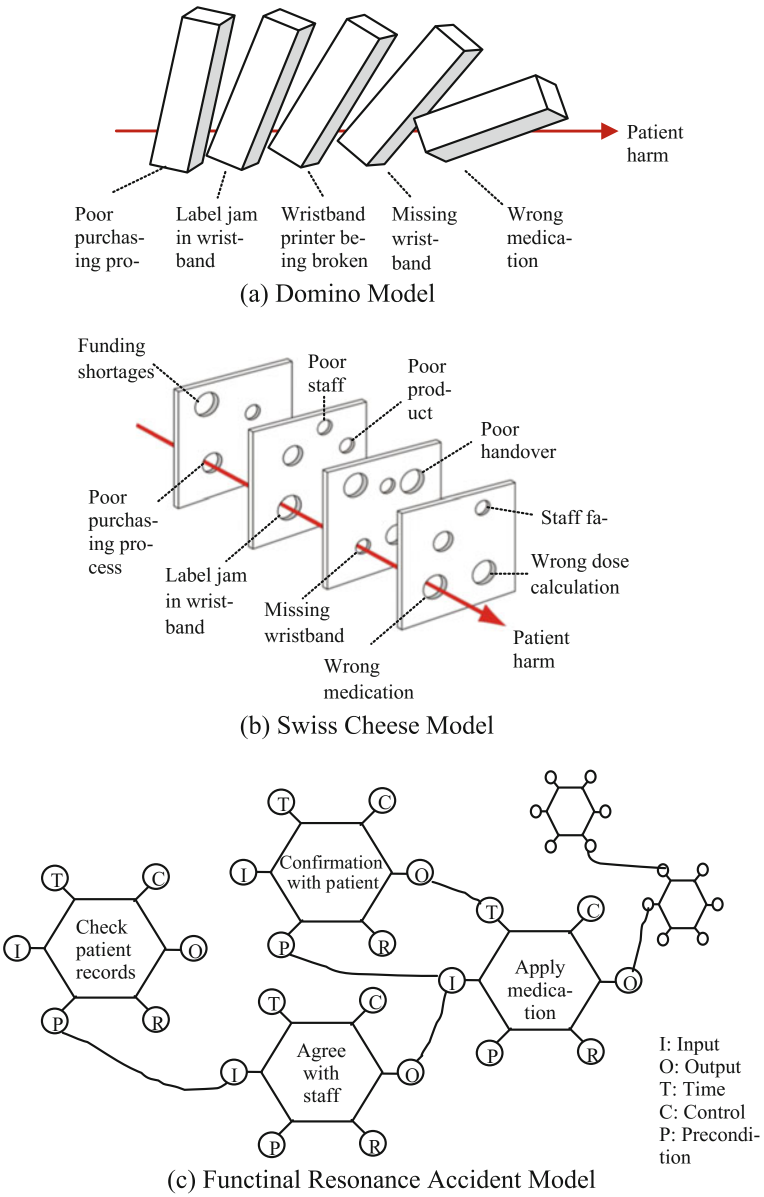

Fig. 1 Representative examples for the application of accident models in wrong medication incident

Epidemiological models view accidents as a result of a combination of factors, which include environmental conditions, performance deviations leading to unsafe acts as well as latent conditions. Such factors pass through system barriers and defences, and, in turn, can lead to accidents. Adding barriers, therefore, can prevent accidents in these models (Hollnagel 2004; Hollnagel et al. 2014; Reason 2000). The Swiss Cheese Model (SCM) is a well-known epidemiological model (Reason 1997a, b). It has been widely accepted in healthcare (Perneger 2005). This model emerges from a triggering event through different levels of barriers from institution to technical. Since these barriers might not be perfect, weaknesses may exist due to latent conditions and active failures. If hazards break through all the "*holes*", this could lead to harm or loss (Vincent 2010). However, epidemiological models still follow the principles of sequential models and, therefore, limit the understanding of incidents. In turn, both of these sequential and epidemiological models were considered as traditional models, and systematic models have been developed to fully understand incidents (Hollnagel et al. 2014).

Systemic accident models have been built on systems theory. In systems theory, multiple factors act concurrently and accidents arise from combined mutually interacting factors (Klockner and Toft 2015; Leveson et al. 2016). Therefore, the interaction of these factors must be considered to understand the accidents and prevent similar ones (SIA 2012; Hollnagel 2004). Accimap (Rasmussen 1997), the Functional Resonance Accident Model (FRAM) (Hollnagel et al. 2014) and the Systems-Theoretic Accident Model and Processes (STAMP) (Leveson 2004) are the examples for systemic accident models.

In the healthcare literature, a few studies have used systemic models (Alm and Woltjer 2010; Clay-Williams and Colligan 2015; Pawlicki et al. 2016; Leveson et al. 2016; Chatzimichailidou et al. 2017). For instance, Clay-Williams et al. (2015) used FRAM and revealed the difference between '*work as done*' and '*work as imagined*'. Alm and Woltjer (2010) used FRAM and uncovered a number of systematic interdependencies within a surgical procedure. Pawlicki et al. (2016) used Systems Theoretic Process Analysis (STPA) and revealed a comprehensive list of causal scenarios as well as a number of unsafe control actions.

Indeed, hospitals are complex by nature, and accidents occur due to several interacting factors. It can, therefore, be expected that hospitals should use incident investigation techniques, which are built on systemic models.

The Problems with Traditional Accident Models

Safety researchers have been accustomed to explain accidents by traditional accident models, which apply the cause-effect way of thinking for centuries. However, defining a sequence of events for an accident does not always lead to the accident itself (Hollnagel et al. 2014). The limitations of the traditional models are summarised as follows:

- They are not adequate for complex systems, and might not explain today's accidents (Leveson 2011).
- Accidents are defined by a chain of events (Leveson 2011).

- Understanding is limited, where active failures play a major role to lead to an accident (Shorrock et al. 2005).
- These models do not provide relationships among causal factors (Luxhoj and Kauffeld 2003).
- Defence layers are not independent and, therefore, one layer may erode another one (Dekker 2002).
- Holes on the layers do not explain where the errors specifically are, what they consist of, and how the holes lead to an incident when there is a change in the system (Dekker 2002; Shappell and Wiegmann 2000).
- Latent conditions can be too difficult to control (Shorrock et al. 2005).

Additionally, Reason, himself comments on SCM by saying

> the pendulum may have swung too far in our present attempts to track down possible errors and accident contributions that are widely separated in both time and place from the events themselves. (Reason 1997b, p. 234).

With all the limitations given, the use of traditional models may result in overlooking some important accident causation factors or using resources ineffectively and thus contribute to more serious incidents in the future. Consequently, the question that arises is how to prevent this from happening? The safety literature addresses this challenge by introducing new models, including FRAM (Hollnagel 2004) and STAMP (Leveson 2004). While FRAM sees the glass as half-full by considering how to sustain success in daily works, STAMP sees the glass as half-empty by considering how to sustain sufficient safety control structure in the systems.

FRAM suggests that accidents occur when systems are unable to tolerate the system variances. This model focuses on performance variances in system functions and links among these functions by considering how things go right rather than how things go wrong (Hollnagel 2004).

STAMP considers that accidents occur when systems are poorly controlled or individual controllers do not perform their responsibilities (Leveson 2004; Leveson et al. 2016). This model focuses on the changes of technology and software, human behaviour, organisational culture and process by time (Leveson 2004).

On one hand, the systemic models can help fully understand incidents occurred in the complex settings of the healthcare system. On the other hand, not all parts of the healthcare system are complex, and so accidents may be able to be understood through the use of epidemiological models. Furthermore, many other complex industries also use epidemiological models and even use methods that were built on sequential models. For instance, Fault Tree Analysis and Event Tree Analysis are still successfully used in nuclear industries. Accident models can, therefore, be selected depending on the system needs, safety objectives and the complexity of the situations and the different parts of the healthcare system may thus require the use of different or a combination of accident models.

It should be also noted that while a few papers have been published regarding the effectiveness and use of the systemic models in healthcare (Clay-Williams et al. 2015;

Alm and Woltjer 2010; Pawlicki et al. 2016; Leveson et al. 2016), these models were found to be difficult to implement as well as time-consuming to use (Larouzée and Guarnieri 2015; Carthey 2013; Roelen et al. 2011).

Discussion and Conclusion

In healthcare, incidents have been explained by the use of traditional accident models. Consequently, it is likely that patient safety incidents might not be understood well, and the true lessons from the incidents might not be learnt. Paving the way towards addressing this problem, it is recommended for incident investigators to consider the following factors.

- Be aware that accidents may occur at any time.
- Recognise that accidents may result from changes in the system, system failures, inadequate interactions among system elements, performance variances, system design, and inadequate controls as well as latent conditions and active failures.
- Determine the use of systematic accident models or a combination of traditional and systemic accident models to understand incidents.
- Consider the limitations of the existing patient safety investigation techniques as they were built on traditional accident models.

While traditional accident models claimed to pass their sell-by date (Reason et al. 2006), the systemic models have not passed the quality control yet. Thus, there is no ideal way to understand and investigate incidents. Perhaps, there is still a need to develop a simple, but effective accident model for the healthcare use alone. Or perhaps, these models should be combined with each other depending on the nature of the situations and the extension of the system under analysis. However, experiences from other industries have shown that accidents occur as a result of multiple interacting factors.

In this paper, recommendations provided might offer insight into acting in relation to understanding patient safety incidents. We hope that this paper would trigger further discussions on the fundamental concept of the incident investigations in healthcare.

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A Markov Decision Process Approach to Estimate the Risk of Obesity Related Cancers

Emine Yaylali and Umut Karamustafa

Abstract Around 13% of the world's adult population was obese in 2016 and the prevalence of obesity increased at a significant rate in the last decade (Deitel in Obes Surg 13:329–330, 2003). One of the health consequences of obesity is an increased cancer risk. In this study, we model obesity levels based on BMI, cancer, and death using a Markov decision process model in order to observe the effect of obesity on cancer and mortality risks. The objective of the model is total discounted quality adjusted life years and we simulate an individual's lifetime from 20 to 70 years by sex. Actions available to the decision makers are no intervention and bariatric surgery. Bariatric surgery is one of the effective clinical prevention methods of obesity and it is particularly recommended for morbidly obese patients. However, it is also associated with increased mortality risk. Our model aims to observe this complex dynamic between obesity, cancer and mortality risks and bariatric surgery. We parametrize the model using randomized clinical trials and published literature and obtain the optimal policy by sex. Our results suggest that obese patients for all obesity levels should undergo bariatric surgery to improve their health outcomes and to decrease cancer risk. This study has the potential to provide guidance to the obese individuals when considering bariatric surgery and it could be further enhanced by the addition of other health outcomes of obesity to the model.

Keywords Medical decision making · Markov decision process
Stochastic modeling · Cancer · Obesity

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_40

Introduction

Cancer is the second most common cause of death in the worldwide, just after heart disease. In 2015, cancer caused 8.8 million deaths globally (World Health Organization 2018). One of the major causes of cancer is obesity, which is ranked second right after tobacco use. According to the Cancer Progress Report of the American Association for Cancer Research (AACR), obesity is the reason for approximately 25% of cancer cases (American Association for Cancer Research 2017). Most common obesity related cancers are kidney, endometrial, liver, colorectal, pancreatic, breast, and thyroid cancer. National cancer guidelines recommend losing weight to decrease the risk of cancer (Wiseman 2008).

Likelihood of obesity related cancers could be correlated with the degree of obesity level. Obesity level is measured by the body mass index (BMI). BMI is related to weight and height of an individual. BMI can be calculated as the weight divided by the square of the height and it is expressed in units of kg/m^2. According to the World Health Organization (WHO), persons with BMI more than 30 kg/m^2 are categorized as obese and there are three stages of obesity. Stage 1, 2 and 3 obese relate to BMI between 30 and 35, 35 and 40, and above 40 kg/m^2, respectively (World Health Organization 2011). Stage 3 obesity is also referred to as morbid obesity.

Obesity is estimated to involve around 1.7 billion people in the world and the prevalence of obesity is increasing at an alarming rate in both developed and developing countries (Deitel 2003). To prevent and reverse obesity, behavioral and clinical interventions could be applied. Behavioral intervention strategies include increasing physical activity, dietary changes, healthy eating habits, and decreasing stress. The most common clinical intervention of obesity is laparoscopic sleeve gastrectomy (bariatric surgery). Although there are debates over the selection of interventions, diet therapy is found to be relatively ineffective in the long term (Buchwald et al. 2004). Therefore, bariatric surgery has been recommended for morbidly obese persons and obese persons with significant comorbidities such as type 2 diabetes (Buchwald and Oien 2013).

In this study, we explore the relationship between cancer and obesity with the help of a Markov decision process (MDP) model. We develop an MDP model where the states are stages of obesity, cancer and death and actions are no intervention and bariatric surgery. The aim of the model is (i) to estimate the risk of developing cancer when obese and (ii) to optimize interventions for obesity while maximizing total discounted quality-adjusted life years. While bariatric surgery reduces obesity stages, it also increases mortality risk due to surgery. Our model explores this trade-off and analyzes the optimal strategy that maximizes the overall health of an individual with respect to their BMI.

MDPs are often employed in modeling a different variety of cancers such as breast (Ayer et al. 2012), prostate (Zhang et al. 2012) and colorectal (Leshno et al. 2003). Ayer et al. developed a partially observable Markov decision process to model progression of breast cancer and developed personalized mammography decisions to maximize total expected quality adjusted life years. Their optimal screening policies also minimized the number of mammograms and false-positive test results (2012). Zhang et al. explored the optimal timing of prostate biopsy decisions based on PSA screening results of patients using a partially observable MDP of prostate cancer and parametrized their model using Mayo Clinic data and published literature (2012). In another study, Leshno et al. conducted a cost-effectiveness analysis of screening for colorectal cancer with the help of a partially observable MDP which simulated stages of colorectal cancer and they suggested screening is cost-effective for average-risk individuals (2003). There are other studies where MDP is applied to model progression of cancer and other chronic diseases as screening and diagnostic methods. Recommendation on how to develop and use Markov models for health care problem can be found at Siebert et al. (2012) and a tutorial on how to formulate MDP models and review of MDP models applied to chronic diseases can be seen at Steimle and Denton (2017).

Most common types of mathematical modeling techniques that are used to model obesity and its related factors are Markov modeling and simulation. Markov models, agent-based simulation and dynamic simulation are often employed due to the complex structure of obesity and its relationship with many diseases. For a short summary of these modeling techniques and their application, see Hammond (2009). These models are often employed to estimate clinical and economic implications of obesity, effectiveness, and cost-effectiveness of prevention methods including bariatric surgery. Su et al., for instance, developed a Markov-based microsimulation to estimate medical expenditures and costs associated with obesity by obesity stages (2015). In a similar study, Sonntag et al. compared the lifetime costs of obesity by socio-economic status using a simulation model (2017). Schauer et al. estimated the impact of bariatric surgery on the lifetime expectancy of morbidly obese patients with a Markov model (2010). Ekwaru et al. evaluated the cost-effectiveness of a healthy living and eating program in schools (2017). A Markov decision analysis was constructed to compare a diet and exercise program and bariatric surgery while improving life expectancy by Patterson et al. (2003). Stroud et al. simulated a Markov model to estimate the timing of bariatric surgery, i.e. whether to have surgery while adolescent or delay surgery until adulthood for morbidly obese patients and observed that early surgery is favored in improving health outcomes (2016).

There are several statistical studies in the literature explores the relationship of cancer, obesity and the effect of bariatric surgery in decreasing the risk of cancer. Schauer et al. observed that weight loss after the bariatric surgery was associated with a lower risk of cancer incidence, however, there was no independent effect of the bariatric surgery on cancer risk based on a large retrospective matched cohort from four US states (2017). Similarly, another study reported that the bariatric surgery resulted in lower cancer risk, probably related to weight loss from a retrospective cohort of severely obese patients in Utah between 1984 and 2002 (2009). On the other hand, Swedish Obese Subjects (SOS) study suggested that the bariatric surgery was associated with reduced cancer incidence in obese women but not obese men (2004). Our model combines mathematical modeling approaches with these statistical studies to analyze cancer and obesity simultaneously and to the best of our knowledge, it is the first mathematical model and Markov decision process model to do so.

The model presented in this study is general to have any type of reward function and the reward function could also depend on the chosen action and current state pair. We select total discounted quality adjusted life years (QALYs) as our main outcome measure. Therefore, the reward function we use in our model is QALYs by state. We do not include disutility of bariatric surgery in the reward function and we only assume the increased mortality risk for bariatric surgery.

QALYs are common measure in the economic analysis and modeling studies in the medical decision making problems. QALYs are assumed to be one for one life year of perfect health and zero for death. Any number between zero to one corresponds to a health state with imperfect health which could be due to pain, disability, illness and side effects of treatment etc. (Gold et al. 1996).

Although the cost of bariatric surgery is significant, we do not include the cost of surgery in our model. Bariatric surgery is covered by insurance in Turkey for morbidly obese patients and the purpose of our study solely focuses on health outcomes of surgery/no surgery decision and cancer risk of obesity, this omission is acceptable in this situation.

We assume the success of bariatric surgery in decreasing BMI only depends on the obesity level and sex. We have not considered other factors such as age, the overall health of patient and comorbidities in the effectiveness of the bariatric surgery. Similarly, we assume that cancer risk is stationary over time. In other words, cancer risk does not change with age or other factors and it depends on obesity level and sex. Although some of the omitted factors may play an important part in transitions between healthy, obese and cancer states, we left addition of these factors starting with age for future research.

The remainder of this paper is organized as follows. In Section "Methodology", we present a Markov decision process model of obesity and cancer including parameter estimation. In Section "Results", we present numerical results of the model and we discuss our key findings, limitations and future research directions in Section "Discussion and Conclusion".

Methodology

Model Formulation

We formulate a discrete-time, finite-horizon discounted MDP model of this problem. The transition probabilities and the reward function are assumed to be stationary. The notation used in the model is as follows.

t: Decision epoch where $t = \{0, 1, \ldots, 70\}$, $t = 0$ represents age 20 and $t = 70$ represents age 90.

s_t: Health state at time t. Note that $s_t \in S = \{1, 2, 3, 4, 5, 6\}$ where $s_t = 1$ corresponds to healthy (non-obese and no cancer); $s_t = 2, 3$ and 4 correspond to stage 1, 2 and 3 obesity, respectively; $s_t = 5$ corresponds to cancer due to obesity or other related causes, and $s_t = 6$ is death from cancer or other related causes.
a_t: Action taken at a time t. Note that $a_t \in A = \{DN, BS\}$ where DN is no intervention or do nothing and BS is undergoing bariatric surgery.
$p_t(s_{t+1}|s_t, a_t)$: Probability that a person will be at the state s_{t+1} given that he/she was at state s_t and selected action a_t at time t.
P: Transition probability matrix, i.e. $P = [p_t(s_{t+1}|s_t, a_t)]$ where $s_t, s_{t+1} \in S$ and $a_t \in A$. Obesity and cancer risk of female and males are substantially different, as a result, we developed separate transition probability matrices for females and males. Considering two actions, a total of four transition matrices are estimated for this model.
$R_t(s_t)$: Expected reward of a person with health state s_t at time t. Rewards are measured as quality-adjusted life years (QALYs) where reward othe f being in a healthy state is 1, death state is 0 and all other states are between 0 and 1.
$V_t(s)$: Maximum total expected a discounted reward that the person can attain when her current state is s until time t.
γ: Discount factor, $0 \le \gamma \le 1$.

Figure 1 shows the state-transition diagram of the MDP. The model allows movements between non-obese and obese states depending on weight gain or loss. Losing weight could be the result of bariatric surgery which is one of two actions that a decision maker can choose at any state s. If a non-obese or obese person has cancer, the person is moved to the cancer state. This state includes any type of cancer. Based on a patient's annual survival probability, the patient in cancer state can stay in cancer state, go back to healthy states based on their weight or die. Death state is an absorbing state with a probability of staying one.

In any state and decision epoch, the decision maker selects one action: do nothing or bariatric surgery. Then, the person receives the immediate reward of state and action pair which is expected QALY and moves to state s_{t+1} with probability $p_t(s_{t+1}|s_t, a_t)$. The optimal solution for all health states and decision epochs can be solved using the following optimality equations (Puterman 2014).

$$V_t(s_t) = \max_{a_t \in A}\left\{R_t(s_t) + \gamma \sum_{s_{t+1} \in S} p_t(s_t + 1|s_t, a_t)V_{t+1}(s_{t+1})\right\} \quad (1)$$

$$a_t(s_t) = \arg\max_{a_t \in A}\left\{R_t(s_t) + \gamma \sum_{s_{t+1} \in S} p_t(s_t + 1|s_t, a_t)V_{t+1}(s_{t+1})\right\} \quad (2)$$

for $\mathrm{t} = 1, 2, \ldots, 70$ and $s_t \in S$.

The discount factor, γ is selected as 3%. This value is widely used in many modeling and cost-effectiveness studies and recommended by the US Public Health

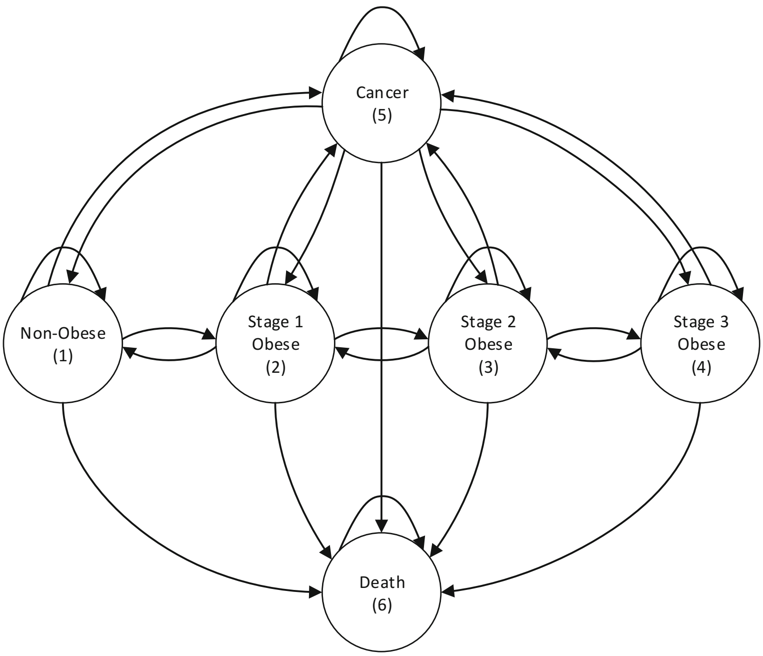

Fig. 1 State-transition diagram

Service Panel on Cost-Effectiveness in Health and Medicine (Weinstein et al. 1996). We also run the model with 1, 5% discounting factor and without discounting to analyze the effect of discounting in the optimal solution.

The optimality Eq. (1) calculates the total expected QALYs of a person with a health state s_t and the optimality Eq. (2) provides the optimal actions that provides the maximum reward. The optimal policy is referred to as optimal action set from age 20–age 90 for any health state s_t.

Parameter Estimation

We conducted a comprehensive literature search to collect required data for estimating transition probability matrices and reward function parameters. If available, we preferred using randomized clinical trial data for estimation of parameters. We obtained information regarding basic parameters of the MDP model such as mortality rates and cancer incidence rate based on sex and BMI, the survival rate of cancer, bariatric surgery outcomes of mortality, weight loss and failure to lose weight and reward function in terms of QALYs based on BMI and health state. We present probability transition values of “no action” in Table 1.

Table 1 Probability transition values of choosing "no action" by sex

Parameters	Probability value (95% CI)		Sources
	Men	Women	
No change in BMI class			
Non-obese	0.9453	0.9486	Fildes et al. (2015)
Stage 1 obesity	0.9054	0.8866	Fildes et al. (2015)
Stage 2 obesity	0.8740	0.8633	Fildes et al. (2015)
Stage 3 obesity	0.8972	0.9055	Fildes et al. (2015)
The decrease in BMI class			
Stage 1 obesity	0.0048 (0.0044–0.0051)	0.0081 (0.0076–0.0085)	Fildes et al. (2015)
Increase in BMI class			
Stage 2 obesity	0.1207	0.0919	Fildes et al. (2015)
Cancer incidence rate			
Non-obese	0.0045	0.0037	US Cancer Statistics Working Group
Stage 1 obesity	0.0049	0.0043	Basen-Engquist and Chang (2011)
Stage 2 obesity	0.0054	0.0049	Basen-Engquist and Chang (2011)
Stage 3 obesity	0.0069	0.0060	Basen-Engquist and Chang (2011)
Cancer survival rate			
Non-obese	0.1968 (0.1964–0.1977)	0.2439 (0.2439–0.2443)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Stage 1 obesity	0.1666 (0.1662–0.1673)	0.1485 (0.1485–0.1488)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Stage 2 obesity	0.0575 (0.0574–0.0578)	0.0762 (0.0762–0.0763)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Stage 3 obesity	0.0371 (0.0370–0.0373)	0.0685 (0.0685–0.0686)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Mortality rate			
Non-obese	0.0062 (0.0061–0.0063)	0.0033 (0.0033–0.0034)	Mayer-Davis et al. (2017)
Stage 1 obesity	0.0105 (0.0101–0.0110)	0.0046 (0.0045–0.0047)	Mayer-Davis et al. (2017)
Stage 2 obesity	0.0166 (0.0158–0.0176)	0.0062 (0.0060–0.0064)	Mayer-Davis et al. (2017)

(continued)

Table 1 (continued)

Parameters	Probability value (95% CI)		Sources
	Men	Women	
Stage 3 obesity	0.0263 (0.0234–0.0295)	0.0091 (0.0086–0.0097)	Mayer-Davis et al. (2017)
Cancer	0.3928	0.3237	The Kaiser Family Foundation's State Health Facts (2017)

CI denotes confidence interval. Probabilities are on annual basis

We have the following assumption about the individuals who decide to have bariatric surgery: their BMI after surgery cannot increase, in other words, there may be only a decrease or no change in the patient's BMI after surgery. As a result, some transition probabilities are assumed to be zero to prohibit any increase in BMI after bariatric surgery. Rest of the transition probabilities for males and females are presented in Table 2.

We assume that the reward function depends on the only state. As a result, we use the published estimates of QALYs for obesity levels and cancer by sex. QALYs by obesity levels are from National Health Information Survey with approximately 2000 respondents (Livingston and Ko 2002) and QALYs for cancer are from a study by Vrettos et al. (2012) (Table 3). The MDP model is solved using Optimization Toolbox of MATLAB software (MathWorks; Natick, Massachusetts) and the optimal solution is obtained under a minute.

Results

We consider an individual at age 20 and have a lifetime of 50 years. We also consider a time horizon of 30 and 70 years to observe the effect of time horizon on the optimal policy. The model suggests the bariatric surgery for all obese states and ages as the optimal policy in both female and male patients and "do nothing" for healthy and cancer states for all ages in the base case. Table 4 presents the optimal policy and total expected discounted QALYs under the optimal policy by sex.

Total expected discounted QALYs by age and sex is the highest for a healthy and non-obese 20 years old woman and the lowest for a 70 years old cancer patient. As expected, total QALYs decreases with age and obesity level. Females have overall better QALYs than males for all states. Figure 2 presents total discounted QALYs by age and sex.

We explore the effect of the length of time horizon on the optimal policy. Although total expected discounted QALYs increase with the length of time horizon as expected, the optimal policy stays the same for all cases as presented in Table 5. The model is robust to the changes in time horizon.

Table 2 Probability transition values of choosing "bariatric surgery" by sex

Parameters	Probability value (95% CI)		Sources
	Men	Women	
No change in BMI class			
Stage 2 obesity	0.1552	0.1552	Michaelson et al. (2013)
Stage 3 obesity	0.0400	0.0400	Michaelson et al. (2013)
The decrease in BMI class			
Stage 3 obesity	0.5503	0.7323	Inge et al. (2010)
Cancer incidence rate			
Non-obese	0.0045	0.0037	US Cancer Statistics Working Group
Stage 1 obesity	0.0044 (0.0041–0.0048)	0.0039 (0.0036–0.0042)	Schauer et al. (2017)
Stage 2 obesity	0.0049 (0.0045–0.0053)	0.0044 (0.0040–0.0047)	Schauer et al. (2017)
Stage 3 obesity	0.0062 (0.0057–0.0067)	0.0054 (0.0050–0.0058)	Schauer et al. (2017)
Cancer survival rate			
Non-obese	0.1968 (0.1964–0.1977)	0.2439 (0.2439–0.2443)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Stage 1 obesity	0.1666 (0.1662–0.1673)	0.1485 (0.1485–0.1488)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Stage 2 obesity	0.0575 (0.0574–0.0578)	0.0762 (0.0762–0.0763)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Stage 3 obesity	0.0371 (0.0370–0.0373)	0.0685 (0.0685–0.0686)	National Center for Health Statistics (2017), Cancer Research UK (2018)
Mortality rate			
Non-obese	0.0242 (0.0241–0.0243)	0.0213 (0.0213–0.0214)	Turrentine et al. (2012), Mayer-Davis et al. (2017)
Stage 1 obesity	0.0247 (0.0243–0.0252)	0.0188 (0.0187–0.0189)	Turrentine et al. (2012), Mayer-Davis et al. (2017)
Stage 2 obesity	0.0269 (0.0261–0.0279)	0.0165 (0.0163–0.0167)	Turrentine et al. (2012, Mayer-Davis et al. (2017)
Stage 3 obesity	0.0285 (0.0201–0.0394)	0.0107 (0.0083–0.0137)	Omalu et al. (2007)
Cancer	0.3928	0.3237	The Kaiser Family Foundation's State Health Facts (2017)

CI denotes confidence interval. Probabilities are on annual basis

Table 3 Annual mean QALYs by state and sex and their standard deviation

Health state	Men	Women	Sources
	Mean (± SD)	Mean (± SD)	
Stage 1 obese	0.83 (± 0.20)	0.79 (± 0.21)	Livingston and Ko (2002)
Stage 2 obese	0.79 (± 0.22)	0.75 (± 0.24)	Livingston and Ko (2002)
Stage 3 obese	0.75 (± 0.23)	0.69 (± 0.25)	Livingston and Ko (2002)
Cancer	0.71 (± 0.32)	0.61 (± 0.34)	Vrettos et al. (2012)

SD denotes standard deviation

Table 4 The optimal policy and total expected discounted QALYs under the optimal policy by sex

	Men		Women	
	Total QALYs	Optimal policy	Total QALYs	Optimal policy
Non-obese	22.01	DN	23.38	DN
Stage 1 obese	21.38	BS	22.76	BS
Stage 2 obese	20.77	BS	22.25	BS
Stage 3 obese	19.73	BS	21.71	BS
Cancer	11.96	DN	14.33	DN

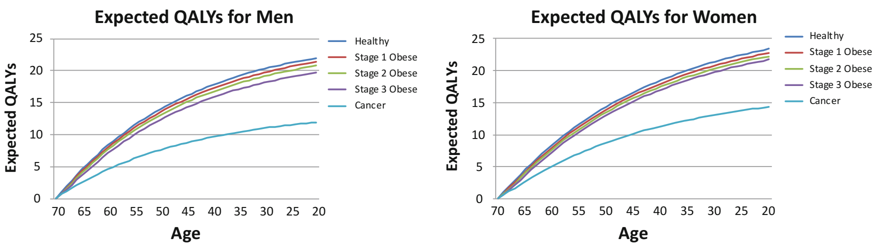

Fig. 2 Total discounted QALYs by age and sex

Although discounting factor of 3% is usually employed, running the model without discounting and with a discounting factor of 5% are recommended in order to analyze the effect of discounting on the optimal solution (Weinstein et al. 1996). Our results suggest that MDP model is robust to the changes in the discounting factor for the optimal policy, however, the total expected QALYs are proportional to the discounting factor and increase when no discounting is preferred (Table 6).

Table 5 The optimal policy and total expected discounted QALYs under the optimal policy by sex for a time horizon of 30 and 70 years

	Time horizon = 30 years				Time horizon = 70 years			
	Men		Women		Men		Women	
	Total QALYs	Optimal policy	Total QALYs	Optimal policy	Total QALYs	Optimal policy	Total QALYs	Optimal policy
Non-obese	17.77	DN	18.50	DN	23.93	DN	25.76	DN
Obese 1	17.23	BS	17.96	BS	23.26	BS	25.09	BS
Obese 2	16.70	BS	17.51	BS	22.61	BS	24.55	BS
Obese 3	15.81	BS	17.02	BS	21.5	BS	23.99	BS
Cancer	9.68	DN	11.31	DN	12.99	DN	15.8	DN

Table 6 The optimal policy and total expected discounted QALYs under the optimal policy by gender for no discounting and a discounting factor of 5%

	No discounting				Discounting factor = 5%			
	Men		Women		Men		Women	
	Total QALYs	Optimal policy	Total QALYs	Optimal policy	Total QALYs	Optimal policy	Total QALYs	Optimal policy
Non-obese	39.94	DN	43.37	DN	16.09	DN	16.88	DN
Obese 1	38.93	BS	42.39	BS	15.58	BS	16.37	BS
Obese 2	37.95	BS	41.62	BS	15.1	BS	15.95	BS
Obese 3	36.23	BS	40.82	BS	14.28	BS	15.48	BS
Cancer	21.59	DN	26.68	DN	8.78	DN	10.31	DN

Discussion and Conclusion

Obesity is one of the major causes of cancer and the cancer risk increases with the level of obesity. Bariatric surgery is a weight loss method recommended for morbidly obese patients. In this study, we explore the relationship between obesity and cancer with the help of a Markov decision process model and determine the optimal decision of no surgery or undergoing surgery by obesity levels and sex. Our results suggest that bariatric surgery should be chosen for all obesity stages to maximize overall expected QALYs. This health outcome involves the cancer risk and mortality risk. Although bariatric surgery increases the mortality risk, its likelihood of returning to non-obese or less BMI stages are substantially larger than no surgery decision, as a result, the optimal policy favors the surgery. This result is insensitive to the changes in the discount factor and time horizon.

There are some limitations to our study. We assume stationary transition probabilities due to lack of data for estimating transition probabilities by age. Therefore, the optimal policy is the same for all ages and only depends on sex and obesity level. However, the effectiveness of surgery, cancer and mortality risks depend on age and other health issues of obesity such as comorbidities could increase with age. The effect of time horizon could also be significant in such case. We use reward function by state, however, the inclusion of action to the reward function may have an effect on the optimal policy. Side effects, short and long term health outcomes of bariatric surgery could be incorporated into our model if the reward function depends on the action selected. In this study, we omit the effect of obesity on specific types of cancers, other health consequences of obesity such as pain, disability and other diseases such as cardiovascular diseases and diabetes and other obesity prevention methods such as diet and healthy living programs. Future work based on these issues could further enhance our model and provide insights on surgery decisions to improve overall health and to decrease the cancer risk based on obesity.

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A Combined Method for Deriving Decision Makers' Weights in Group Decision Making Environment: An Application in Medical Decision Making

Emrah Koksalmis, Gulsah Hancerliogullari Koksalmis and Ozgur Kabak

Abstract The complexity of the problem grows as multiple individuals involved in the decision making process. Since each individual may have a different experience, attitudes, and knowledge, their approaches might be different from each other on the same problem. Therefore, more comprehensive techniques are needed in group decision making methods in order to determine how much a decision maker's contribution is considered in the final solution (i.e., the weight of each decision maker). The purpose of this study is to determine the combined weights of decision makers based on both the objective weights, using the geometric cardinal consensus index, and the subjective weights provided by a supervisor. In order to represent the implementation of the method, the study includes a case study in a medical decision making. There are several anesthesia method alternatives to apply; specifically, general anesthesia, local anesthesia, and sedation, which are considered by surgeons. In the case study, the combined relative weights of the medical doctors are derived regarding this issue.

Keywords Weights of decision makers · AHP group decision making
Geometric cardinal consensus index · Combined weights

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F. Calisir et al. (eds.), *Industrial Engineering in the Big Data Era*,
Lecture Notes in Management and Industrial Engineering,
https://doi.org/10.1007/978-3-030-03317-0_41

Introduction

In the decision-making problem, the aim is to find the suitable alternative or alternatives from the set of feasible alternatives. This problem can occur in many different real life circumstances, including economics, education, military, medical sciences, logistics, etc. Therefore, one can find numerous studies related to the decision-making problems in the literature.

In recent years, since the complexity of the problem grows, it is almost impossible for a decision maker to consider all the relevant factors of the problem (Dey et al. 2017). Additionally, most of the decision-making problems occur in an environment where multiple experts must contribute in order to reach a final decision. Therefore, there is a need for new techniques, which require the contribution of multiple decision makers whose experiences, attitudes, knowledge are not same or similar (Ölçer and Odabaşi 2005; Cabrerizo et al. 2013). In literature, these kinds of problems are known as the Group Decision Making (GDM) problem (Lu and Ruan 2007).

As mentioned above, in GDM, decision makers may come from different fields, which means they are not supposed to be homogenous in terms of their knowledge, skills, and characteristics. This results in a variation in their attitudes, motivations, and acceptance of the common problem. That requires different approaches than the regular decision-making problem with the single decision maker. In these approaches, the main problem is to find how much a decision maker should contribute to the final solution, in other words, what should be the weight of each decision maker. If the weights of decision makers are not taken into account in GDM, this can cause improper and mistaken results that may not be compensated in the final solution (Mianabadi et al. 2008). Therefore, in current years, how to derive the weights of decision makers become a challenging and interesting research subject for the researchers.

In literature, the techniques for deriving the decision makers' weights are grouped into three classes; the subjective techniques, the objective techniques and the combination of these two (Saaty 1980; Ramanathan and Ganesh 1994). In subjective techniques, a supervisor, who evaluates the decision makers, assigns weights to each of them depending on his or her assessment about the decision makers or, these weights are obtained by mutual evaluations of each decision maker which may be accepted as a more democratic way than the first one. On the other side, in objective methods, researchers use numerical methods to determine the weights of decision makers. All the data in hand are used in objective methods and it aims to be more objective in all aspects when compared to subjective methods. In the combined method, these two weights are integrated into one weight, which reflects the effects of both objective and subjective weights.

Kabak and Ervural (2017) state that only in 41% of selected studies, weights of experts are taken into account. It is also stated that, in most of the studies, subjective methods are used. On the other hand, even though it is not as popular as criteria weighting methods, there are some studies that utilize the objective methods in order to determine the weights of decision makers. For instance, Wang et al. (2015) measure the similarity degrees of two partial rankings given by two decision makers and use this measure to find the relative weights of decision makers. In this study, a larger weight is assigned to a decision maker with more similarity to other decision makers. In a similar study, Yue (2011) finds the distance measure of each decision maker to the aggregated solution in interval-valued intuitionistic fuzzy GDM. Pang et al. (2017) use a technique depending on the consensus value, to find the weights of decision makers. In their study, authors develop a mathematical model to maximize the consensus degree, by altering the weights of decision makers. In a similar study, instead of using the consensus value, Zhang and Xu (2014) use two different consistency indexes. Liu et al. (2015) utilize a two level (experts and cluster level) method to find the weights of decision makers in complex multi attribute large GDM problem in a linguistic environment where there are more than 20 decision makers.

In above literature and other related studies in GDM, decision makers chose to express their preferences using different preference formats such as crisp value (real numbers), interval numbers, fuzzy sets (e.g. hesitant fuzzy sets, Type-2 fuzzy sets, intuitionistic fuzzy sets etc.), rankings, linguistics, and other data types. However, most of the approaches in the literature are independent of the data format.

Even though decision making problem can occur in many different real life circumstances including economics, education, military, medical sciences and logistics, the concentration on multi-criteria decision making in the healthcare industry is quite new. The methodologies implemented in medical and health care decision making analysis are provided in the literature (Stang et al. 1988). Among these, most of them prefer using AHP in health care and medical decision making analysis, specifically, evaluation and selection of medical treatments and therapies, for organ transplant eligibility and allocation decisions (Dolan et al. 1993, 1989; Liberatore and Nydick 2008). Our study provides a case study on a medical decision making, specifically, selection of a suitable anesthesia method to apply in the surgery is a multi-criteria decision making which involves conflicting criteria and several alternatives, to illustrate how the combined relative weights of decision makers (doctors or experts) are derived.

We will apply the Analytic Hierarchy Process (AHP) based method in order to derive the relative weights of decision makers depending on the geometric cardinal consensus index (GCCI), and we will combine it with the subjective weights of decision makers provided by a supervisor. Information about the method is provided in the following section. For the details of the approach, readers can refer to the study proposed by Blagojevic et al. (2016).

The rest of the paper is structured as follows. The second section presents the methodology proposed in the study. Next, an illustrative example is provided to show the implementation of the proposed method. The paper ends with our conclusion and suggestions for future research.

Methodology

In this section, before introducing the basis of the weight determination method provided by Blagojevic et al. (2016), we provide some information about AHP and GCCI, which is a well-known consensus index of AHP that is used in the proposed approach.

AHP and Geometric Consistency Index

AHP requires a problem that can be represented as a hierarchy. In this hierarchy, the main goal of the problem should be placed at the top (Level 1), while alternatives (Level 3) are placed at the bottom as presented in Fig. 1.

Here, the main goal is the overall objective of the problem that must be satisfied by more than one criterion (Level 2). In AHP, preferences of decision makers among the alternatives and criteria are determined by pairwise comparison with respect to the scale in Table 1 provided by Saaty (1980).

As it can be easily seen on Table 1, if two elements are considered to have equal importance and contribute same to the upper level, a value of "1" is given to the related element (a_{ij}) of the following matrix A. In the same manner, a value of "9" is given if one has extreme importance in pairwise comparison.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

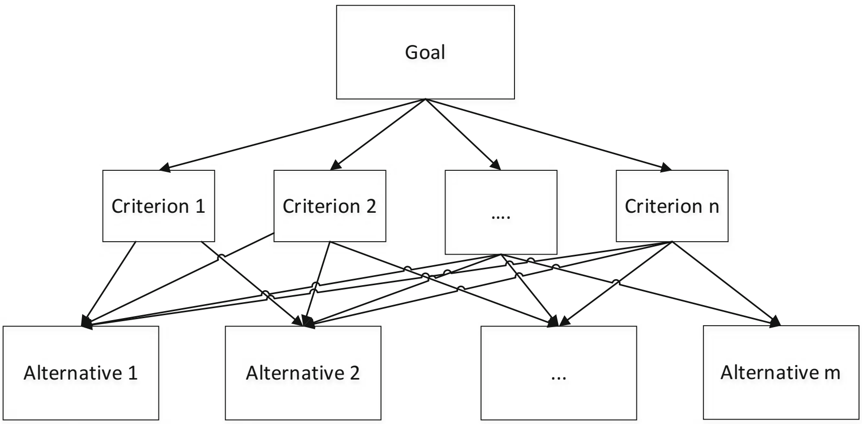

Fig. 1 Hierarchy of the problem

Table 1 Importance scale proposed by (Saaty 1980)

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance

The constructed matrix must be symmetric and reciprocal, which means all elements of the matrix must be greater than "0", $a_{ij} = 1/a_{ji}$ and all main diagonal elements must be "1". Saaty (1980) also proves that, for this matrix, the eigenvector method, which is based on squaring and normalization of row sums, can be used to derive the required priority vector, for both consistent and inconsistent evaluation of the decision maker.

However, there are some other prioritization methods used in the literature [combining different prioritization methods in AHP synthesis] including least squares method (LSM) proposed by Crawford and Williams (1985). In this study, it is suggested that the priorities can be calculated by the following non-linear mathematical model (Eqs. 1 and 2):

$$\min_{w} \sum_{i=1}^{n} \sum_{i<j}^{n} \left(\ln a_{ij} - \left(\ln w_i - \ln w_j\right)\right)^2 \tag{1}$$

subject to:

$$w_i > 0, \quad \sum_{i=1}^{n} w_i = 1, \quad i = 1, \ldots, n. \tag{2}$$

They also prove that the solution of the model is equal to the geometric means of the rows of matrix A and simply can be calculated by the following Eq. 3.

$$w_i = \frac{\sqrt[n]{\prod_{j=1}^{n} a_{ij}}}{\sum_{i=1}^{n}\left(\sqrt[n]{\prod_{j=1}^{n} a_{ij}}\right)} \tag{3}$$

In this study, we use LSM based index like the study of Blagojevic et al. (2016), mainly because, while eigenvector method produces different group priority vector for both AIJ (Aggregation of individual judgments-group acts like a unit) and AIP (Aggregation of individual priorities-group acts separately), LSM produces same group priority vector in both situations (Barzilai and Golany 1994).

After finding the final decision by aggregation procedures, the consistency index must be measured to check the consistency of the preferences. In literature, there are several consistency measures for AHP. One of the comprehensive studies about the subject is proposed by Aguaron and Moreno-Jiménez (2003). They have developed the geometric consistency index (GCI) in Eq. 4 in order to measure individual consistency:

$$\mathrm{GCI}(A) = \frac{2}{(n-1)(n-2)} \sum_{i<j}^{n} \left(\ln a_{ij} - \ln w_i + \ln w_j\right)^2 \tag{4}$$

Matrix A can be called as fully consistent if GCI (A) is equal to 0. It is acceptable inconsistent if GCI (A) < 0.31 for n = 3 and GCI (A) < 0.35 for n = 4. For larger n values, GCI must be less than 0.37.

In literature, consensus indexes including the GCCI, are computed by measuring the distance of decision makers' preference matrix to group aggregated preference matrix (Dragincic et al. 2015; Srdjevic et al. 2015). For AHP, using the idea behind GCI, GCCI is developed by (Dong et al. 2010) and provided in Eq. 5.

$$\mathrm{GCCI}\left(A^{(k)}\right) = \frac{2}{(n-1)(n-2)} \sum_{i<j\; i,j=1}^{n} \left(\ln\left(a_{ij}^{(k)}\right) - \ln\left(w_i^{(g)}\right) + \ln\left(w_j^{(g)}\right)\right)^2 \tag{5}$$

Since the GCCI is derived from GCI, LSM method must be used for prioritization in AHP in order to calculate the GCCI, as it is provided by Blagojevic et al. (2016). Here, it can be stated that a decision maker is totally in cardinal consensus if he/she has a value of 0 for the GCCI, and cardinal consensus for a decision maker decreases when the GCCI value increases.

A Method for Deriving Combined Weights

As already mentioned in the previous sub-section, in order to find the GCCI, LSM prioritization method must be applied to obtain the decision makers' priority vectors from the preference matrices of each decision maker. Therefore, in the first step, LSM must be applied to each decision maker' preference matrix.

In the second step, these preference matrices must be aggregated into group decision and aggregated priority vector must be determined. As in the first stage, the aggregated priority vector must be obtained by using LSM.

By using Eq. 5. GCCI for each decision maker must be computed in the third step.

In the fourth step, the objective weight of each decision maker will be computed by the following Eq. 6 as it is proposed by (Blagojevic et al. 2016). Since cardinal consensus for a decision maker decreases when the GCCI value increases, reciprocals of GCCI values will be used in order to find the objective weight of kth decision maker (W_0^k).

$$w_0^k = \frac{\left(\mathrm{GCCI}^k\right)^{-1}}{\sum_{k=1}^{d}\left(\mathrm{GCCI}^k\right)^{-1}} \tag{6}$$

In the last step, decision makers' objective weights w_0^k are integrated with the subjective weights w_s^k provided by a supervisor with a predefined proportion of α in order to obtain the final combined weights w_c^k, using Eq. 7.

$$w_c^k = \alpha\left(w_0^k\right) + (1-\alpha)\left(w_s^k\right) \tag{7}$$

An Illustrative Example

There are several approaches to handle multi-criteria problems in the literature. A variety of decision making approaches and tools are available to support health care and medical decision making. Hancerliogullari et al. (2017) study preferences of surgeons for anesthesia method selection, which is the first in the literature, where multi-criteria decision making tools, fuzzy Analytic Hierarchy Process and fuzz, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), are used to evaluate the anesthesia methods for a surgery. Nevertheless, the objective and subjective weights of the decision makers were not taken into account in that study.

Therefore, in order to show the application of the proposed method, we provide an example of medical decision making. Medical doctors face different alternatives while selecting an appropriate anesthesia method to apply in the surgical procedures. The decision is complex since there are several factors affecting the operations. The alternatives of anesthesia methods performed include general anesthesia, local anesthesia, and sedation. Selection of a suitable anesthesia method and deciding the appropriate method is a real concern since an inappropriate method may threaten patients' lives and lead to a loss of resources and time.

In this study, we provide an illustrative example to derive the combined relative weights of three decision makers (DM1, DM2, DM3), specifically three medical doctors, depending on the GCCI and subjective weights provided by a supervisor. The alternatives to anesthesia methods, general anesthesia (A1), local anesthesia (A2) and sedation (A3), are determined by the decision makers. As stated in the Blagojevic et al. (2016), we assume that the inconsistency of decision makers is greater than 0.31 since $n = 3$. Other calculations are expressed in the following steps below:

Step 1. Preference matrices of decision makers are provided in Table 2. Decision makers' priority vectors from the preference matrix of each decision maker are calculated by the LSM method (geometric means of the rows of the matrix) formulation provided in Eq. 3.

Table 2 The preference matrices of each decision maker with priority vectors

DM1	A1	A2	A3	LSM	DM2	A1	A2	A3	LSM	DM3	A1	A2	A3	LSM
A1	1	3	5	0.63	A1	1	5	3	0.63	A1	1	3	3	0.64
A2	1/3	1	3	0.26	A2	1/5	1	5	0.26	A2	1/3	1	1	0.21
A3	1/5	1/3	1	0.11	A3	1/3	1/5	1	0.11	A3	1/3	1/3	1	0.15

Table 3 Group priority vector

	A1	A2	A3
Aggregated-LSM	0.63	0.25	0.12

Table 4 GCCI, objective, subjective and combined weights for each decision maker

	DM1	DM2	DM3
GCCI	0.17	1.56	0.29
Objective weights (W_0^k)	0.58	0.07	0.35
Subjective weights (W_s^k)	0.33	0.33	0.33
Combined weights (W_c^k)	0.48	0.17	0.34

Step 2. Preference matrix of each decision maker given in Step 1 must be aggregated into group decision and aggregated priority vector must be determined. The aggregated priority vector must be obtained by using LSM. Since we do not assign a weight to decision makers at the beginning, we assume that they are equally important. Therefore, in this step, we use subjective weights while aggregating the decision makers' preference matrix. Table 3 summarizes the group priority vector values for each alternative.
Step 3. By using Eq. 5. geometric cardinal consensus index for each decision maker is computed in the third step, and the results are provided in Table 4.
Step 4. The objective weight of each decision maker is computed by using Eq. 6, and the results are shown in Table 4.
Step 5. Decision makers' objective weights w_0^k are integrated with the subjective weights w_s^k provided by a supervisor and combined weights w_c^k are calculated, using Eq. 7. The values of the combined weights are provided in Table 4. Here, α, which shows the proportion of the impact of subjective and objective weights, is taken 0.6. Subjective weights are assumed to be equal, 0.33 for each decision maker.

After having found the combined weights for each decision makers, we determine the best alternative by using Table 2, which is the preference matrices of each decision maker with priority vectors, and apply the weighted product method (Yoon and Hwang 1995). When the weighted product method is used, weights become exponents associated with each attribute value. This method requires that all ratings be greater than 1 due to exponent property. Otherwise, when an attribute has fractional ratings, as in this study, all ratings in that attribute are multiplies by 10^{m} to meet the following

Table 5 Order of the alternatives

	A1	A2	A3
Weighted product method	4.23	1.73	1.32

requirement, given in Eq. 8. By applying the given formula, the order of the alternatives is determined, as given in Table 5. As a result, A1, general anesthesia, is determined to be the anesthesia method based on the decision makers' preferences and combined weights calculated by these preferences.

$$V_i = \prod_j \left(x_{ij}\right)^{w_j} \tag{8}$$

Conclusion

The primary objective of the decision makers is to make the best decision among a set of different alternatives. The complexity of the situation grows as multiple decision makers involved in decision making process. Since each decision maker may have different background and perspective, their approaches might be different from each other on the same problem, which is specifically called GDM problem in the literature, and more comprehensive techniques are needed. Such decision making problems take place on several occasions; especially military operations, medical sciences, economics, etc. Here, the primary problem is to determine how much a decision maker should contribute to the final solution (i.e., the weight of each decision maker).

In literature, the techniques for deriving the decision makers' weights are grouped into three classes; the subjective techniques, the objective techniques and the combination of these two. The main aim of this study is to propose a combined method to determine decision makers' weights in decision making environment. The contribution of this study is twofold. First, the suggested method integrates the AHP based methodology depending on the geometric cardinal consensus index proposed by Blagojevic et al. (2016) and the subjective weights of decision makers provided by a supervisor. Second, an application in a medical decision making is provided; the methodology is used to derive the pediatric surgeons' weights for the first time. We derive the combined relative weights of the medical doctors who face with different alternatives while selecting an appropriate anesthesia method among 3 alternatives, general anesthesia, local anesthesia, and sedation, to apply in the surgical procedures. In this study, the alternatives and decision makers' opinions were considered. As a future research, a multi-attribute group decision making problem can be studied where criteria will also be taken into account. Additionally, different consistency indices can be utilized other than GCCI and results can be compared. Moreover, further collaborative studies can be conducted with the other decision makers in the health care industry.

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