Lecture Notes in Management and Industrial Engineering

Fethi Calisir
Hatice Camgoz Akdag *Editors*

Industrial Engineering in the Industry 4.0 Era

Selected Papers from the Global Joint Conference on Industrial Engineering and Its Application Areas, GJCIE 2017, July 20–21, Vienna, Austria

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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) 2017 held in Vienna, Austria. 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 Industry 4.0 Era". Industry 4.0 is a collective term for the technologies and concepts of value chain organization, which bring together Cyber-Physical Systems, the Internet of Things, the Industrial Internet of Things, and the Internet of Services. These systems allow intelligent products, processes, and services to communicate with each other and with people in real time over a global network. This challenges the way that we educate engineers and the way that we manage companies. 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 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 (ITU Ari Teknokent, Aselsan, and Entertech) of GJCIE 2017.

Istanbul, Turkey
July 2017

Fethi Calisir
Hatice Camgoz Akdag

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Part I
Industrial Engineering

A Note on Fuzzy Multiattribute Grey Related Analysis Using DEA

Mohammad Sadegh Pakkar

Abstract Wu and Olson (2010) applied data envelopment analysis (DEA) in a grey-related fuzzy methodology to derive attribute weights that are most favorable for each alternative. However, their model may not reflect the desired degree of discrimination between alternatives for unlikely weight combinations. In this paper, we propose an extended version of their model by using two sets of weights that are most favorable and least favorable for each alternative. An illustrated example of a nuclear waste dump site selection is used to highlight the usefulness of the proposed "extended model".

Keywords Grey related analysis · Data envelopment analysis · Fuzzy numbers Multiple attribute decision making

Introduction

In a paper, Wu and Olson (2010) propose the application of data envelopment analysis (DEA) as an objective way to derive weights in a fuzzy multiattribute grey related analysis methodology. The advantage of their model is that all alternatives are treated impartially and equitably by giving full flexibility to obtain a set of most favorable weights in a way that maximizes their grey related grades. This relaxes the negative impacts of subjective factors on weight settings. The disadvantage is that some alternatives may obtain a grey related grade of 1 because of assigning zero values to the weights of some attributes and neglecting the importance of these attributes in a decision-making process. To avoid this issue, Wu and Olson (2010) apply restrictions on the attribute weights based on the ratio of weights, without further explanation on how a decision maker can define the relationships between the attribute weights using weight restrictions. When using weight restrictions, it is important to estimate the appropriate values for the parameters in the restrictions.

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The purpose of this short paper is to present an extended version of the Wu and Olson (2010) model by incorporating some additional features to avoid the aforementioned deficiencies for a fuzzy multiattribute grey related analysis methodology.

Grey Related Analysis with Data Envelopment Analysis

Let $A = \{A_1, A_2, \ldots, A_m\}$ be a discrete set of alternatives and $C = \{C_1, C_2, \ldots, C_n\}$ be a set of attributes. Let $\tilde{y}_{ij} = (y_{1ij}, y_{2ij}, y_{3ij}, y_{4ij})$ be a trapezoidal fuzzy number representing the value of attribute $C_j (j = 1, 2, \ldots, n)$ for alternative $A_i (i = 1, 2, \ldots, m)$. Using the α-cut technique, a trapezoidal fuzzy number can be transformed into an interval number as follows:

$$y_{ij} = \left[y_{ij}^{-}, y_{ij}^{+}\right] = \left[\alpha y_{2ij} + (1-\alpha) y_{1ij}, \alpha y_{3ij} + (1-\alpha) y_{4ij})\right] \tag{1}$$

where $y_{ij} = [y_{ij}^{-}, y_{ij}^{+}]$, $y_{ij}^{-} \leq y_{ij}^{+}$, is an interval number representing the value of attribute $C_j (j = 1, 2, \ldots, n)$ for alternative $A_i (i = 1, 2, \ldots, m)$. Then alternative A_i is characterized by a vector $Y_i = \left([y_{i1}^{-}, y_{i1}^{+}], [y_{i2}^{-}, y_{i2}^{+}], \ldots, [y_{in}^{-}, y_{in}^{+}]\right)$ of attribute values. The term Y_i can be translated into the comparability sequence $R_i = \left([r_{i1}^{-}, r_{i1}^{+}], [r_{i2}^{-}, r_{i2}^{+}], \ldots, [r_{in}^{-}, r_{in}^{+}]\right)$ by using the following equations:

$$\left[r_{ij}^{-}, r_{ij}^{+}\right] = \left[\frac{y_{ij}^{-}}{y_{j(\max)}^{+}}, \frac{y_{ij}^{+}}{y_{j(\max)}^{+}}\right] \forall j, \quad y_{j(\max)}^{+} = \max\left\{y_{1j}^{+}, y_{2j}^{+}, \ldots, y_{mj}^{+}\right\} \tag{2}$$

for desirable attributes,

$$\left[r_{ij}^{-}, r_{ij}^{+}\right] = \left[\frac{y_{i(\min)}^{-}}{y_{ij}^{-}}, \frac{y_{i(\min)}^{-}}{y_{ij}^{+}}\right] \forall j, \quad y_{j(\min)}^{-} = \min\left\{y_{1j}^{-}, y_{2j}^{-}, \ldots, y_{mj}^{-}\right\} \tag{3}$$

for undesirable attributes.

Now, let A_0 be a virtual ideal alternative which is characterized by a reference sequence $U_0 = \left([u_{01}^{-}, u_{01}^{+}], [u_{02}^{-}, u_{02}^{+}], \ldots, [u_{0n}^{-}, u_{0n}^{+}]\right)$ of the maximum attribute values as follows:

$$u_{0j}^{-} = \max\left\{r_{1j}^{-}, r_{2j}^{-}, \ldots, r_{mj}^{-}\right\} \forall j, \tag{4}$$

$$u_{0j}^{+} = \max\left\{r_{1j}^{+}, r_{2j}^{+}, \ldots, r_{mj}^{+}\right\} \forall j. \tag{5}$$

To measure the degree of similarity between $r_{ij} = [r_{ij}^{-}, r_{ij}^{+}]$ and $u_{0j} = [u_{0j}^{-}, u_{0j}^{+}]$ for each attribute, the grey related coefficient, ξ_{ij}, can be calculated as follows:

$$\xi_{ij} = \frac{\min_i \min_j \left| \left[\left[u_{0j}^-, u_{0j}^+ \right] \right] - \left[r_{ij}^-, r_{ij}^+ \right] \right| + \rho \max_i \max_j \left| \left[u_{0j}^-, u_{0j}^+ \right] - \left[r_{ij}^-, r_{ij}^+ \right] \right|}{\left| \left[u_{0j}^-, u_{0j}^+ \right] - \left[r_{ij}^-, r_{ij}^+ \right] \right| + \rho \max_i \max_j \left| \left[u_{0j}^-, u_{0j}^+ \right] - \left[r_{ij}^-, r_{ij}^+ \right] \right|} \tag{6}$$

while the distance between $u_{0j} = [u_{0j}^-, u_{0j}^+]$ and $r_{ij} = [r_{ij}^-, r_{ij}^+]$ is measured by $\left|u_{0j} - r_{ij}\right| = \max\left(\left|u_{0j}^- - r_{ij}^-\right|, \left|u_{0j}^+ - r_{ij}^+\right|\right) \rho \in [0, 1]$ is the distinguishing coefficient, generally $\rho = 0.5$. It should be noted that the final results of GRA for multiple attribute decision making problems are very robust to changes in the values of ρ. Therefore, selecting the different values of ρ would only slightly change the rank order of alternatives (see Kuo et al. 2008). Now, let k be the index for the alternative under assessment (known as a decision making unit in the DEA terminology) where k ranges over 1, 2,…, m. To find an aggregated measure of similarity between alternative A_k, characterized by the comparability sequence R_k, and the ideal alternative A_0, characterized by the reference sequence U_0, over all the attributes, the grey related grade can be computed as follows:

$$\begin{aligned} &\Gamma_k = \max \sum_{j=1}^{n} w_j \xi_{kj} \\ &\text{s.t.} \sum_{j=1}^{n} w_j \xi_{ij} \leq 1 \ \forall i, \\ &w_j \geq 0 \ \forall j, \end{aligned} \tag{7}$$

where Γ_k is the grey related grade for alternative under assessment A_k and w_j is the weight of attribute $C_j (j = 1, 2, \ldots, n)$. The first set of constraints assures that if the computed weights are applied to a group of m alternatives, $(i = 1, 2, \ldots, m)$, they do not attain a grade of larger than 1. The process of solving the model is repeated to obtain the optimal grey related grade and the optimal weights required to attain such a grade for each alternative. It should be noted that the grey related coefficients are normalized data. Consequently, the weights attached to them are also normalized.

The Proposed Model

Model (7) assesses the performance of each alternative based on the ratio of its distance from the best-practice frontier that is constructed by the best alternatives. Therefore, the weights obtained for each alternative are the most favorable weights in comparison to the other alternatives. However, as mentioned before, the disadvantage of model (7) is that some alternatives may obtain a grey related grade of 1

because of assigning zero values to the weights of some attributes and neglecting the importance of these attributes in a decision-making process. To avoid this issue, we extend a similar model as follows:

$$\begin{aligned} \Gamma'_k &= \max \sum_{j=1}^{n} w'_j \xi_{kj} \\ \text{s.t.} &\sum_{j=1}^{n} w'_j \xi_{ij} \leq 1 \ \forall i, \\ & w'_j \geq \varepsilon'_{\min} \ \forall j, \end{aligned} \tag{8}$$

where $\varepsilon'_{\min}$ is the minimum weight bound on the attribute weights which can be estimated by solving the following model (Wu et al. 2012):

$$\begin{aligned} &\max \varepsilon' \\ &\text{s.t.} \sum_{j=1}^{n} w'_j \xi_{ij} \leq 1 \forall i, \\ &w'_j \zeta_{kj} \geq \varepsilon' \forall j, \end{aligned} \tag{9}$$

The main idea of model (9) is to maximize the weighted grey related coefficients. Obviously, ε' is a positive variable. Solving model (9) respectively, for each alternative, we can obtain $m\varepsilon'$ values. Then, we select the minimum one, i.e., $\varepsilon'_{\min} = \min\{\varepsilon'_1, \ldots, \varepsilon'_m\}$, as the lower bound for the attribute weights.

On the other hand, a similar model can be developed in order to assess the performance of each alternative under the least favorable weights as follows:

$$\begin{aligned} \Gamma''_k &= \min \sum_{j=1}^{n} w''_j \xi_{kj} \\ \text{s.t.} &\sum_{j=1}^{n} w''_j \xi_{ij} \geq 1 \ \forall i, \\ & w''_j \geq \varepsilon'_{\min} \ \forall j, \end{aligned} \tag{10}$$

Here, we seek the worst weights in the sense that the objective function in model (10) is minimized. Each alternative is compared with the worst alternatives and is assessed based on the ratio of distance from the worst-practice frontier. The first set of constraints assures that the computed weights do not attain a grade of smaller than 1. The second set of constraints imposes the minimum weight bound on the attribute weights as estimated by model (9). It is worth pointing out that the worst-practice frontier approach is not a new approach in the DEA literature. Conceptually, it is parallel to the worst possible efficiency concept as discussed in Zhou et al. (2007) and Takamura and Tone (2003).

In order to combine the grey related grades obtained from models (8) and (10), i.e., the best and worst sets of weights, the linear combination of corresponding normalized grades is recommended as follows:

$$\Delta_k(\lambda) = \lambda \frac{\Gamma'_k - \Gamma'_{\min}}{\Gamma'_{\max} - \Gamma'_{\min}} + (1-\lambda) \frac{\Gamma''_k - \Gamma''_{\min}}{\Gamma''_{\max} - \Gamma''_{\min}} \tag{11}$$

where $\Gamma''_{\max} = \max\{\Gamma'_k, k = 1, 2, \ldots, m\}$, $\Gamma'_{\min} = \min\{\Gamma'_k, k = 1, 2, \ldots, m\}$, $\Gamma''_{\max} = \max\{\Gamma''_k, k = 1, 2, \ldots, m\}$, $\Gamma''_{\min} = \min\{\Gamma''_k, k = 1, 2, \ldots, m\}$ and $0 \le \lambda \le 1$ is an adjusting parameter, which may reflect the preference of decision maker on the best and worst sets of weights. $\Delta_k(\lambda)$ is a normalized compromise grade in the range [0,1].

Numerical Example: Nuclear Waste Dump Site Selection

In this section we present the application of the proposed approach for nuclear waste dump site selection. The multi-attribute data, adopted from Wu and Olson (2010), are presented in Table 1. There are twelve alternative sites and 4 performance attributes. *Cost*, *Lives lost*, and *Risk* are undesirable attributes and *Civic improvement* is a desirable attribute. *Cost* is in billions of dollars. *Lives lost* reflects expected lives lost from all exposures. *Risk* shows the risk of catastrophe (earthquake, flood, etc.) and *Civic improvement* is the improvement of the local community due to the construction and operation of each site. *Cost* and *Lives lost* are crisp values as outlined in Table 1, but *Risk* and *Civic improvement* have fuzzy data for each nuclear dump site. We use the processed data as reported in Wu and Olson (2010). First the trapezoidal fuzzy data are used to express linguistic data in Table 1. Using the α-cut technique, the raw data is expressed in fuzzy intervals as shown in Table 2. These data are turned into the comparability sequence by using Eqs. (2) and (3). Each attribute is now on a common 0–1 scale where 0 represents the worst imaginable attainment on an attribute, and 1.00 the best possible attainment.

Using Eq. (6), all grey related coefficients are computed to provide the required (output) data for models (7), (8), (9) and (10) as shown in Table 3. Note that grey related coefficients depend on the distinguishing coefficient ρ, which here is 0.80. The minimum weight bound for the attribute weights, using model (9), is equal to $\varepsilon'_{\min} = 0.1418$ that belongs to Anaheim. Table 4 presents the results obtained from models (7), (8) and (10) as well as the corresponding composite grades at $\lambda = 0.5$. If decision makers have no strong preference, $\lambda = 0.5$ would be a fairly neutral and reasonable choice. It can be seen from Table 4, Rock Sprgs with a compromise

Table 1 Data for nuclear waste dump site selection

Site	Cost	Lives	Risk	Civic
Nome	40	60	Very high	Low
Newark	100	140	Very low	Very high
Rock Sprgs	60	40	Low	High
Duquesne	60	40	Medium	Medium
Gary	70	80	Low	Very high
Yakima	70	80	High	Medium
Turkey	60	70	High	High
Wells	50	30	Medium	Medium
Anaheim	90	130	Very high	Very low
Epcot	80	120	Very low	Very low
Duckwater	80	70	Medium	Low
Santa Cruz	90	100	Very high	Very low

Table 2 Fuzzy interval nuclear waste dump site data

Site	Cost	Lives lost	Risk	Civic
Nome	[0.80–1.00]	[0.40–0.70]	[0.00–0.10]	[0.10–0.30]
Newark	[0.00–0.05]	[0.00–0.05]	[0.90–1.00]	[0.90–1.00]
Rock Sprgs	[0.70–0.95]	[0.70–0.90]	[0.70–0.90]	[0.70–0.90]
Duquesne	[0.50–0.85]	[0.70–0.90]	[0.40–0.60]	[0.40–0.60]
Gary	[0.40–0.60]	[0.10–0.30]	[0.70–0.90]	[0.90–1.00]
Yakima	[0.50–0.70]	[0.10–0.30]	[0.10–0.30]	[0.40–0.60]
Turkey	[0.75–0.90]	[0.20–0.40]	[0.10–0.30]	[0.70–0.90]
Wells	[0.85–0.95]	[0.85–1.00]	[0.40–0.60]	[0.40–0.60]
Anaheim	[0.00–0.30]	[0.00–0.10]	[0.00–0.10]	[0.00–0.10]
Epcot	[0.10–0.40]	[0.00–0.20]	[0.90–1.00]	[0.00–0.10]
Duckwater	[0.30–0.50]	[0.20–0.40]	[0.40–0.60]	[0.10–0.30]
Santa Cruz	[0.10–0.40]	[0.10–0.30]	[0.00–0.10]	[0.00–0.10]

grade of 1 stands in the first place while seven and four alternatives are ranked in the first position by models (7) and (8), respectively. This indicates that the proposed approach can significantly improve the degree of discrimination among alternatives. It is worth noting that, although Rock Sprgs has the highest compromise grade (=1), it does not have the highest grey related coefficient with respect to each attribute (Table 3). It is likely due to the fact that Rock Sprgs not only has relatively high values of grey related coefficients but also has a better combination among the different attributes.

Table 3 Results of grey related coefficients for nuclear waste dump site selection

Site	Cost	Lives lost	Risk	Civic
Nome	0.9383	0.6281	0.4578	0.4872
Newark	0.4444	0.4444	1	1
Rock Sprgs	0.8352	0.8352	0.7917	0.7917
Duquesne	0.6847	0.8352	0.6032	0.6032
Gary	0.6281	0.5033	0.7917	1
Yakima	0.6847	0.5033	0.4872	0.6032
Turkey	0.8837	0.539	0.4872	0.7917
Wells	0.9383	1	0.6032	0.6032
Anaheim	0.472	0.4578	0.4578	0.4578
Epcot	0.5033	0.472	1	0.4578
Duckwater	0.5802	0.539	0.6032	0.4872
Santa Cruz	0.5033	0.5033	0.4578	0.4578

Table 4 Results of grey related grades obtained from models (7), (8) and (10), and the corresponding compromise grades

Site	Γ_k	Γ'_k	Γ''_k	$\Delta_k(\lambda = 0.5)$
Nome	1.0000 (1)	0.9102 (7)	1.0944 (9)	0.4592 (8)
Newark	1.0000 (1)	1.0000 (1)	1.1048 (7)	0.5710 (5)
Rock Sprgs	1.0000 (1)	1.0000 (1)	1.7382 (1)	1.0000 (1)
Duquesne	0.8921 (8)	0.8755 (8)	1.3594 (3)	0.5982 (4)
Gary	1.0000 (1)	1.0000 (1)	1.2262 (4)	0.6532 (3)
Yakima	0.7855 (9)	0.7565 (9)	1.1088 (6)	0.2895 (9)
Turkey	1.0000 (1)	0.9448 (5)	1.1688 (5)	0.5499 (6)
Wells	1.0000 (1)	1.0000 (1)	1.4187 (2)	0.7836 (2)
Anaheim	0.5735 (12)	0.5715 (12)	1.0000 (12)	0.0000 (12)
Epcot	1.0000 (1)	0.9441 (6)	1.0833 (10)	0.4912 (7)
Duckwater	0.7351 (10)	0.7154 (10)	1.0991 (8)	0.2350 (10)
Santa Cruz	0.5943 (11)	0.5937 (11)	1.0109 (11)	0.0333 (11)

*The site ranks are given in parentheses

Conclusion

In this short paper, we present an extended version of the DEA model, introduced in Wu and Olson (2010) to obtain the weights of attributes in a fuzzy GRA methodology. The proposed model can lead to grey related grades with higher discrimination power since it uses two sets of weights that are most favorable and least favorable for each alternative. An illustrative example of a nuclear waste dump

site selection is presented to compare our model with the Wu and Olson's model. The interested readers who seek the further studies on the combined methodologies with DEA and GRA may refer to Pakkar (2016a, b, 2017, 2018).

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Storage and Retrieval Machine with Elevated Track Opens New Applications in Warehouse Technology and Material Supply

Reinhard Koether

Abstract An innovative Storage and Retrieval (S/R-) machine can drive around obstacles like conveyor lines or escape routes in the upper and lower part of a warehouses shelf. This innovative S/R machine can also drive around a second S/R machine in its warehouses aisle, so that one or two of these machines can operate independently in one aisle. These improvements open new applications in warehouse planning, management and production:

- The dimensions of the warehouse (height, length width) can be easier adjusted to the existing building development and building regulations.
- The handling capacity can be upgraded aisle by aisle, which allows to scale the handling capacity to the increasing demand.
- The warehouse can be integrated in the manufacturing or assembly area and integrates in house transport into storage.

These improvements enhance storage capacity, save space and expand handling capacity, thus saving investment and cost compared to conventional warehouse technology.

Warehousing and the Design Concept of the Innovative Storage and Retrieval Machine

The best warehouse is no warehouse. This rule of lean management and lean process design is almost impossible to realize in real life material supply. Warehouses are still needed

- to level out batch supply and continuous consumption,
- to secure supply,

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- to guarantee supply,
- to enable economies of scale in centralized manufacturing and decentralized consumption by worldwide customers.

But warehouses need investment in warehouse technology, space and inventory and they generate operation cost for handling and warehouse administration. In standard warehouses like a storage for palletized goods the palettes are handled, stored and retrieved by

- high bay fork trucks with driver or by
- automated Storage and Retrieval Machines (S/R-Machines) that are guided by tracks on the floor and on top of the shelf.

The S/R machines are faster and automated but they are less flexible in use than fork trucks. In almost any case an S/R machine is configured to a specific warehouse location.

The number of S/R-machines determine the handling capacity of the warehouse system, measured in double cycles per hour (= numbers of storage and retrieval operations per hour). As only one S/R machine can be operated in an aisle of the warehouse, the desired handling capacity determines the minimum number of aisles and in consequence the width of the warehouses layout.

In any case the warehouse is like an impermeable block that does not allow crossway traffic. Therefore, the warehouse is located in a separate building or at the border area of a production building. This is to avoid fixed points and obstacles in future changes of the layout.

An innovative S/R machine changes these rules and additionally allows a better use of space in a warehouse facility: The innovative S/R-machine is guided by an upper and a lower track, which is fixed on the storage rack (Fig. 1). A telescopic mast is used to access the bottom and top areas of the shelf. A conventional load handling device on the telescopic mast stores and retrieves the load units from the shelves on both sides of the aisle.

Improved Space Utilization

The telescopic mast of the innovative S/R machine allows driving around obstacles in the aisle or in the shelves (Fig. 2). Such obstacles can be conveyor lines on the floor or on higher level, they can be traverses of the building, pipe lines for ventilation or power supply. In conventional warehouses these high obstacles would limit the accessible height of the S/R machine on the full length of the aisle, but not only at the point of installation like for the innovative S/R machine. This function improves the space utilization of the warehouse building. Compared to conventional warehouses the alternative warehouse saves investment in floor space and building volume.

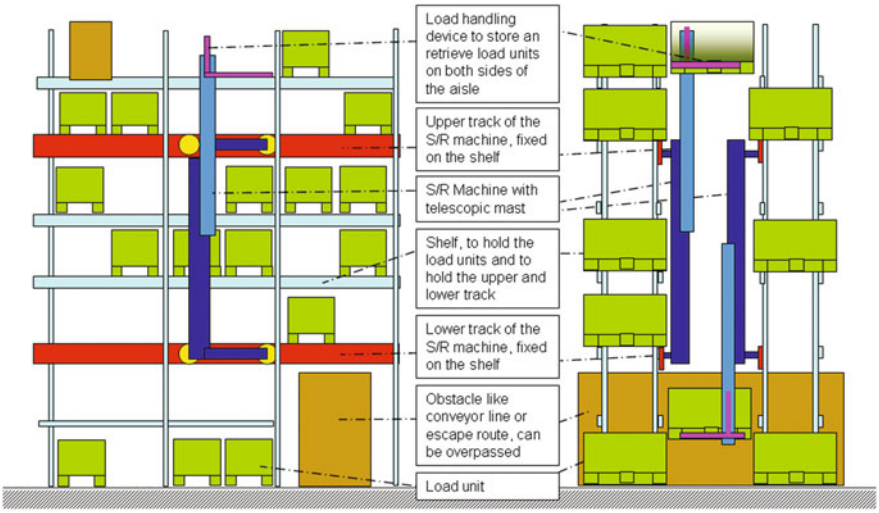

Fig. 1 Sketch of the innovative S/R machine with elevated tracks

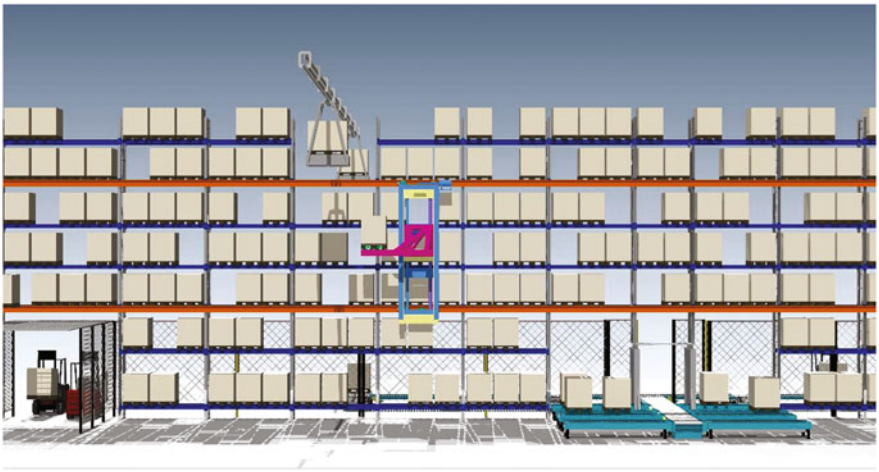

Fig. 2 The innovative S/R machine (center) can drive around obstacles in a warehouses shelf like an aisle for escape route and material transport (bottom left), an overhead conveyor (top center) or the cross conveyor to connect the marshalling area with the storage area (bottom right)

Benefits of the Design Concept in Warehousing

Flexibility in Warehouse Design and Warehouse Upgrade

The obstacle to drive around can also be a dynamic obstacle, in the aisle of a warehouse: Another S/R machine can be passed if one S/R machine has lowered its

load handling device, while the other S/R machine in the same aisle lifts its load handling device (see Fig. 1). Two S/R machines in one aisle run on tracks fixed on the racks on both sides of the aisle, one on the left shelf, the other on the right shelf. As the two S/R machines can operate in one aisle independently, except when the pass, the handling capacity in one aisle can be almost doubled.

In warehouse planning, the room (length × width × height) determines together with the width of the aisle the storage capacity measured in number of bin locations. The width of the aisle is wider for fork trucks and smaller for S/R machines. The number of fork trucks or S/R machines determines the handling capacity measured in double cycles per hour (= number of storage and retrieval operations per hour). As in conventional warehouses only one or less S/R machines or fork trucks can operate in one aisle, the number of aisles determines the maximum handling capacity. So in conventional warehouses handling capacity can only be enlarged by adding aisles which can conflict with the footprint of the space available.

The innovative S/R machine enlarges flexibility in warehouse planning. As S/R machines can operate independently in one aisle, the handling capacity is no longer connected with the number of aisles. Consequently, it is much easier to adjust the warehouses dimensions to the footprint of the available space. The number of aisles can be designed to the space available, no longer to the handling capacity needed. In the fictive example shown in Fig. 3, the same storage capacity and handling capacity could be attained with six aisles or three aisles, if two S/R machines can work in one aisle independently.

If an upgrade of handling capacity is needed after years of operation, the handling capacity can be even enlarged after start of operation. The additional S/R

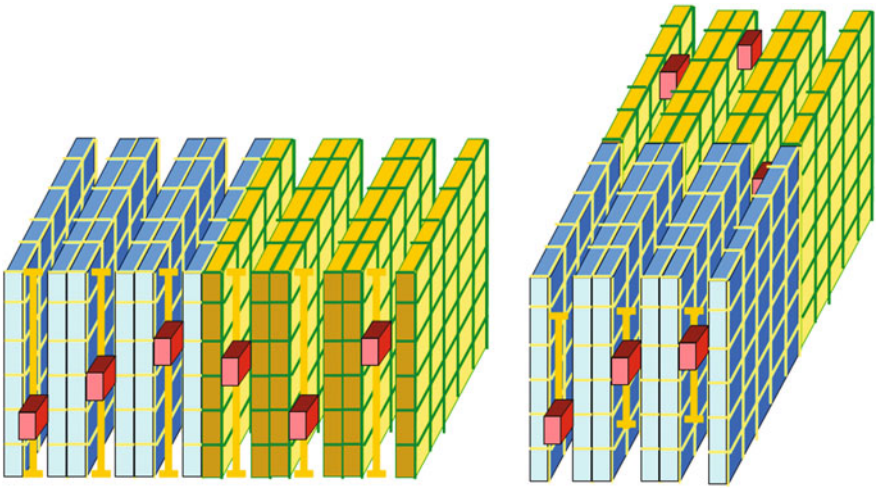

Fig. 3 Two innovative S/R machines can operate in one warehouses aisle independently, thus enhancing flexibility in warehouse

machines can be added aisle by aisle and the handling capacity can be scaled. In contrast adding handling capacity to an existing conventional warehouse means greater measures on the warehouse building.

High Handling Capacity

The function to drive around obstacles opens a further opportunity for high handling capacity, which is needed for intensive order picking (see Koether 2014) or any other high turnover rate. In a conventional warehouse the cross conveyor that connects the aisles of the warehouse to the marshalling area is installed at the front of the warehouses racks. The innovative S/R machine can jump over conveyors like the cross conveyor. So this conveyor can be placed in the middle of the racks (Fig. 4), with two effects:

1. The average distance from the cross conveyor to the shelf space is shorter, allowing shorter driving time and speeding up the S/R machine's handling operations.
2. The warehouse can be divided in two virtual blocks on the right and left side of the cross conveyor. In every aisle now up to four S/R machines can operate independently, two on each side.

Again this feature can scale the number of S/R machines operating in one aisle from one to four S/R machines and the number of S/R machine in a specific aisle can be chosen independently from other aisles.

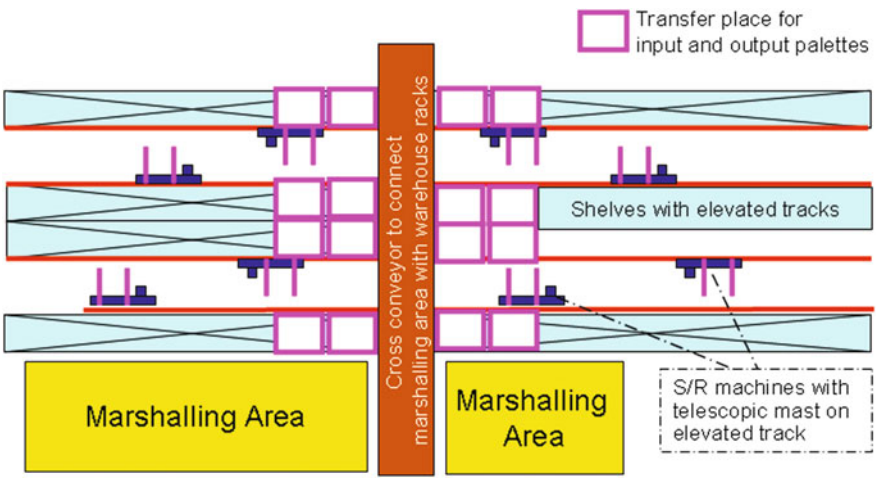

Fig. 4 With the central cross conveyor in every aisle 2 S/R machines can operate left of the conveyor and 2 S/R machines right of the conveyor independently

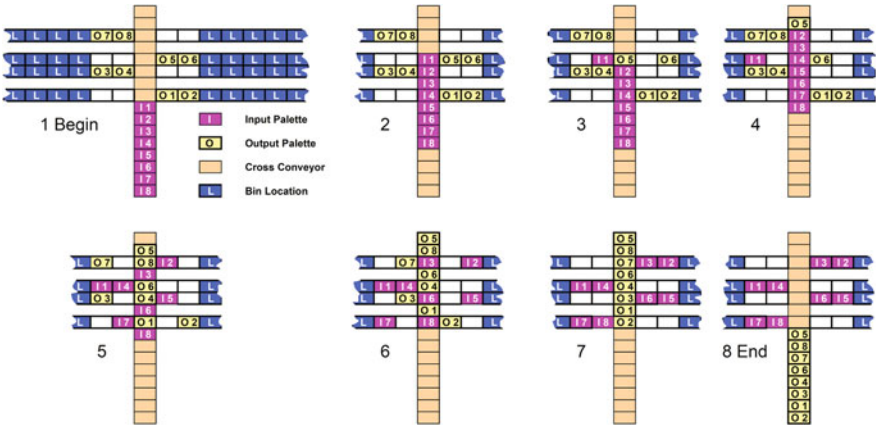

Fig. 5 Supply and collections of palettes on the central cross conveyor

The highest handling capacity is achieved by four S/R machines in one aisle, which are connected to the marshalling area by a central cross conveyor. To avoid bottlenecks in the supply of goods to store (input palettes) and the collection of stored items (output palettes) a synchronized handling process of the cross conveyor was developed (see Fig. 5).

In the marshalling area the input palettes are placed on the cross conveyor (1 Begin) and then driven halfway into the shelf area (2). Input palette I1 is pushed on the empty transfer place to the left, while simultaneously output palette O5 is loaded on the cross conveyor from the right (3). In the next step the palettes on the cross conveyor move forward and at the same time palettes I1 and O6 move one position to the left (4). In the 5th step input palettes I2, I4, I5 and I7 are pushed to the transfer places on the left and right side of the cross conveyor und the output palettes O1, O4, O6 and O8 are loaded on the cross conveyor, so that in step 5 8 palettes are moved simultaneously. The row of input and output palettes on the cross conveyor is moved by one position. At the same time output palettes O2, O3 and O7 approach the cross conveyor and input palettes I2, I5 and I7 leave the transfer places next to the cross conveyor (6). Then similar to step 5 6 palettes are loaded and unloaded simultaneously: I3, I6 and I8 are pushed from the conveyor to the respective transfer places while O2, O3 and O7 are loaded on the cross conveyor. Only output palettes are now sitting on the cross conveyor (7). They are moved in one chain to the marshalling area (8 End).

Save Investment for Floor Space and Building

The feature of multiple S/R machines operation in one aisle allows saving floor space for warehouses with high turnover rate, because the number of aisles can be

determined by the storage spaces needed, not by the handling capacity. In addition, the handling capacity of existing warehouses can be enlarged without building measures.

The aspect of floor space which is needed per aisle to achieve the handling capacity is even greater for manually operated warehouses with fork trucks. As fork trucks offer less handling capacity per device than S/R machines, even more aisles would be needed for a certain handling capacity. In addition, the aisle width for fork truck operation must be larger which consumes even more floor space and building volume. The investment for floor space and for the building can be saved. These savings allow paying off the larger investment for the innovative S/R machine compared to conventional ones or compared to fork trucks.

New Opportunities in Material Supply

Figure 6 shows an exemplary modular layout of an assembly line with warehouse in a 15 m × 15 m raster of pillars. The warehouse that guarantees a secure supply is located adjacent to the manufacturing or assembly area.

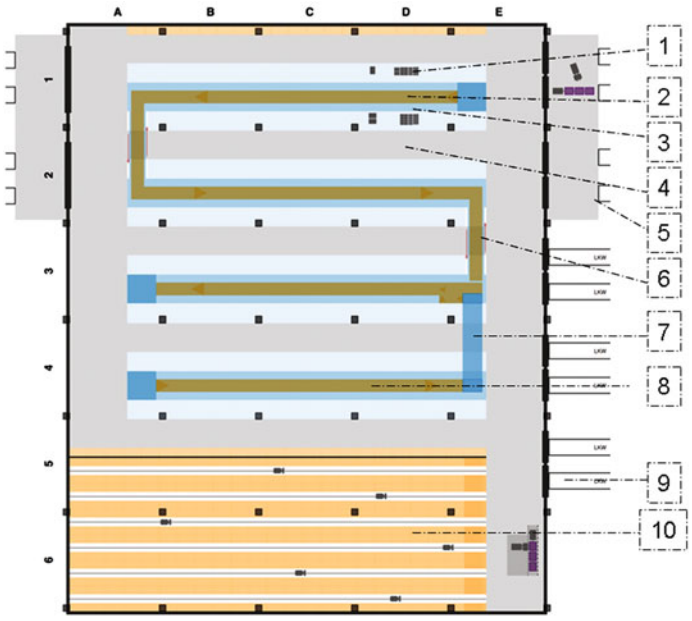

Fig. 6 Layout of assembly with adjacent warehouse (exemplary sketch). Legend: 1 Material supply zone, 2 assembly line, 3 working area 4 drive way for internal transport and for escape route, 5 loading docks, 6 floor transfer of assembly line, 7 overhead transfer of assembly line, 8 preassembly line, 9 loading docks for just in time (JIT) supply, 10 conventional warehouse for assembly material

Table 1 Process for material supply and return of empty containers

Conventional process, separate warehouse	Lean process, integrated warehouse with innovative S/R machine
Receive purchased item form outside supplier or prefabricated item from in house cost center	Receive purchased item form outside supplier or prefabricated item from in house cost center
Place item in warehouse	Place item in warehouse
Demand of manufacturing or assembly	Demand of manufacturing or assembly
Retrieve item from warehouse	Move item in the warehouse from bin position to point of consumption by innovative S/R machine
Ship item with internal transportation (fork truck or tugger train) to manufacturing or assembly	
Place item at point of consumption (machine, workplace, assembly station)	
Remove empty container and return it to staging area	Remove empty container by innovative S/R machine and place in storage bin until return to supplier
Return empty container from staging area to supplier	

A typical supply process in production is shown in the left column of Table 1.

Conventional warehouses are set apart from assembly or manufacturing area for two reasons: It is hard to move a warehouse with racks and inventory when the layout is changed. And warehouses are like blocks that cannot be penetrated crossways e.g. by escape routes that have to be clear all the time.

The innovative S/R machine can get over obstacles on the floor, it can get over escape routes. This characteristic allows using these S/R machines in manufacturing and assembly areas with people operating machines or assembling work pieces. Consequently, the shelves for warehousing and the innovative S/R machines can be located in the manufacturing or assembly area, which give two opportunities for cost saving:

1. Simplify the supply process (Table 1, compare left and right column)
2. Save space for aisles and save investment for floor space and building.

Figure 7 illustrates an exemplary sketch of an assembly's layout with integrated warehouse. The assembly line with working area and material supply zone is similar to the conventional layout (Fig. 6). So is the infrastructure with loading docks and handling area next to assembly line and warehouse area. The warehouse area which is separate from the assembly in Fig. 6 is integrated in the assembly lines in Fig. 7. Two integrated warehouse aisles with four shelves fill a space that used to be a driveway for internal transportation and for emergency exits. The emergency exists are specific escape routes (15), crossways to the shelves in the integrated layout (Fig. 7).

As the assembly of every part number is assigned to a specific station of the assembly line, it is dedicated where the part number has to be stored in the upper or lower aisle of the warehouse block. The S/R machine can retrieve the part's

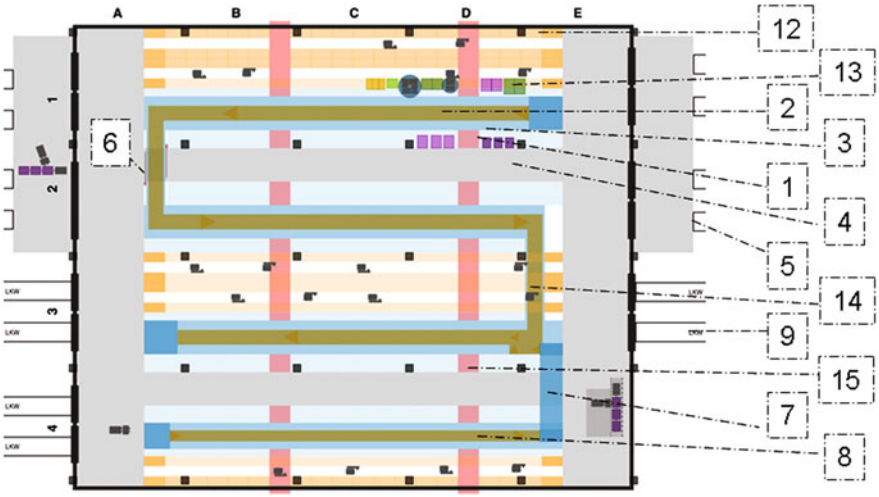

Fig. 7 Layout of assembly with integrated warehouse (exemplary sketch). Legend: 1 Material supply zone, 2 assembly line, 3 working area 4 drive way for internal transport and for escape route, 5 loading docks, 6 floor transfer of assembly line, 7 overhead transfer of assembly line, 8 preassembly line, 9 loading docks for just in time (JIT) supply, 12 integrated warehouse for assembly material, 13 material supply zone, material placed by innovative S/R machine, 14 floor transfer of assembly line over passed by innovative S/R machine, 15 escape route crossing shelves

container from shelves of either side of the aisle and relocate it to the material zone of the assembly line.

Every second driveway still exists to connect the escape routes (15) with the drive ways (4) and to enable conventional transportation for all material that is not stored in the warehouse sections with innovative S/R machine. Such parts can be packed in oversized or special containers, they can be sequenced or preassembled items or they can be parts that are delivered Just In Time (JIT) form outside or inside suppliers. So every workplace and every section of the assembly line has access to the driveway.

As two innovative S/R machines can operate independently in one aisle one machine can handle palettes, the other one small part containers. Thus it is possible to supply palletized material and small parts directly from the warehouse without intermediate handling.

The warehouse sections in the integrated layout (Fig. 7) are part of the assembly layout structure. This structure typically can be reused for modernized, upgraded and new products. To match the layout and the number of assembly stations with the planned volume the layouts in Figs. 6 and 7 are configured by modular elements of area. These modules can be copied and inserted (see Fig. 8). To enlarge the length of the assembly lines, the elements of vertical area module in column B and C can be copied, multiplied and pasted like column BCa, BCb, BCc and so on. To insert more assembly lines the elements of horizontal area module between the

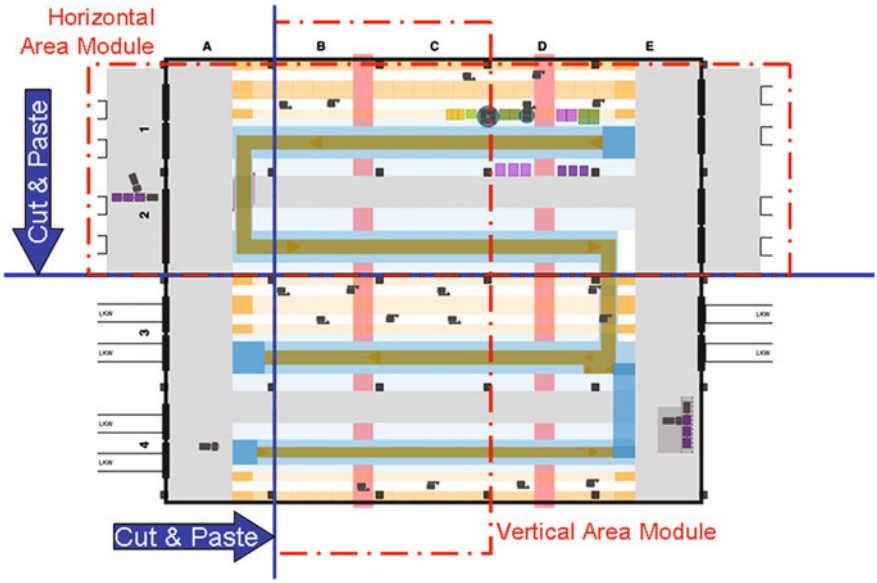

Fig. 8 Modular design of layout with integrated warehouse

pillars in row 1 and 2 can be copied. The sequence of the assembly hall naves from top to bottom would then be: 1,2, 1,2, 1,2, .. 3, 4.

A short glance at Figs. 6 and 7 already shows that the assembly line with integrated warehouse demands less floor space than the conventional layout with separated assembly and warehouse zones. Less floor space means less investment for land and for the building. Furthermore, the simplified and automated process (Table 1), saves time and handling cost.

Conclusion

The innovative S/R machine described is applied for a patent. Together with an industrial partner a detailed design and control concept will be developed in the near future.

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Nurse Scheduling with Shift Preferences in a Surgical Suite Using Goal Programming

Esra Agca Aktunc and Elif Tekin

Abstract Nurse scheduling is a crucial part of hospital personnel scheduling. For effective nurse scheduling, fair workload and job satisfaction should be taken into account, as these factors affect the quality of service in healthcare. In this study, monthly nurse scheduling constraints for a surgical suite are determined according to government regulations, hospital management requirements, and nurse preferences. A multi-objective integer program with hard and soft constraints is formulated and solved as a goal programming model to produce an optimal nurse schedule which provides fair workload and satisfies shift preferences of nurses. Our goal is improving job satisfaction of nurses as well as reducing medical errors caused by fatigue, a result of disproportional shift assignment. Resulting schedules for various shift preference scenarios are compared to show the improvement in the schedule quality in terms of performance measures such as distribution of preference violations among nurses.

Keywords Nurse scheduling · Integer program · Shift preferences
Multi-objective optimization · Goal programming

Introduction

Healthcare systems have experienced drastic changes in the last few decades as a result of increasing population and technological developments that both increased life expectancy and incurred additional costs. There have also been budget cuts that force hospitals to use their resources more efficiently. Healthcare organizations have to work twenty-four hours a day for every day of the year and shift work is used in healthcare organizations in order to provide continuous service for patients.

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An important resource of a hospital is its surgical suite of operating rooms where nurse scheduling is one of the most challenging workforce planning problems since the quality of care provided by nurses depends greatly on their shift assignments and, thus, job satisfaction. Compared to the globally increasing demand for healthcare, the supply and retention of qualified nursing staff has been insufficient (Oulton 2016). This makes nurse scheduling one of the most significant issues in terms of hospital managements' expectations to use their budget wisely, patient expectations of continuous high quality care, and nurses' expectations of fair workload distribution.

Nurse scheduling is the task of specifying the work pattern for individual nurses and it can be generated manually by a head nurse or using software systems for scheduling. In most hospital units, nurse schedules are still manually developed by experienced head nurses who have to gather information from nurses about their time conflicts and have to adjust schedules as needed. However, developing a fair schedule manually is time consuming and difficult because of the vast number of possible schedules and all the constraints to consider. In practice, nurse schedules are typically developed for a period of four weeks. These schedules can be flexible, changing every period, or fixed. Fixed (or cyclical) schedules generally provide good solutions, but they cannot easily address staff preferences or fluctuating demand (Burke et al. 2004). While generating nurse schedules, significant constraints should be considered such as observing work regulations, distinguishing between permanent and temporary staff, ensuring that night and weekend shifts are distributed fairly, allowing for leave and days off, and accommodating a range of employee preferences (Ernst et al. 2004). In this study, we address the flexible scheduling of nurses in a surgical suite where the nurse preferences for shifts are used as input to generate fair shift assignments.

The remainder of this paper is organized as follows. In Section "Literature Review", we review relevant work from the nurse scheduling literature. In Sect. "Model Development", we present our integer programming model for nurse scheduling. We describe the solution methodology by formulating the goal programming model in Section "Solution Methodology" and demonstrate the use of this model with a case study in Section "Computational Results". We conclude the paper with our discussion of the study results and possible extensions of this work in Section "Conclusions".

Literature Review

In this section, we provide an overview of existing literature on nurse scheduling, which is a special case of personnel scheduling. Personnel scheduling can be defined as generating and arranging duty timetables for employees while considering certain work regulations, coverage constraints, or personnel preferences in order to satisfy the demand for the goods and services of organizations. Personnel scheduling has been studied widely for several decades in various application areas

such as transportation systems, healthcare systems, call centers, emergency services, restaurants, hotels, and retail stores (Ernst et al. 2004; Baker 1976; Tien and Kamiyama 1982; Bradley and Martin 1991; Bechtold et al. 1991; Van den Bergh et al. 2013).

Our paper focuses on the nurse scheduling problem in a surgical suite (or operating theatre) that consists of operating rooms (ORs) and recovery rooms. This is especially a significant issue since the surgical suite has high operating costs and workforce planning directly impacts the efficiency of not only this unit, but also other units of the hospital that are related to the surgical suite (Marques et al. 2015). According to Health Care Financial Management Association Report, ORs have been estimated to account for more than 40% of a hospital's total revenues, and it is both the greatest source of revenues and the largest cost center for hospitals (Sitompul and Radhawa 1990). Therefore, management of the workforce of a surgical suit is a crucial and complex issue for hospital administration. Nurse scheduling plays an important role in the efficiency of surgical suites.

In order to develop a nurse schedule, first of all, the required number of qualified nurses from various skill sets should be determined for each shift to meet the demand based on the number of patients in the wards or a predetermined patient-to-nurse ratio. Then, adequate nurses should be assigned to shifts in order to meet the service needs. The quality of nurse scheduling directly affects the quality of healthcare and job satisfaction of nurses (Cheang et al. 2003). Therefore, the schedule must strive to satisfy nurse preferences, distribute shifts fairly among nurses, and distinguish between full-time and part-time staff, in addition to abiding by work regulations determined by governments or other authorities and other hospital-specific constraints. These constraints can be classified as hard constraints, that cannot be violated, and soft constraints, that can be violated at a cost. Finding an optimal solution that minimizes the costs can be complicated regarding all these constraints at the same time. A wide range of solution methods are used to solve these complex problems, such as mathematical programming, simulation, queueing, constraint programming, and metaheuristics (Ernst et al. 2004; Van den Bergh et al. 2013).

Several studies have been published since the 1960s on various aspects of computerized healthcare personnel scheduling. Mathematical programming methods such as linear and integer programming are widely used for solving nurse scheduling problems (Cheang et al. 2003). While most of the mathematical programs have a single objective function subject to a restricted set of constraints as a result of oversimplifying assumptions, there are also several studies that use goal programming or multi-objective decision making. The most commonly used objectives of nurse scheduling problems are versions of cost minimization, that may either directly consider recruitment costs, nurse wages, and overtime costs or consider penalty costs for violating a set of soft constraints. Ozkarahan and Bailey (1988) defined three goals to avoid understaffing while maximizing coverage and the utilization of nurses, then solved the problem using a two-phase approach that

first determines the day-of-week schedules and then the time-of-day schedules. Arthur and Ravindran (2015) proposed a goal programming model solved similarly in two phases, first by assigning day-on/day-off patterns using goal programming and then by assigning shifts using a heuristic. Berrada et al. (1996) treated the problem as a multi-objective model with hard and soft constraints, where soft constraints are used to define goals, and they solved the problem by goal programming and tabu search. Azaiez and Al Sharif (2005) developed a 0-1 goal program with five goals and solved the monthly scheduling problem by subgrouping the nurses and workloads into manageable sizes. Wright and Mahar (2013) compare centralized and decentralized nurse scheduling across two multi-unit hospitals and show that the centralized model performs better in terms of scheduling cost and schedule desirability.

The literature on nurse scheduling in surgical suites can be considered scarce compared to nurse scheduling in other hospital units. Belien and Demeulemeester (2008) solve an integrated nurse and surgery scheduling problem using column generation. The daily surgery assignment of nurses is modeled as a multi-objective integer programming model and solved using a solution pool method and a variant of goal programming in Mobasher et al. (2011). Similarly, a nurse scheduling model with the objectives of minimizing labor costs, patient dissatisfaction, nurse idle time, and maximizing job satisfaction is presented in Lim et al. (2012).

Although there is a considerable amount of literature on nurse scheduling, there are only a few studies that are based on nurse preferences to improve job satisfaction and that also have multiple goals for equitable shift assignment among nurses. In this study, we give nurse preferences the highest priority after the demand-related hard constraints and consider multiple goals to ensure fair workload distribution. Next, we introduce our multi-objective integer programming model.

Model Development

The nurse scheduling model proposed in this study is an integer programming model with the objectives of minimizing schedule cost and maximizing job satisfaction for nurses. The assumptions of our mathematical model for our multi-objective nurse scheduling problem are as follows:

1. Minimum number of required nurses in each shift is deterministic and known based on experience of demand since mostly elective surgeries are performed in the surgical suite.
2. There are three 8-h shifts in a day: (1) from 7:00 to 15:00 day shift, (2) from 15:00 to 23:00 evening shift, and (3) 23:00 to 07:00 night shift for 7 days a week and 24 h a day.
3. There are two skill classes of nurses: regular nurses and intern nurses.

4. Regular nurses are classified into three groups based on their specialty: (1) cardiovascular surgery, (2) general surgery, and (3) neurosurgery.
5. Minimum staff level requirements must be satisfied.
6. Each nurse has to work at least 24 h and at most 72 h per week.
7. Nurses cannot work for more than 6 consecutive working days.
8. A nurse should not work more than 3 consecutive night shifts.
9. Each nurse works at most one shift a day. This is especially a necessary constraint for a surgical suite because of the high service level expectations and more arduous workload than other hospital units.

Assumptions similar to the assumptions 1, 2, 5, 6, and 9 can be observed in the literature. However, the assumptions regarding classes of nurses (3, 4), shift durations (2), and hospital-specific work regulations (6, 7, 8) above are made based on an interview with the head nurse of a surgical unit at a private hospital.

The notation used in the model formulation are explained below.

Sets

I set of nurses
S set of specialties
I_s set of nurses in specialty $s \in S$
J set of shifts in a day, where $j = 1$ for day shift, $j = 2$ for evening shift, and $j = 3$ for night shift
T set of days in the scheduling period
W set of weeks in the scheduling period

Parameters

$$p_{ijt} = \begin{cases} 1, & \text{if nurse } i \in I \text{ prefers to work shift } j \in J \text{ on day } t \in T \\ 0, & \text{otherwise} \end{cases}$$

R number of regular nurses
NR_{sjt} minimum number of regular nurses in specialty $s \in S$ required for shift $j \in J$ on day $t \in T$
NI_{jt} minimum number of intern nurses required for shift $j \in J$ on day $t \in T$
h_L lower limit on the number of hours that a nurse can work per week
h_U upper limit on the number of hours that a nurse can work per week
cr_i cost of a regular nurse $i \in \{1, 2, \ldots, R\}$ per shift
c_i cost of an intern nurse $i \in \{R+1, \ldots, |I|\}$ per shift

Decision Variables

$$x_{ijt} = \begin{cases} 1, & \text{if nurse } i \in I \text{ is assigned to shift } j \in J \text{ on day } t \in T \\ 0, & \text{otherwise} \end{cases}$$

Model Formulation

$$\text{Min} \quad cr_i\left(\sum_{i=1}^{R}\sum_{j\in J}\sum_{t\in T}x_{ijt}\right)+c_i\left(\sum_{i=R+1}^{|I|}\sum_{j\in J}\sum_{t\in T}x_{ijt}\right) \tag{1}$$

Subject to

$$\sum_{i\in I_s}x_{ijt}\geq NR_{sjt},\quad \forall \mathrm{s}\in \mathrm{S}, j\in J, t\in T \tag{2}$$

$$\sum_{i=R+1}^{|I|}x_{ijt}\geq NI_{jt},\quad \forall j\in J, t\in T \tag{3}$$

$$\sum_{t=7(w-1)+1}^{7w}\sum_{j\in J}x_{ijt}\geq h_L/8,\quad \forall i\in I, w\in W \tag{4}$$

$$\sum_{t=7(w-1)+1}^{7w}\sum_{j\in J}x_{ijt}\leq h_U/8,\quad \forall i\in I, w\in W \tag{5}$$

$$\sum_{j\in J}x_{ijt}\leq 1,\quad \forall i\in I, t\in T \tag{6}$$

$$x_{i3t}+x_{i1(t+1)}\leq 1,\quad \forall i\in I, t\in T \tag{7}$$

$$\sum_{j\in J}\sum_{t=k}^{k+6}x_{ijt}\leq 6,\quad \forall i\in I, k=1,2,\ldots,|T|-6 \tag{8}$$

$$\sum_{t=k}^{k+3}x_{i3t}\leq 3,\quad \forall i\in I, k=1,2,\ldots,|T|-3 \tag{9}$$

$$\sum_{t\in T}x_{i3t}\geq 3,\quad \forall i\in I \tag{10}$$

$$x_{ijt}-p_{ijt}\leq 0,\quad \forall i\in I, j\in J, t\in T \tag{11}$$

$$\sum_{t\in T}x_{i3t}-\left(\sum_{t\in T}x_{i1t}+\sum_{t\in T}x_{i2t}\right)\leq 0,\quad \forall i\in I \tag{12}$$

$$\left(1-\sum_{j\in J} x_{ijt}\right)+\sum_{j\in J} x_{ij(t+1)}+\left(1-\sum_{j\in J} x_{ij(t+2)}\right)\leq 2,\quad \forall i\in I, t=1,2,\ldots,|T|-2 \tag{13}$$

$$\sum_{j\in J} x_{ijt}+\left(1-\sum_{j\in J} x_{ij(t+1)}\right)+\sum_{j\in J} x_{ij(t+2)}\leq 2,\quad \forall i\in I, t=1,2,\ldots,|T|-2 \tag{14}$$

$$x_{ijt}\in\{0,1\},\ \forall i\in I, j\in J, t\in T \tag{15}$$

The initial objective function (1) minimizes the total cost of nurses assigned to shifts. Constraints (2) and (3) ensure that the required numbers of regular nurses and intern nurses are met, respectively, for each shift on each day. Constraints (4) and (5) bound the total weekly hours assigned to a nurse using the minimum and maximum allowed working hours, respectively. Constraint (6) avoids the assignment of more than one shift per day to a nurse. Assigning a day shift followed by a night shift or a night shift right before a day shift is prevented by constraint (7). According to constraints (8) and (9), a nurse can work for at most 6 consecutive days and can be assigned at most 3 consecutive night shifts, respectively. Constraint (10) ensures that each nurse is assigned at least 3 night shifts in a month. Constraint (11) avoids shift assignments on days that are not preferred by a nurse, in other words, over-assignment. Constraint (12) requires the total night shifts assigned to be at most as many as the total day and evening shifts assigned to a nurse. Constraints (13) and (14) avoid the "0-1-0" or "1-0-1" types of assignments where a day on would be between two days off or a day off would be between two days on, which are both undesired cases from the nurse's perspective. Constraint (15) defines the binary decision variables.

In this model, constraints (2)–(10) are hard constraints that cannot be violated and constraints (11)–(14) are soft constraints that can be violated at a cost in order to obtain a feasible schedule. In the following section, the goal programming model is formulated by incorporating the penalty of violating these soft constraints in the objective function.

Solution Methodology

In the proposed model, soft constraints are (11)–(14). In order to penalize the violation of these soft constraints, appropriate decision variables should be added to the model as explained below.

Goal 1: We modify the soft constraint (11) as follows:

$$x_{ijt} - p_{ijt} - o_{ijt} + u_{ijt} = 0, \quad \forall i \in I, j \in J, t \in T \tag{16}$$

where the binary decision variables $o_{ijt} \in \{0,1\}, \forall i \in I, j \in J, t \in T$, and $u_{ijt} \in \{0,1\}, \forall i \in I, j \in J, t \in T$, represent the over- and under-assignment of shifts based on nurse preferences, respectively. It would be undesirable if a nurse is assigned to a shift that the nurse does not prefer as well as if a nurse is not assigned a shift that the nurse prefers to work. Therefore, both of these variables are penalized using the following objective function:

$$\text{Minimize} \quad \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} \left(\alpha o_{ijt} + \beta u_{ijt} \right) \tag{17}$$

where α is the penalty cost for assignment of a shift that a nurse does not prefer and β is the penalty cost for not assigning a shift that a nurse prefers, such that $\alpha \geq \beta$ because over-assignment is even more undesirable than under-assignment.

Goal 2: Soft constraint (12) is modified as follows to allow for deviations:

$$\sum_{t \in T} x_{i3t} - \left(\sum_{t \in T} x_{i1t} + \sum_{t \in T} x_{i2t} \right) - d_i^+ + d_i^- = 0 \quad \forall i \in I \tag{18}$$

where $d_i^+ \in \{0,1\}, \forall i \in I$, and $d_i^- \in \{0,1\}, \forall i \in I$, are the positive and negative deviations from the goal of assigning less night shifts than day and evening shifts in total. The positive deviations from this goal is penalized by adding the following objective function:

$$\text{Minimize} \quad \sum_{i \in I} d_i^+ \tag{19}$$

Goal 3: Soft constraint (13) is modified as follows to allow for deviations:

$$\begin{aligned} &\left(1 - \sum_{j \in J} x_{ijt}\right) + \sum_{j \in J} x_{ij(t+1)} + \left(1 - \sum_{j \in J} x_{ij(t+2)}\right) \\ &\quad - da_{it}^+ + da_{it}^- = 2 \quad \forall i \in I, t = 1, 2, \ldots, |T| - 2 \end{aligned} \tag{20}$$

where $da_{it}^+ \in \{0,1\}, \forall i \in I, t \in T$, and $da_{it}^- \in \{0,1\}, \forall i \in I, t \in T$, are the positive and negative deviations from the goal of avoiding isolated days on. Only the positive deviations from this goal is penalized by adding the following objective function:

$$\text{Minimize} \quad \sum_{i \in I} \sum_{t \in T} da_{it}^+ \tag{21}$$

Goal 4: Soft constraint (14) is modified as follows to allow for deviations:

$$\sum_{j\in J} x_{ijt} + \left(1 - \sum_{j\in J} x_{ij(t+1)}\right) + \sum_{j\in J} x_{ij(t+2)} - db_{it}^{+} + db_{it}^{-} = 2 \quad \forall i \in I, t = 1, 2, \ldots, |T| - 2 \tag{22}$$

where $db_{it}^{+} \in \{0,1\}, \forall i \in I, t \in T$ and $db_{it}^{-} \in \{0,1\}, \forall i \in I, t \in T$ are the positive and negative deviations from the goal of avoiding isolated days off. Only the positive deviations from this goal is penalized by adding the following objective function:

$$\text{Minimize} \quad \sum_{i\in I}\sum_{t\in T} db_{it}^{+} \tag{23}$$

As a result of these goal formulations, the initial objective function is modified as follows.

$$\begin{aligned}\text{Minimize} \quad z = {} & cr_i\left(\sum_{i=1}^{R}\sum_{j\in J}\sum_{t\in T} x_{ijt}\right) + c_i\left(\sum_{i=R+1}^{|I|}\sum_{j\in J}\sum_{t\in T} x_{ijt}\right) \\ & + \sum_{i\in I}\sum_{j\in J}\sum_{t\in T}\left(\alpha o_{ijt} + \beta u_{ijt}\right) + \sum_{i\in I} d_i^{+} + \sum_{i\in I}\sum_{t\in T} da_{it}^{+} \\ & + \sum_{i\in I}\sum_{t\in T} db_{it}^{+}\end{aligned} \tag{24}$$

The objective function (24) is the weighted sum of five different objectives: (i) minimizing the total cost of nurses assigned to shifts as in (1), (ii–v) minimizing the total violation of soft constraints as shown in (17), (19), (21), and (23), respectively.

Next, we describe our case study and present the computational results of our proposed model in terms of various performance measures.

Computational Results

In this section, we provide a numeric example for illustrating the nurse scheduling model presented above. This example is based on an actual surgical unit of a private hospital in terms of the number of available nurses and the minimum required total number of nurses; however, due to the lack of data regarding the number of surgeries of each type performed, the minimum requirement for each surgery type is estimated based on an interview with the surgical unit nurses. Consider a surgical suite in which 30 nurses are employed, 5 of whom are intern nurses who are still in training. The other 25 nurses are regular nurses with more experience and they have

Table 1 Minimum nurse requirements

Shifts (j)	1	2	3
NR_{1jt}	2	2	1
NR_{2jt}	2	2	1
NR_{3jt}	2	2	1
NI_{jt}	1	1	1

higher priority in terms of shift preferences and taking time off work. Regular nurses are split into three groups based on their specialties: 10 nurses are in cardiovascular surgery $(s = 1)$, 8 nurses are in general surgery $(s = 2)$, and 7 nurses are in neurological surgery $(s = 3)$. The planning horizon is four weeks (28 days, including the weekends). The minimum required number of regular nurses of each specialty and intern nurses in each shift are provided in Table 1. These numbers are assumed for each day since there are as many elective surgeries on the weekends as on the weekdays. The cost of a regular nurse per shift is $cr_i = 3, i = 1, 2, \ldots, 25$ and the cost of an intern per shift is $c_i = 2, i = 26, 27, \ldots, 30$.

In order to measure the performance of the model solutions, we define the following terms (25)–(27). Let ω be the number of nurses who are over-assigned, i.e., that are assigned a shift they did not prefer to work, as shown below.

$$\omega = \sum_{i \in I : \exists o_{ijt} = 1} 1 \tag{25}$$

Let ρ_o be the ratio of the total number of over-assigned shifts to the total number of assigned shifts, i.e., the ratio of shifts assigned that nurses do not prefer to work on, as shown below.

$$\rho_o = \frac{\sum_{i,j,t} o_{ijt}}{\sum_{i,j,t} x_{ijt}} \tag{26}$$

Let ρ_u be the ratio of the total number of under-assigned shifts to the maximum possible number of under-assigned shifts, i.e., the total number of shifts that nurses prefer to work on, as shown below.

$$\rho_u = \frac{\sum_{i,j,t} u_{ijt}}{\sum_{i,j,t} p_{ijt}} \tag{27}$$

The optimization model is formulated using GAMS 24.6 and solved using CPLEX 12.6 software on a 2.20 GHz Windows laptop computer with 6 GB RAM.

Base Case Scenario 0

In our Base Case Scenario 0, all shift preferences are set to zero, i.e., $p_{ijt} = 0, \forall i \in I, j \in J, t \in T$. Assuming that $\alpha = \beta = 1$, the optimal value for the objective function (24) in this scenario is $z^* = 1940$, where the total number of

shifts assigned is $\sum_{i,j,t} x_{ijt} = \sum_{i,t} o_{ijt} = 506$. In this case, the proportion of over-assignment (out of 2520 shifts) is $\rho_o = 100\%$.

Base Case Scenario 1

The other extreme is having all nurses available on all shifts over the planning horizon, i.e., $p_{ijt} = 1, \forall i \in I, j \in J, t \in T$. Assuming that $\alpha = \beta = 1$, the optimal value for the objective function (24) is $z^* = 3451$, where, again, $\sum_{i,j,t} x_{ijt} = 506$, and $\sum_{i,t} u_{ijt} = 2014$. In this case, since there cannot be any over-assignment, $\rho_o = 0\%$.

These base case scenarios show us the limits on the objective function value and the limits on the quantity $\sum_{i,j,t} o_{ijt}$, as well as ρ_o, when $\alpha = \beta = 1$ at the two extreme nurse preference values.

Four different Preference Scenarios (PS) are developed to test the performance of the scheduling model. These scenarios, PSn (n = 1, 2, 3, 4), are designed such that n*20% of all shifts in a month are preferred by nurses. Therefore, PS1 is the most restrictive one out of these scenarios. The problem is solved for these scenarios with different penalty cost, α, values for not meeting the nurse preferences and all the problem instances are solved to optimality within at most 1000 s. We present the optimal solutions of the proposed model for the four scenarios for various α values in Table 2, 3 and 4 below.

In all of the problem instances, it is observed that constraint (12), regarding the "0-1-0" type of assignment, is never violated, i.e., $\sum_{i,t} da^+_{i,t} = 0$ in all cases.

When PS1 is used, at any α level the same optimal schedule is obtained. In this solution, 78.5% of assignments (397 of 506) are over-assignments made for all 30 nurses as can be seen from Table 2. When PS4 is assumed, the ratio of over-assigned shifts is reduced to 13.2% (67 of 506) and the number of nurses affected by over-assignment is reduced to 18. In PS4, there is also no "1-0-1" type of assignment in the optimal solution.

It is observed that the ratio of over-assigned shifts is significantly reduced to 37.6% for $\alpha = 1$ when PS2 is assumed and the minimum possible value for this ratio is 34.2% in this scenario as shown in Table 3. The number of nurses affected by over-assignment, ω, is reduced to 27 as α is increased. The ratio, ρ_o, is further

Table 2 Results for PS1 and PS4

	PS1						PS4					
α	CPU time (s)	z^*	$\sum_{i,t} db^+_{i,t}$	ρ_o	ρ_u	ω	CPU time (s)	z^*	$\sum_{i,t} db^+_{i,t}$	ρ_o	ρ_u	ω
1	5.38	2228	2	0.785	0.784	30	4.42	3078	0	0.132	0.782	18
2	5.11	2625	2	0.785	0.784	30	4.11	3146	0	0.132	0.782	18
3	5.22	3024	2	0.785	0.784	30	2.72	3215	0	0.132	0.782	18
4	5.45	3419	2	0.785	0.784	30	4.33	3282	0	0.132	0.782	18
5	15.64	3816	2	0.785	0.784	30	4	3348	0	0.132	0.782	18

Table 3 Results for PS2

α	CPU time (s)	z^*	$\sum_{i\in I} d_i^+$	$\sum_{i,t} db_{i,t}^+$	ρ_o	ρ_u	ω
1	16.17	2324	0	2	0.376	0.686	30
2	19.52	2514	0	2	0.373	0.686	30
3	19.19	2704	0	2	0.373	0.686	30
4	85.81	2882	24	2	0.342	0.660	27
5	72.20	3060	24	2	0.342	0.660	27

Table 4 Results for PS3

α	CPU time (s)	z^*	$\sum_{i\in I} d_i^+$	$\sum_{i,t} db_{i,t}^+$	ρ_o	ρ_u	ω
1	772	2678	0	6	0.224	0.739	29
2	42.31	2785	11	14	0.204	0.731	29
3	41.98	2888	14	16	0.200	0.729	29
4	1000.09	2977	42	17	0.168	0.711	25
5	1000.05	3063	46	19	0.163	0.708	25

reduced to 22.4% when PS3 is used and the minimum possible value becomes 16.3% in this scenario as shown Table 4. The number of nurses affected by over-assignment is reduced to 25 as α is increased.

Additionally, in PS2, at $\alpha = 4$ and $\alpha = 5$, three nurses are assigned 8 more night shifts than their total day and evening shifts in the optimal schedule, i.e., $\sum_{i\in I} d_i^+ = 24$. The sum of these positive slack variables increases in PS3 to 43 and 46 for the same α values, respectively. Also, when PS3 is used, the number of "1-0-1" type assignments made increases as α increases, whereas, in PS2, this number is fixed at 2 for all α values.

In Fig. 1, it is shown that the impact of increasing the penalty cost for over-assignments, α, diminishes as the number of preferred shifts is increased in the

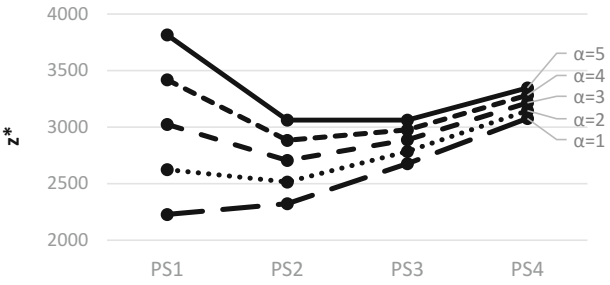

Fig. 1 The optimal objective function values for the four preference scenarios at different α levels

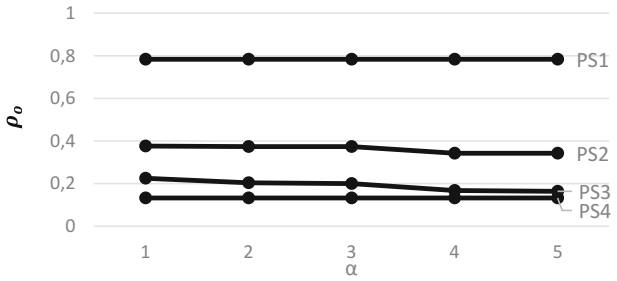

Fig. 2 The ratio of over-assignment for the four preference scenarios at different α levels

preference matrix. This is mostly due to the reduction in the number of over-assignments required in the optimal schedule.

The PS1 and PS4 scenarios result in constant ρ_o values at all α levels as shown in Fig. 2. As the number of preferred shifts is increased by the same amount, in other words as we move from PS1 to PS4, the improvement in the value of ρ_o diminishes at all α levels. Our case study shows that the job satisfaction of nurses measured in terms of ρ_o can be increased as much as 6% in a scenario like PS2.

Conclusions

In this study, we focus on the nurse scheduling problem in a surgical suite where cardiovascular, general, and neurological surgeries are performed. Shift preferences of nurses are given the highest priority while meeting the demand-related constraints. We develop a multi-objective integer programming model with hard and soft constraints and solve the model using goal programming. The model is formulated to produce the best possible schedule in terms of meeting nurse preferences and fair distribution of workload. We illustrate the performance of the proposed model with an example under various shift preference scenarios. Computational results show that the multi-objective nature of the model leads to higher job satisfaction for nurses in terms of the performance measures evaluated, by avoiding the assignment of shifts that are not preferred, by avoiding isolated days on or off, and by avoiding disproportionate night shift assignments. The proposed model can easily be used in practice to produce the best possible nurse schedule given a certain shift preference scenario by adjusting the penalty cost, α.

This model can be extended such that stochastic demand is used as input rather than deterministic demand so as to include emergency surgeries. Our model considers a wide set of constraints already, however, there are other scheduling constraints in the literature that can easily be added to this model such as constraints dealing with annual vacations or minimum number of weekend days off.

Surgical units are especially important for hospital management due to the high level of medical care provided and the high revenues generated through the

operations. The efficiency and quality of surgical suite operations can be improved by assuring the job satisfaction of nurses who are one of the essential resources. Fair distribution of workload among nurses in terms of shift schedule and minimum possible deviation from the shift preferences of each nurse, as demonstrated in this study, can increase job satisfaction of surgical unit nurses. We believe that hospitals would benefit from adopting such staff schedules in terms of not only job satisfaction of the surgical unit nurses, but also the quality of medical care provided which would result in higher credibility in return.

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Implementing EWMA Yield Index for Product Acceptance Determination in Autocorrelation Between Linear Profiles

Yeneneh Tamirat

Abstract In this manuscript, a new sampling plan based on the exponentially weighted moving average (EWMA) yield index for lot sentencing for autocorrelation between linear profiles is proposed. The advantage of the EWMA statistic is the accumulation of quality history from previous lots. In addition, the number of profiles required for lot sentencing is more economical than the traditional single sampling plan. As the value of the smoothing parameter is equal to one, the sampling plan based on the EWMA statistic becomes a traditional single sampling plan. Considering the acceptable quality level at the producer's risk and the lot tolerance percent defective at the consumer's risk, the plan parameters are determined. The plan parameters are tabulated for various combinations of the smoothing constant of the EWMA statistic and the acceptable quality level and lot tolerance proportion defective at the producer's risk and the consumer's risk respectively.

Keywords Yield index · Acceptance sampling plans · Exponentially weighted moving average · Autocorrelation between linear profiles

Introduction

The existence of an intensely competitive business environment obliges manufacturers to protect the quality of their products in the most efficient and economical way possible. Judicious use of acceptance control can supplement and support applications of statistical process control (Schilling and Neubauer 2009). The use of acceptance sampling on its own provides a proven resource for the evaluation of products. When inspection is for the purpose of acceptance or rejection of a product, based on adherence to a standard, the type of inspection procedure employed is usually called acceptance sampling (Montgomery 2013). An acceptance sampling

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plan consists of the sample size to be used and the associated acceptance or rejection criteria.

A profile occurs when a critical-to-quality characteristic is functionally dependent on one or more independent variables. Thus, instead of observing a single measurement on each unit or product we observe a set of values over a range that, when plotted, takes the shape of a curve (Montgomery 2013). The curve explains the possible effect on the dependent variable that might be caused by different levels of the independent variable. A review of research topics on the monitoring of linear profiles is provided by Woodall (2007). Noorossana et al. (2011a, b) provided an inclusive review of profile monitoring. With the assumption that the process data are uncorrelated, many studies have been done by researchers on the monitoring of simple linear/nonlinear profiles (see Li and Wang 2010; Noorossana et al. 2010; Noorossana et al. 2011a, b; Chuang et al. 2013; Ghahyazi et al. 2014). For simple nonlinear profiles and linear profiles, a process-yield index S_{pkA} with a lower confidence bound is proposed by Wang and Guo (2014) and Wang (2014), respectively. However, process data in continuous manufacturing processes are often autocorrelated. In the presence of autocorrelation between profiles, Wang and Tamirat (2014) proposed a process-yield index $S_{pkA;AR(1)}$ and its approximate lower confidence bound (LCB).

In a highly competitive environment, acceptance sampling plans must be appropriately applied. For example, when the required fraction defective is very low, the sample size taken must be very large in order to adequately reflect the actual lot quality, to tackle this problem variable sampling plans based on capability indices have been developed by various authors including Pearn and Wu (2006, 2007), Wu and Pearn (2008), and Wu and Liu (2014). However, the sample size required by process capability based plans would be very large. For example, for auto correlated profiles with a given $\rho = 0.5$, and $n = 4$ it requires 1046 profiles at a consumer and producer risk of 0.05 and 0.10 respectively.

To improve the inspection efficiency, the accumulated quality history from previous lots should be included. The exponentially weighted moving average (EWMA) statistic has been widely used in quality control charts, which consider the present and past information. The weights decline geometrically with the time of the observations. This EWMA statistic is known to be efficient at detecting a small shift in the process ((Hunter 1986; Lucas and Saccucci 1990; Čisar and Čisar 2011; Montgomery 2013). The EWMA statistic based on yield index was first introduced in an acceptance sampling by Aslam et al. (2013). Yen et al. (2014) developed a variable sampling plan based on the EWMA yield index S_{pk} and Aslam et al. (2015) applied the EWMA statistic to the quality characteristic itself based on the mean and standard deviation to develop an acceptance sampling plan. However, the proposed methods consider only a single quality characteristic and cannot be applied to profile data. Furthermore, process autocorrelations may affect the performance of the process yield index. Based on our knowledge, there is no work on the sampling plans based on the yield index for autocorrelation between linear

profiles. The main purpose of this paper is to develop a variable sampling plan based on yield index $S_{pkA;AR(1)}$ to deal with lot sentencing of auto correlated profiles.

In this study we propose a new method for economic appraisal of materials. In the presence of autocorrelation between linear profiles, we present a variable acceptance sampling plan using the EWMA statistic with yield index. Taking into account the acceptable quality level at the producer's risk and the lot tolerance percent defective at the consumer's risk, a non-linear optimization method is proposed to determine the number of profiles required for inspection and the corresponding acceptance or rejection criteria. The rest of this paper is organized as follows. In the next section, a yield index $S_{pkA;AR(1)}$ is summarized. Section "Proposed Sampling Plan" describes the proposed sampling plan based on the EWMA statistic. Finally, we offer a conclusion and suggestions for future studies.

Yield Index for Linear Profiles

In this section, we review the yield index for autocorrelation between linear profiles. The first order autocorrelation between linear profiles is modeled by

$$\begin{cases} y_{ij} = \alpha + \beta x_i + \varepsilon_{ij} \\ \varepsilon_{ij} = \rho \varepsilon_{i(j-1)} + a_{ij} \end{cases} \quad i = 1, 2, \ldots, n \text{ and } j = 1, 2, \ldots, k \tag{1}$$

where y_{ij} is the response value at the ith level of the independent variable from the jth profile, x_i is the ith level of the independent variable, n is the number of levels for the independent variable, k is the number of profiles, ε_{ij} denotes correlated random error, α is the intercept of linear profiles, β is the slope of linear profiles, ρ denotes the autocorrelation coefficient, and $a_{ij} \sim N(0, \sigma^2)$.

The process yield at the ith level of the independent variable can be derived by the process yield index proposed by Boyles (1994). This index is useful to describe the relationship between manufacturing specifications and actual process performance and is defined as follows:

$$\begin{aligned} S_{pki} &= \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\Phi\left(\frac{USL_i - \mu_i}{\sigma_i}\right) + \frac{1}{2}\Phi\left(\frac{\mu_i - LSL_i}{\sigma_i}\right)\right] \\ &= \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\Phi\left(\frac{1 - C_{dr_i}}{C_{dp_i}}\right) + \frac{1}{2}\Phi\left(\frac{1 + C_{dr_i}}{C_{dp_i}}\right)\right] \end{aligned} \tag{2}$$

where USL_i and LSL_i are the upper and lower specification limits of the response variable at the ith level of the independent variable, μ_i and σ_i are the process mean and the standard deviation at the ith level of the independent variable, $C_{dr_i} = (\mu_i - m_i/d_i)$, $C_{dp_i} = \sigma_i/d_i$, $m_i = USL_i + LSL_i/2$, $d_i = USL_i - LSL_i/2$, Φ is

the cumulative distribution function of a standard normal distribution, and Φ^{-1} is the inverse function of Φ.

Wang and Tamirat (2014) derived the following estimator of the yield index for autocorrelation between linear profiles.

$$\hat{S}_{pkA;AR(1)} = \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\left\{1 + \sum_{i=1}^{n}\frac{1}{n}\left[2\Phi\left(3\hat{S}_{pki}\right) - 1\right]\right\}\right] \tag{3}$$

where

$\hat{S}_{pki} = \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\Phi\left(\frac{USL_i - \bar{y}_i}{S_i}\right) + \frac{1}{2}\Phi\left(\frac{\bar{y}_i - LSL_i}{S_i}\right)\right] = \frac{1}{3}\Phi^{-1}\left[\frac{1}{2}\Phi\left(\frac{1-\hat{C}_{dr_i}}{\hat{C}_{dp_i}}\right) + \frac{1}{2}\Phi\left(\frac{1+\hat{C}_{dr_i}}{\hat{C}_{dp_i}}\right)\right]$, $\hat{C}_{dr_i} = (\bar{y}_i - m_i/d_i)$, $\hat{C}_{dpi} = S_i/d_i$, $\bar{y}_i$ and S_i are the sample mean and the sample standard deviation at the ith level of the independent variable, which may be obtained from a stable process, and $\hat{S}_{pkA;AR(1)}$ is the estimator of the process-yield index $S_{pkA;AR(1)}$.

The asymptotic normal distribution of index $\hat{S}_{pkA;AR(1)}$ was derived by Wang and Tamirat (2014) and is given as follows:

$$\hat{S}_{pkA;AR(1)} \sim N\left(S_{pkA;AR(1)} + \sum_{i=1}^{n}\frac{[a_i(1-f)]}{12n\phi\left(3S_{pkA;AR(1)}\right)}, \frac{\sum_{i=1}^{n}\left[\frac{ka_i^2F}{(k-1)^2} + b_i^2g\right]}{36n^2k\phi\left(3S_{pkA;AR(1)}\right)^2}\right) \tag{4}$$

where

$$a_i = \frac{d_i}{\sqrt{2}\sigma_i}\left\{(1 - C_{dr_i})\phi\left(\frac{1 - C_{dr_i}}{C_{dp_i}}\right) + (1 + C_{dr_i})\phi\left(\frac{1 + C_{dr_i}}{C_{dp_i}}\right)\right\},$$

$$b_i = \phi\left(\frac{1 - C_{dr_i}}{C_{dp_i}}\right) - \phi\left(\frac{1 + C_{dr_i}}{C_{dp_i}}\right),$$

$$f = 1 - \frac{2}{k(k-1)}\sum_{i=1}^{k-1}(k-i)\rho_i$$

$$g = 1 + \frac{2}{k}\sum_{i=1}^{k-1}(k-i)\rho_i$$

$$F = k + 2\sum_{i=1}^{k-1}(k-i)\rho^{2i} + \frac{1}{k^2}\left[k + 2\sum_{i=1}^{k-1}(k-i)\rho^i\right]^2 - \frac{2}{k}\sum_{i=0}^{k-1}\sum_{j=0}^{k-i}(k-i-j)\rho^i\rho^j$$

ρ_i is the ith lag autocorrelation, and ϕ is the probability density function of a standard normal distribution.

Proposed Sampling Plan

An acceptance sampling plan must consider two levels of quality such as the acceptable quality level (AQL) and the lot tolerance proportion defective (LTPD). The AQL is also called the quality level desired by the consumer. The producer's risk (α) is the risk that the sampling plan will fail to verify an acceptable lot's quality. The LTPD is also called the worst level of quality that the consumer can tolerate. The probability of accepting a lot with LTPD quality is the consumer's risk (β). An operating characteristic (OC) curve depicts the discriminatory power of an acceptance sampling plan. Thus, its designed plan parameters are determined by the OC curve, which must pass through the two designated points (AQL, $1 - \alpha$) and (LTPD, β).

In some situations, the accumulation of quality history from previous lots is available. We proposed the variable sampling plan using the EWMA statistic. The sampling procedure is described as follows:

Step 1: Choose the producer's risk (α) and the consumer's risk (β). Select the process capability requirements (C_{AQL}, C_{LTPD}) at two risks respectively.

Step 2: Select a random number of profiles k at the current time t and collect the preceding acceptance lots with their yield index values. Then, we compute the following EWMA sequence, say Z_t for $t = 1, 2, 3, \ldots, T$.

$$Z_t = \lambda \hat{S}_{pkA;AR(1)t} + (1 - \lambda) Z_{t-1} \tag{5}$$

where λ is a smoothing constant and ranges from 0 and 1. The choice of its optimal value is based on minimizing the sum of the square errors, $SSE = \sum_{t=2}^{T} \left(Z_t - \hat{S}_{pkA;AR(1);t}\right)^2$, where $Z_2 = \hat{S}_{pkA;AR(1);1}$ (Hunter 1986). To find the optimal λ value, a simple R program using the DEoptim algorithm is developed (Ardia et al. 2011).

Step 3: Accept the lot from the supplier if $Z_t \geq c$, where c is the critical value; otherwise reject it.

The OC function of our proposed plan is derived as follows:

$$P(Z_t \geq c) = P\left(\frac{Z_t - E(Z_t)}{\sqrt{\left(\frac{\lambda}{2-\lambda}\right) \frac{\sum_{i=1}^{n} \left[\frac{k a_i^2 F}{(k-1)^2} + b_i^2 g\right]}{36 n^2 k \phi \left(3 S_{pkA;AR(1)}\right)^2}}} \geq \frac{c - \left(S_{pkA;AR(1)} + \sum_{i=1}^{n} \frac{[a_i(1-f)]}{12 n \phi \left(3 S_{pkA;AR(1)}\right)}\right)}{\sqrt{\left(\frac{\lambda}{2-\lambda}\right) \frac{\sum_{i=1}^{n} \left[\frac{k a_i^2 F}{(k-1)^2} + b_i^2 g\right]}{36 n^2 k \phi \left(3 S_{pkA;AR(1)}\right)^2}}} \right) \tag{6}$$

In Eq. (5), the mean and variance of Z_t can be obtained as

$$E(Z_t) = S_{pkA;AR(1)} + \sum_{i=1}^{n} \frac{[a_i(1-f)]}{12n\phi(3S_{pkA;AR(1)})}$$

and

$$Var(Z_t) = \left(\frac{\lambda}{2-\lambda}\right) \frac{\sum_{i=1}^{n} \left[\frac{ka_i^2F}{(k-1)^2} + b_i^2 g\right]}{36n^2k\phi(3S_{pkA;AR(1)})^2}.$$

Therefore, Eq. (6) can be rewritten as follows:

$$P(Z_t \geq c) = 1 - P\left(Z < \frac{c - \left(S_{pkA;AR(1)} + \sum_{i=1}^{n} \frac{[a_i(1-f)]}{12n\phi(3S_{pkA;AR(1)})}\right)}{\sqrt{\left(\frac{\lambda}{2-\lambda}\right) \frac{\sum_{i=1}^{n} \left[\frac{ka_i^2F}{(k-1)^2} + b_i^2 g\right]}{36n^2k\phi(3S_{pkA;AR(1)})^2}}}\right) \tag{7}$$

where Z is a standard normal random variable.

Finally, the lot acceptance probability, say $\pi_A(Z_t)$, is derived by

$$\pi_A(Z_t) = 1 - \Phi\left(\frac{c - \left(S_{pkA;AR(1)} + \sum_{i=1}^{n} \frac{[a_i(1-f)]}{12n\phi(3S_{pkA;AR(1)})}\right)}{\sqrt{\left(\frac{\lambda}{2-\lambda}\right) \frac{\sum_{i=1}^{n} \left[\frac{ka_i^2F}{(k-1)^2} + b_i^2 g\right]}{36n^2k\phi(3S_{pkA;AR(1)})^2}}}\right) \tag{8}$$

The parameters of our proposed plan can be determined through the non-linear optimization problem given in Eq. (9), where the number of profiles (k) and critical value (c) are decision variables. For a particular sampling plan, the producer is interested in finding the probability that a type I error can be committed. Using Eq. (9), the producer is able to find a sampling plan which guarantees that the lot acceptance probability is larger than the desired confidence level, $1 - \alpha$, at the lot acceptable quality level (C_{AQL}). Concurrently the consumer desires that, based on sample information, the probability that a bad (quality) population will be accepted is smaller than the risk at the lot tolerance proportion defective(C_{LTPD}). That is, $S_{pkA;AR(1)} = C_{AQL}$ for the producer and $S_{pkA;AR(1)} = C_{LTPD}$ for the consumer.

$$\begin{aligned} &\text{Minimize k} \\ &\text{Subject to} \end{aligned} \tag{9a}$$

$$1 - \Phi\left(\frac{c - \left(C_{AQL} + \sum_{i=1}^{n} \frac{[a_i(1-f)]}{12n\phi(3C_{AQL})}\right)}{\sqrt{\left(\frac{\lambda}{2-\lambda}\right) \frac{\sum_{i=1}^{n} \left[\frac{ka_i^2F}{(k-1)^2} + b_i^2 g\right]}{36n^2k\phi(3C_{AQL})^2}}}\right) \geq 1 - \alpha \tag{9b}$$

$$1-\Phi\left(\frac{c-\left(C_{LTPD}+\sum_{i=1}^{n}\frac{[a_i(1-f)]}{12n\phi(3C_{LTPD})}\right)}{\sqrt{\left(\frac{\lambda}{2-\lambda}\right)\frac{\sum_{i=1}^{n}\left[\frac{ka_i^2F}{(k-1)^2}+b_i^2g\right]}{36n^2k\phi(3C_{LTPD})^2}}}\right)\leq\beta \tag{9c}$$

Given $\rho, \lambda, C_{AQL}, C_{LTPD}, \alpha$, and β as inputs, we evaluate the constraints (9b) and (9c), where the objective function is to minimize the number of profiles. A search procedure is considered to determine the plan parameters. First, 10,000 combinations of k and c are randomly generated, where k ranges from 2 to 3000 and c follows a uniform distribution from C_{AQL} to C_{LTPD}. The above procedure is repeated 1,000 times to determine the optimal parameters.

To investigate the performance of the proposed method, a computer program written in R language is used. In Tables 1 and 2, we tabulate sampling plan parameters for various combinations of two quality levels (C_{AQL}, C_{LTPD}) at $\alpha = 0.05$ and $\beta = 0.10$. The sampling parameters are found under a given $\lambda = 0.10, 0.20, 0.50$, and

Table 1 Plan parameters using the single sampling plan on EWMA yield index under various $(\lambda, C_{AQL}, C_{LTPD})$ at $\alpha = 0.05, \beta = 0.10, \rho = 0.5$ and $n = 4$

	$\lambda = 0.1$		$\lambda = 0.2$		$\lambda = 0.5$		$\lambda = 1.0$	
	$C_{AQL} = 1.33$		$C_{AQL} = 1.33$		$C_{AQL} = 1.33$		$C_{AQL} = 1.33$	
C_{LTPD}	k	c	k	c	k	c	k	c
1.15	36	1.2534	149	1.2348	1313	1.2295	2560	1.2347
1.10	15	1.2550	57	1.2159	499	1.2025	2105	1.2061
1.05	8	1.2691	28	1.2027	228	1.1771	1720	1.1749
1.00	5	1.2771	16	1.1948	118	1.1521	1046	1.1452
	$\lambda = 0.1$		$\lambda = 0.2$		$\lambda = 0.5$		$\lambda = 1.0$	
	$C_{AQL} = 1.5$		$C_{AQL} = 1.5$		$C_{AQL} = 1.5$		$C_{AQL} = 1.5$	
C_{LTPD}	k	c	k	c	k	c	k	c
1.25	11	1.4317	42	1.3803	353	1.3620	2120	1.3581
1.20	7	1.4314	22	1.3708	172	1.3366	1518	1.3320
1.15	4	1.4607	13	1.3687	94	1.3128	821	1.3044
1.10	3	1.4643	8	1.3703	58	1.2901	487	1.2771
1.05	3	1.4451	6	1.3708	36	1.2710	306	1.2507
	$\lambda = 0.1$		$\lambda = 0.2$		$\lambda = 0.5$		$\lambda = 1.0$	
	$C_{AQL} = 2.0$		$C_{AQL} = 2.0$		$C_{AQL} = 2.0$		$C_{AQL} = 2.0$	
C_{LTPD}	k	c	k	c	k	c	k	c
1.60	4	1.9094	9	1.8580	58	1.7907	493	1.7768
1.55	3	1.9262	6	1.8646	36	1.7712	304	1.7503
1.50	2	1.9317	5	1.8610	25	1.7523	201	1.7231
1.45	2	1.9488	4	1.8494	18	1.7345	140	1.6964
1.40	2	1.8900	3	1.8368	13	1.7249	98	1.6717

Table 2 Plan parameters using the single sampling plan on EWMA yield index under various $(\lambda, C_{AQL}, C_{LTPD})$ at $\alpha = 0.05, \beta = 0.10, \rho = 0.75$ and $n = 4$

	$\lambda = 0.1$		$\lambda = 0.2$		$\lambda = 0.5$		$\lambda = 1.0$	
	$C_{AQL} = 1.33$		$C_{AQL} = 1.33$		$C_{AQL} = 1.33$		$C_{AQL} = 1.33$	
C_{LTPD}	k	c	k	c	k	c	k	c
1.15	162	1.2447	696	1.2325	2680	1.2279	2761	1.2268
1.10	64	1.2404	268	1.2109	2176	1.2013	2314	1.2102
1.05	31	1.2498	124	1.1937	1074	1.1752	1920	1.1565
1.00	18	1.2674	67	1.1823	558	1.1491	1243	1.1379
	$\lambda = 0.1$		$\lambda = 0.2$		$\lambda = 0.5$		$\lambda = 1.0$	
	$C_{AQL} = 1.5$		$C_{AQL} = 1.5$		$C_{AQL} = 1.5$		$C_{AQL} = 1.5$	
C_{LTPD}	k	c	k	c	k	c	k	c
1.25	48	1.4113	196	1.3726	1679	1.3611	2612	1.3578
1.20	25	1.4248	97	1.3575	816	1.3350	2481	1.3290
1.15	14	1.4499	54	1.3500	444	1.3096	2123	1.2856
1.10	9	1.4710	33	1.3483	263	1.2851	1753	1.2642
1.05	6	1.4851	22	1.3514	165	1.2629	1483	1.2493
	$\lambda = 0.1$		$\lambda = 0.2$		$\lambda = 0.5$		$\lambda = 1.0$	
	$C_{AQL} = 2.0$		$C_{AQL} = 2.0$		$C_{AQL} = 2.0$		$C_{AQL} = 2.0$	
C_{LTPD}	k	c	k	c	k	c	k	c
1.60	9	1.9716	34	1.8482	263	1.7856	2210	1.7876
1.55	6	1.9895	22	1.8514	166	1.7632	1430	1.7489
1.50	4	1.9991	15	1.8593	110	1.7425	951	1.7214
1.45	3	1.9793	11	1.8680	77	1.7245	655	1.6959
1.40	2	1.9974	8	1.8658	56	1.7070	459	1.6682

1.0, considering two different autocorrelation coefficients $\rho = 0.5$ and 0.75 and $n = 4$ levels of the independent variable. The number of profiles required for lot sentencing with a smoothing parameter $\lambda < 1$ is more economical than the traditional single sampling plan ($\lambda = 1$). The smaller the value of λ, the lower the number of profiles required. In practice, relatively small values of λ generally work best when the EWMA is the most appropriate model.

For instance, when $C_{AQL} = 1.5$, $C_{LTPD} = 1.2$, and $n = 4$, at given values of $\alpha = 0.05$, $\beta = 0.10$, and $\rho = 0.5$, the plan parameters (k and c) obtained with $\lambda = 0.10, 0.20$, and 0.50 are (7 and 1.4314), (22 and 1.3708), and (172 and 1.3366), respectively. In addition, with a given $\rho = 0.75$, we found that the plan parameters (k and c) obtained are (25 and 1.4248), (97 and 1.3575), and (816 and 1.3350), respectively. Increasing the autocorrelation coefficient significantly increases the number of profiles required to achieve the desired levels of protection for both producers and consumers.

Conclusion

In this paper, we developed an acceptance sampling plan based on the process yield index $S_{pkA;AR(1)}$ to deal with lot sentencing for autocorrelation between profiles. Our proposed method considers the quality history of the previous lot's information and the current lot; as a result the sample size required is smaller than the traditional single sampling plan. With a given $\lambda = 1$, the sampling plan based on the EWMA statistic is reduced to a traditional single sampling plan. In addition, we tabulated the required number of profiles k and the critical acceptance value c for various combinations of two quality levels (C_{AQL}, C_{LTPD}) at $\alpha = 0.05$ and $\beta = 0.10$ and with $\lambda = 0.10, 0.20, 0.50$, and 1.0 and $\rho = 0.5$ and 0.75 under $n = 4$. The proposed sampling plan provides the alternative for implementing the acceptance sampling plan.

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Evaluating Airline Network Robustness Using Relative Total Cost Indices

Peiman Alipour Sarvari and Fethi Calisir

Abstract This research to the best of our knowledge is the first paper to quantify airline network robustness in the presence reversible capacity of legs and alternative flights. In this study, we try to recognize the critical legs via changing the functional capacity of flights. Besides, we attempt to gauge the behavior of the flight network via shifting of leg capacities proposing a new leg cost function. In addition, we indicate how to capture the robustness of airline network in the case of variable flight capacities. Relative Total Cost Indices have been used to assess air network robustness in the case of behavior associated with both User-Optimization and System-Optimization. In this article from the different point of view, the variability of passenger's route preferences is the main subject. This paper may shed light on the robustness of networks in real life not only for the particular case of airlines but also for systems sharing similar topological properties. The paper presents a numerical case study with real data from an airline in Turkey for illustration purposes.

Keywords User optimality · System optimality · Network robustness
Flight networks

Introduction

Networks are complex, typically, large-scale systems, and their formal study has attracted much interest from a plethora of scientific disciplines (Bazargan 2010). A broad variety of practices in the real world can be explained as complex or heterogeneous networks, like the postal networks, energy distribution networks as

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well as air transportation networks. Recently studies in the context of complex systems have attained successes in many spheres (Newman 2003; Boccaletti et al. 2014; Wei et al. 2013), such as system modeling (de Dios et al. 2001; Soysal et al. 2014; Sarvari et al. 2016; Abdelghany et al. 2008), optimization (Eskandarpour et al. 2015; Storn 1996; Jindal et al. 2015) and traffic dynamics (Yan et al. 2006; Wu et al. 2016; Zhang et al. 2010) and so on. Large infrastructure networks such as the Internet, power grids and transportation systems (Zang et al. 2010; Du et al. 2016), play a significant role in the modern world. As the robustness of base networks is maturing, so the robustness of heterogeneous networks has interested and inspired researchers to develop many papers (Buldyrev et al. 2010; Science et al. 2016; Lordan et al. 2015; Tan et al. 2015; Trajanovski et al. 2012). Recently, (Schneider et al. 2011) proposed a new measure R for network robustness and studied the optimal arrangement of arcs and nodes considering this measure. The results confirmed that network robustness could be significantly enhanced (Hong et al. 2017).

Airline schedule planning typically involves four steps from schedule design, fleet assignment, aircraft routing to crew pairing/rostering. Each stage is planned and optimized in interaction with other three steps. At the stage of aircraft routing, schedule planning involves the optimization of aircraft routing by formulating aircraft routing as integer programming problems. The lack of consideration in aircraft routing optimization to reflect real operational issues may result in lower schedule robustness and reliability in daily operations. The observable consequences of lower schedule reliability are flight delays and potential delay propagation in an airline's network (Wu 2006). So the whole network is affecting with tiny changes in its sub-systems. Changing the flight routes, changing hubs, overloading a flight arc or expanding the network in case of increasing the destination numbers are common phenomena in the airline industry. Adding even one flight node to the airline's transportation network can affect each step of the schedule planning and may destabilize the whole network. These effects can lower the reliability/robustness of the network decreasing the turnaround efficiency and triggering delay propagation.

As Dios et al. (2001) mentioned, the transportation system can be considered as a conventional economic system with demand and supply subsystems. In traffic authorization, an O-D trip matrix is loaded onto the system, and a set of connection flows is generated (Campbell 2009). The Relative Total Cost Indices (RTCI) can be evaluated at either user-optimal (U-O) traffic streams, or system-optimal (S-O) traffic streams. A recommended leg cost function empowers the quantitative evaluation of the variations in the relative total cost of an air transportation network, in the case of alternative travel behavior, when the link functional capacities are decreased or increased (Nagurney 2010).

Nagurney and Qiang (2008a, b) provides an overview of some of the recent developments in the assessment of network vulnerability through proper mechanisms that support in the quantification of network performance and the classification of the effect of network elements, such as nodes and links. The boom and drop on the number of airplanes in networks due to maintenance, scheduling and

routing approaches, air carriers and airports deterioration over time, as well as politic decisions lead to time-consuming and costly connection flights, lack of flights and poor service quality would effects passenger decision manners (Bazargan 2010). That is why; we introduce a new procedure for evaluating the robustness of an airline network based on the RTCI for the transportation system in the case of leg variation captured through a uniform link capacity ratio. In an air network, there are hub and spokes that every leg and flight deviation is changing the whole network robustness.

The paper has been organized as follows; In Section "Relative Total Cost Index", the proposition of the relative total cost index is provided. In Section "Principal and Components of RTCI", we explain the RTCI that can be used to evaluate transportation network robustness and which allows either U-O or S-O travel behavior. In Section "Assessment of Airline network robustness", for the first time, we try to assess the airline network robustness by reducing and increasing of flight capacity by network robustness measure. In Section "Case Study", a case study and related discussions on a partial network of an airline have been considered to analysis, and finally, Section "Conclusion" presents a brief closure.

Principal and Components of RTCI

Decentralized Decision-Making and Centralized Decision-Making (U-O and S-O)

Wardrop and Whitehead (1952) explicitly recognized possible alternative behaviors of transportation networks users and stated two principles, which are commonly named after them. These principles match, in consequence, to decentralized versus centralized behavior on networks and, albeit stated in a transportation circumstances, have connections to many various networks. Hence, we now recall Wardrop's two principles; The first implies that the journey times of all used routes are equal and less than those that would be experienced by a single vehicle on any unused route, and the second one assumes that the average journey time is minimal.

The fundamental principle reactions to the behavioral principle in which passengers query to determine their minimal costs of travel whereas the second principle corresponds to the behavioral policy in which the total cost of the system is decreased. Nagurney (2003) proved the equality between the traffic network equilibrium statuses, which assert that all used paths connecting an origin-destination pair will have equal and minimal travel times (or costs); corresponding to Wardrop's first principle, and the Kuhn-Tucker conditions of an appropriately formed optimization problem, under a balance assumption on the underlying functions. Consequently, in this case, the equilibrium link and path flows could be captured as the solution to the problem.

Dafermos (1980) coined the terms user-optimized (U-0) and system-optimized (S-0) transportation networks to distinguish between the two distinct situations in which users act unilaterally, in their self-interest in selecting their routes. In the latter problem, marginal (total) costs rather than average costs are equilibrated equalized, in which users select routes according to what is modeled and assumed as optimal from a societal point of view, so that cost in the system is minimized (Sarvari and Erol 2013). The problems mentioned above coincide with Wardrop's first principle and the latter with Wardrop's second principle.

As a mathematical description, let xp represents the nonnegative flow on path p and let fa denotes the flow on flight a. The cost experienced by a user traversing flight a is denoted by $t_a(f_a)$ and the total cost experienced by the system (company) on flight a denoted by $\hat{t}_a(f_a)$. Additionally, dw, denotes the demand associated with O-D pairs of w for all $w \in W$. On the condition that path p contains link a then $\delta_{ap} = 1$, otherwise, $\delta_{ap} = 0$ (Bazaraa et al. 2006). Formulations (1) and (2) demonstrate the mathematical optimization models for both user and system optimality.

- *For User Optimality*

$$\begin{aligned} Min \quad & \sum_{a \in A} \int_0^{f_a} t_a(y) d_y \\ s.t. \quad & \sum_{p \in p_w} x_p = d_w, \\ & f_a = \sum_{p \in P} x_p . \delta_{ap}, \\ & x_p \geq 0, \end{aligned} \tag{1}$$

- *For System Optimality*

$$\begin{aligned} Min \quad & \sum_{a \in A} \hat{t}_a(f_a) \\ s.t. \quad & \sum_{p \in p_w} x_p = d_w, && \forall w \in W \\ & f_a = \sum_{p \in P} x_p . \delta_{ap}, && \forall a \in A \\ & x_p \geq 0, && \forall p \in P \end{aligned} \tag{2}$$

In this section, a detailed trip cost function that is a combination of passenger flow function and arc cost function has been applied. As cost of a path in a flight network is cost of legs plus the cost of transshipment or hub (Campbell 2009), what's more, the flows of passengers by plane **a** and **b** have been named as f_a and f_b respectively. Provided that the nominal capacity of plane **a** is c_a, consequently the practical capacity of **a** is $lf \times c_a$ where lf is the load factor (Bazargan 2010) and providing flight cost or ticket price by fc then the rate of flow for the **ath** plane can be calculated by $\frac{f_a}{lf \times c_a}$.

Considering the *fc* as the lowest ticket price for the **ath** fight operating by **ath** plane and the total cost for a selected flight by the passenger is calculated via Eq. (3) where α, β and k are the congestion rates (are positive and unique coefficients for every field and company).

$$t_a = fc\left[\alpha\left(\frac{kf_a}{lf \times c_a}\right)^{\beta}\right] \tag{3}$$

From the other hand, there are two types of flights; the transshipment flights and the connection flights. On condition that the ath plan is flying a direct flight, the cost function from the system view can be calculated by Eq. (4), otherwise Eq. (5) is covering the connection flight too, where, $f'c$ is the least flight cost for ath plan and tsc is the transshipment cost (Note: the connections is allowed just for the flights passing the hub airport).

$$\widehat{t}_a = f'c\left[\alpha\left(\frac{kf_a}{lf \times c_a}\right)^{\beta}\right] + arc\ \cos t \tag{4}$$

$$\widehat{t}_a = f'c\left[\alpha\left(\frac{kf_a}{lf \times c_a}\right)^{\beta}\right] + arc\ 1\ \cos t + arc\ 2\ \cos t + \ tsc \tag{5}$$

Performance Measure of Nagurney and Qiang for Evaluating of Critical Arcs

The network performance/efficiency ratio (Nagurney and Qiang 2008a, b), in a flexible demand case, is described as Eq. (6);

$$\varepsilon = \varepsilon(G, d) = \frac{\sum_{w \in W} \frac{d_w}{\lambda_w}}{n_w} \tag{6}$$

where;

n_w The number of O-D pairs in the network
λ_w The cost of the most reasonable or the shortest way
n_w The total number of flight demands (between O-D)

Relative Total Cost Index

The total cost of the network is named as TC and is specified by Eq. (7);

$$TC = \sum_{g \in A} \hat{t}_g = \sum_{g \in A} t_g(f_g) f_g \tag{7}$$

Let's suppose $g \in A$, is an arc on the network and Ψ ({g}) is the relative total cost increase of G, and on the condition of eliminating {g} from the network, relative total cost increase will be equal to Eq. (8):

$$\psi(\{g\}) = \frac{TC(G - \{g\}) - TC(G)}{TC(G)} \tag{8}$$

where TC (G) is the total cost of the network G, TC (G − {g}) is the total cost of the network G − {g}. Because of deriving total cost from U-O and S-O, Eqs. (9) and (10) can be derived, where Eq. (9) is the relative total cost derived with U-O, and Eq. (10), is the relative total cost derived with S-O.

$$\psi_{U-O}(\{g\}) = \frac{TC_{U-O}(G - \{g\}) - TC_{U-O}(G)}{TC(G)} \tag{9}$$

$$\psi_{S-O}(\{g\}) = \frac{TC_{S-O}(G - \{g\}) - TC_{S-O}(G)}{TC(G)} \tag{10}$$

Note: Functions mentioned above will distinguish critical nodes. On the condition that the g has been affected by capacity changes then, the relative total cost indices appear as:

$$\psi^{\gamma}_{(g)} = \frac{TC^{\gamma}_{(g)} - TC}{TC} \tag{11}$$

$$\psi^{\alpha}_{(g)} = \frac{TC^{\alpha}_{(g)} - TC}{TC} \tag{12}$$

TC Total cost of the network without capacity changes.
$TC^{\gamma}_{(g)}$ Network total cost if capacity decrease rate of g is γ
$TC^{\alpha}_{(g)}$ Network total cost, if capacity increase rate if g is α

Assessment of Airline Network Robustness

In Case of Changing the Capacity of a Leg

To evaluate network robustness let's decrease legs (flight) carrying capacity with a fixed rate. Network efficiency measures are capturing under this reduction. If the original capacity of a leg is c_g and $\gamma(\gamma \in (0, 1])$ is the reduction rate of capacity, γc_g is the leg's decreased capacity and, $c_g - \gamma c_g$ is reduction measurement of the leg. The robustness measurement of network G is R^{γ} (Nagurney 2010).

Airline Network Robustness with Reduction Flight Capacity

$$R^{\gamma} = R^{\gamma}(G, d, t, c, \gamma) = \frac{\varepsilon^{\gamma}}{\varepsilon} \times 100\% \tag{13}$$

d G demand vector
t Flight cost function
c Flight capacity vector
γ Flight capacity reduction rate
ε Network performance index when capacity is c
ε^{γ} Network performance index when capacity decreased to γc

Provided that the performance index of a network with γc capacity approximately equals to c, then that network will be robust (Nagurney and Qiang 2008a, b). On the condition of presenting of just one flight between O-D, the assumed conjunction rate will be β where robustness upper bound will be $\gamma^{\beta} \times 100\%$, and then The robustness measurement of network G is R^{γ}.

$$R^{\gamma} = \frac{\gamma^{\beta}\left[c_g^{\beta} + kd_w^{\beta}\right]}{\gamma^{\beta} c_g^{\beta} + kd_w^{\beta}} \times 100\% \tag{14}$$

If there are more than one flight between O-D then;

$$c \equiv c_a + c_b + \cdots + c_n$$

So the lower bound is $\gamma \times 100\%$, and the robustness measurement of network G is R^{γ} as Eq. (15).

$$R^{\gamma} = \frac{\gamma c + k\gamma d_w}{\gamma c + kd_w} \times 100\% \tag{15}$$

Airline Network Robustness with Increasing Capacity of Flights

To evaluate network robustness let's increase legs (plane) carrying capacity with a fixed rate. Network efficiency measures are capturing under this reduction. If the original capacity of a leg is c_g and α; $\alpha \geq 1$, is the inflation rate of capacity, αc_g is the leg's increased capacity and, $\alpha c_g - c_g$ is inflation measurement of the leg (flight). The network of G robustness or robustness measure can be calculated by Eq. (16).

$$R^{\alpha} = R^{\alpha}(G, d, t, c, \alpha) = \frac{\varepsilon^{\alpha}}{\varepsilon} \times 100\% \tag{16}$$

α leg capacity inflation rate

$\alpha^{\beta} \times 100\%$ is upper bound of network robustness and $\alpha \geq 1$, and upper bound is $\alpha \times 100\%$

$$R^{\alpha} = \frac{\alpha c + k\alpha d_w}{\alpha c + k d_w} \times 100\% \tag{17}$$

Network Robustness Assessment Through Using Relative Total Cost Index (Through Capacity Variations of All Legs)

Network Assessment with Capacity Reduction

Relative total cost index for network G using U-O and S-O as below (Boyce et al. 2004; Konnov et al. 2007);

$$\psi^{\gamma}_{U-O} = \psi^{\gamma}_{U-O}(G, d, t, c, \gamma) = \frac{TC^{\gamma}_{U-O} - TC_{U-O}}{TC_{U-O}} \times 100\% \tag{18}$$

$$\psi^{\gamma}_{S-O} = \psi^{\gamma}_{S-O}(G, d, t, c, \gamma) = \frac{TC^{\gamma}_{S-O} - TC_{S-O}}{TC_{S-O}} \times 100\% \tag{19}$$

Therefore, upper bound for ψ^{γ}_{U-O} is $\frac{1-\gamma}{\gamma} \times 100\%$, and upper bound for ψ^{γ}_{S-O} is $\frac{1-\gamma^{\beta}}{\gamma^{\beta}} \times 100\%$, $\gamma \in (0, 1]$.

Network Assessment with Capacity Inflation

Leg capacity is increasing at a fixed rate, and following this increase, the total cost of network changes is evaluating. Where leg capacity is c_g and α, $(\alpha \geq 1)$ is an inflation rate of capacity and $\alpha c_g - c_g$ is the inflated leg (flight) capacity amount. Equation (20) is presenting the relative total cost index for the network G sing U-O, while $\frac{1-\alpha}{\alpha} \times 100\%$ is the desired lower bound.

$$\psi_{U-O}^{\gamma} = \left(\frac{\alpha c + k d_w}{\alpha c + k \alpha d_w} - 1 \right) \times 100\% \tag{20}$$

Case Study

The capacity change of some links in the network does not affect the total cost of that link considerably, but the capacity change of some links can affect the sustainability of that network; Even if this change is very small, even worse, causing great increases in the total cost of travel. Such sensitive links are called critical links.

The data for a partial network of an airline in Turkey is illustrated in Table 1; there are five airports in five different cities and Ankara is the hub node. We are interested in assessing this network robustness with critical legs upon supply and demand sets between Istanbul-Antalya and Istanbul-Trabzon. Load factor policy of firm averagely is 90%. Transshipment cost for every hour 7$ per passenger. All ticket prices averagely 17$ per path (without taxes). The other information about the O-Ds is illustrated in Table 1.

In order to solve the revealed problem, we need to use the following steps considering the formulations mentioned above.

- Step 1. Using leg cost function.
- Step 2. Deriving fg for Variational Inequality and trip assignment (Coding can be provided from the author's E-mail address).
- Step 3. To identify critical paths through the results.

Table 1 A partial flight data of the airline network

O/D	Flight count	Plane type	Demand
IST-TRZ	5	1, 3, 5	1700
IST-ANK	38	1, 2, 3, 4, 8, 9	12000
IST-KNY	3	2, 3	1400
IST-ANT	10	1, 2, 5, 4	4200
ANK-ANT	2	8	1150
ANK-TRZ	2	4	780
TRZ-ANT	2	6	750
KNY-ANT	1	5	330

In order to recognize critical links, it is necessary to use the relative total cost index (RTCI), but first the total cost index needs to be calculated. Using the flow quantities, the total cost of each link was calculated with five different capacity reduction and capacity inflation rates and is given in Tables 2 and 5, respectively.

The Relative Total Cost obtained with the help of U-O and S-O models are given in Tables 3 and 6 accordingly with Eqs. (18) and (19).

In this study, network sustainability referring the U-O is demonstrated in all dimensions by reducing or increasing the connections capacities. Table 4 illustrates the robustness variations of the network considering the reductions and inflations in the whole network (Tables 5 and 6).

We have examined the sustainability of the entire network by using the Relative Total Cost Indices obtained with U-O and S-O in Table 7. In the user optimality approach, if the capacities of all connections of the network are increased by 1.2%, the total net capacity of the network decreases further and therefore the network can be more sustainable. In the system optimality approach, if the capacities of all connections of the network are increased by 1.4%, the total cost of the network decreases more and therefore the network can be more sustainable.

Taking the results of analysis above to catch the robustness conditions of the network based on the proposed assessment approach leads us to the following recommendations;

Table 2 Total cost with U-O and the rates of inflation and reduction of leg capacities

TC^{γ}	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$
IST-TRZ	3567	3590	3605	3700	3945
IST-ANK	4044	4030	4060	3840	3765
IST-KNY	4900	4900	4900	4900	4900
IST-ANT	5442	5545	5625	5664	5619
ANK-ANT	5209	5209	5199	5199	5091
ANK-TRZ	3416	3416	3416	3416	3416
TRZ-ANT	6309	6309	6309	6309	6309
KNY-ANT	2670	2670	2670	2670	2670
TC^{α}	$\alpha = 1$	$\alpha = 1.2$	$\alpha = 1.4$	$\alpha = 1.6$	$\alpha = 1.8$
IST-TRZ	3567	3472	3357	3158	3158
IST-ANK	4044	4190	4230	4304	4370
IST-KNY	4900	4900	4900	4900	4900
IST-ANT	5442	5012	5230	5307	5411
ANK-ANT	5209	5400	5469	5498	5502
ANK-TRZ	3416	3128	3139	3141	3260
TRZ-ANT	6309	6309	6302	6309	6309
KNY-ANT	2670	2670	2670	2670	2670

Table 3 Relative total cost with U-O and the rates of inflation and reduction of leg capacities

ψ^{γ}	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$
IST-TRZ	0	0.0065	0.011	0.037	0.1
IST-ANK	0	−0.004	0.0039	−0.05	−0.069
IST-KNY	0	0	0	0	0
IST-ANT	0	0.0005	0.033	0.04	0.032
ANK-ANT	0	0	−0.002	−0.002	−0.02
ANK-TRZ	0	0	0	0	0
TRZ-ANT	0	0	0	0	0
KNY-ANT	0	0	0	0	0
ψ^{α}	$\alpha = 1$	$\alpha = 1.2$	$\alpha = 1.4$	$\alpha = 1.6$	$\alpha = 1.8$
IST-TRZ	0	−0.026	−0.058	−0.11	−0.11
IST-ANK	0	0.036	0.046	0.064	0.08
IST-KNY	0	0	0	0	0
IST-ANT	0	−0.08	−0.039	−0.02	−0.005
ANK-ANT	0	0.036	0.05	0.055	0.056
ANK-TRZ	0	−0.08	−0.081	−0.08	−0.045
TRZ-ANT	0	0	0	0	0
KNY-ANT	0	0	0	0	0

Table 4 Network robustness with whole network capacity changes via U-O using

$\beta = 4, \alpha = 1, k = 0.15$	R^{γ}	$\beta = 4, \alpha = 1, k = 0.15$	R^{α}
$\gamma = 0$	0	$\alpha = 1$	0
$\gamma = 0.2$	0.988	$\alpha = 1.2$	1.1432
$\gamma = 0.4$	1.054	$\alpha = 1.4$	1.1328
$\gamma = 0.6$	0.941	$\alpha = 1.6$	**1.1556**
$\gamma = 0.8$	1.014	$\alpha = 1.8$	1.1437

- Considering Table 2, the arcs of IST-TRZ, IST-ANK, IST-ANT, ANK-ANT and ANK-TRZ are critical legs.
- Considering Table 3, reduction capacity of (IST-TRZ) is not suggested but the inflation rate 1.8 is the priority.
- The decreasing capacity of (IST-KNY) with the rate of 0.4–0.8 is suggested.
- Increasing capacity of (ANK-ANT) with the rate of 1.6 is obviously more logical.
- The decreasing capacity of (ANK-TRZ) will be logical. Decreasing or increasing the capacity of (TRZ-ANT) is not suggested. Considering Table 4, increasing the total capacity of the network by the rate of 1.6 is firmly suggested.

Table 5 Total cost with S-O and the rates of inflation and reduction of leg capacities

TC^{γ}	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$
IST-TRZ	3847	3870	3885	3980	4225
IST-ANK	4324	4310	4340	4120	4045
IST-KNY	5180	5180	5180	5180	5180
IST-ANT	5722	5825	5905	5944	5899
ANK-ANT	5489	5489	5479	5479	5371
ANK-TRZ	3696	3696	3696	3696	3696
TRZ-ANT	6589	6589	6589	6589	6589
KNY-ANT	2950	2950	2950	2950	2950
TC^{α}	$\alpha = 1$	$\alpha = 1.2$	$\alpha = 1.4$	$\alpha = 1.6$	$\alpha = 1.8$
IST-TRZ	335,298	32,984	307,924	293,694	287,378
IST-ANK	380,136	39,805	38,948	400,272	39,767
IST-KNY	4606	4655	4508	4557	4459
IST-ANT	511,548	47,614	482,904	493,551	492,401
ANK-ANT	489,646	5130	5037	511,314	500,682
ANK-TRZ	321,104	29,716	288,876	292,113	29,666
TRZ-ANT	593,046	599,355	579,728	586,737	574,119
KNY-ANT	25,098	25,365	24,564	24,831	24,297

Table 6 Relative total cost with S-O and the rates of inflation and reduction of leg capacities

ψ^{γ}	$\gamma = 0$	$\gamma = 0.2$	$\gamma = 0.4$	$\gamma = 0.6$	$\gamma = 0.8$
IST-TRZ	0	0,00597	0.009877	0.034572	0.098258
IST-ANK	0	−0.0032	0.0037	−0.0471	−0.0645
IST-KNY	0	0	0	0	0
IST-ANT	0	0.0180	0.031981	0.038797	0.030933
ANK-ANT	0	0	−0.00182	−0.00182	−0.02149
ANK-TRZ	0	0	0	0	0
TRZ-ANT	0	0	0	0	0
KNY-ANT	0	0	0	0	0
ψ^{α}	$\alpha = 1$	$\alpha = 1.2$	$\alpha = 1.4$	$\alpha = 1.6$	$\alpha = 1.8$
IST-TRZ	0	−0.0162	−0.0816	−0.1240	−0.1429
IST-ANK	0	0.04712	0.0245	0.0529	0.0461
IST-KNY	0	0.01063	−0.0212	0.0106	−0.0319
IST-ANT	0	−0.0692	−0.0559	−0.0351	0.0374
ANK-ANT	0	0.04769	0.0287	0.0442	0.0225
ANK-TRZ	0	−0.0745	−0.1003	−0.0902	−0.07612
TRZ-ANT	0	0.01063	−0.0224	−0.0829	−0.03191
KNY-ANT	0	0.01063	−0.0212	−0.0106	−0.0319

Table 7 Using RTCI to evaluate robustness in case of network capacity changes

$\beta = 4, \alpha = 1, k = 0.15$	ψ^{γ}_{U-O}	ψ^{γ}_{S-O}
$\gamma = 0$	0	0
$\gamma = 0.2$	0.003149872	0.005978685
$\gamma = 0.4$	0.003224088	0.009877827
$\gamma = 0.6$	−0.002403309	0.47231609
$\gamma = 0.8$	0.004443569	0.098258383
$\beta = 4, \alpha = 1, k = 0.15$	ψ^{α}_{U-O}	ψ^{α}_{S-O}
$\alpha = 0$	0	0
$\alpha = 1$	−0.013386956	−0.016278057
$\alpha = 1.2$	−0.007312203	−0.081640809
$\alpha = 1.4$	−0.007593442	−0.124080669
$\alpha = 1.8$	0.000646849	−0.142917643

Conclusion

Systems fit the infrastructure upon which the operating of the economies and societies count on. Networks that form the solid backbones of the modern age include transportation networks that support the flows of vehicles from origins to destinations. This paper provides an approach to the assessment of network robustness through proper tools that serve in the quantification of network performance and the naming of the importance of network segments, such as nodes and links. We illustrated how rigorously formed and well-defined system measures can obtain not only the network topology bearing a particular system, but also the primary behavior of decision-makers, the resulting issues, and affected expenses in the presence of demands for resources. In this paper for the first time, we analyzed leg and flight capacity variations of an airline, proposing a modified leg cost function from a different perspective. We tried to identify critical legs via changing functional capacities of air network components. In addition, we demonstrated how to capture the robustness of airline network in the cases of decreasing and increasing capacities. Finally, yet importantly, we used Relative Total Cost Indices (RTCI) to assess air network robustness of the case of behavior associated with both User-Optimization and System–Optimization while passengers' route preferences behaviors were the main subject. Future work will use traffic counts to update the O/D matrix for catching better results.

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A Two-Phase Optimization Approach for Reducing the Size of the Cutting Problem in the Box-Production Industry: A Case Study

Sam Mosallaeipour, Ramtin Nazerian and Mazyar Ghadirinejad

Abstract In this study, the cutting problem as one of the main problems within the box-production industries is discussed. The cutting problem refers to the problem of dividing a piece of rectangular raw material, which is usually large, into smaller pieces to produce various products. Cutting problems are NP-hard problems. Numerous researches offering good solutions to these problems have been conducted over the past few years. In the present study, considering the complexity of the problem, a model reflecting the nature of the problem is proposed and a new two-phase solution approach is suggested. Utilizing the proposed method significantly reduces the size of the problem and simplifies the applicability of the solution approach in real life. Furthermore, to evaluate the efficiency and utilization of the proposed method, its application in a specific company is tested. Finally, the performance of the method is calculated and its use is compared with the company's traditional method.

Keywords Material selection · Production planning · Cutting problem

Introduction and Literature Review

In several industrial applications such as the wood, paper, and glass industries, it is necessary to cut rectangular raw materials into smaller rectangle pieces with specific measures such that the amount of waste is minimized (Russo et al. 2014). Up to the present, numerous researches have been conducted to investigate the best method

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for cutting the raw materials. The resulting problems are optimization problems referred to as bin packing problems, two-dimensional cutting problems (2DCP), or two-dimensional strip packing problems in the literature. Most of the investigations of these problems are devoted to cases where the items to be packed have a fixed orientation and are not rotatable. In other words, a set of rectangular items (products) defined by their width and height is given. Having an unlimited number of identical rectangular raw materials (objects) of certain width and height, the objective is to allocate the items to a minimum number of the objects or, identically, to divide the objects into smaller pieces such that the maximum number of items is delivered with minimum wastage. With no loss of generality, it is assumed that all input data are positive integers and the dimension of the items is always less than or equal to the objects. This problem is NP-hard (Lodi et al. 2002).

Gilmore and Gomory were the first contributors to model two-dimensional packing problems. They proposed a column generation approach based on the enumeration of all subsets of items (patterns) such that they can be packed into a single object (Gilmore and Gomory 1965). Continuing in this line, Beasley associated the concept of profit for each item to be packed in two-dimensional cutting problems with the aim of packing the subset of items with the maximum profit into a single object (Beasley 1985b). Hadjiconstantinou and Christofides (1995) proposed a similar model for this problem. The function of both modes is to provide upper bounds that benefit the Lagrangian relaxation and sub-gradient optimization method. Later, Scheithauer and Terno (1996) introduced raster points constituting a subset of the discretization points. These raster points are capable of being used in an exact dynamic programming algorithm without losing the optimality (Beasley 1985a). Working on Beasley's idea, Cintra et al. (2008) proposed an exact dynamic programming procedure that simplifies the computation of the knapsack function and provides an efficient procedure for the computation of the discretization points. Additionally, the number of discretization points introducing an idea which partially recalls the raster points in reduces in their approach. Kang and Yoon (2011) suggested a branch and bound algorithm for Unconstrained Two Dimensional Cutting Problems (U2DCP), which is amongst the best algorithms proposed for this category of problem. Moreover, they performed a pre-processing procedure before running the algorithm, with the aim of reducing the number of valid pieces for entering the process which is independent from the main solving approach. Recently, a two-phase heuristic for the non-guillotine case of U2DCP was proposed by Birgin et al. (2012); it solves the guillotine variant of the problem in the first phase in two steps: a fast heuristic step based on the earlier two-stage algorithm proposed by Gilmore and Gomory (1965) and an exact dynamic programming step proposed by Russo et al. (2013). The latter method introduces a solution-correcting procedure and improves one of the two dynamic programming procedures of Gilmore and Gomory (1966). Furthermore, in their algorithm, they employed the reduction of the discretization points method proposed by Cintra et al. (2008) and pre-processing method proposed by Birgin et al. (2012). This algorithm is one of the most effective exact dynamic programming algorithms proposed for solving the U2DCPs. The objective of this research is to maximize the profit of an enterprise dealing with the cutting problem by

minimizing the amount of wastage and surpluses generated during the production. A two-phase algorithm is proposed to serve the mentioned objective, which determines the proper dimension of the raw material required for the production such that all products of the company can be produced with minimum wastage. Moreover, through determining the best combination and quantity of raw materials, the number of surpluses and procurement cost are reduced. In the next section, the characteristics of the problem are introduced.

Problem Description and Preliminaries

The aim of this study is to offer a solution to the cutting problem of the box production industry. To deal with this problem, a two-phase approach is proposed. In these industries, the products are carton boxes of various sizes according to the customer's demands. These carton boxes must meet accurate specifications regarding their material types and dimensions in accordance with the customer's requested specifications. The carton boxes are produced from raw sheets of carton provided by the company's suppliers in various predefined sizes. The suppliers can supply the raw sheets in specific standardized sizes. More details about the problem are given as follows:

- In each planning horizon, the customer orders a specific number of boxes;
- Several sizes of the raw materials are available at each supplier known to the company;
- The number of deliverable products is easily determined by the company if and only if a specific raw material is assigned to produce a specific product;
- There exists more than one suitable candidate raw material for producing one or more products;
- The raw material procured by the companies is distinguished and separated based on its dimensions and the combination of the materials used for building them;
- Each specific size of the raw material used in production generates a certain amount of waste. This wastage is dependent on the production strategy employed for assigning the products to the raw material;
- Each company may have its own individual policies for selecting the measures of the purchased raw materials.

Like any other industry, the profitability of the business is its most important concern. Therefore, nearly all companies in this industry are interested in achieving the following objectives:

- Reducing the wastage cost through minimizing the production-related wastage of materials;
- Reducing the size of the cutting problem through minimizing the variety of the selected raw material such that all products are producible.

A high variety of raw material is confusing. In this industry, due to the need to minimize waste, accurate determination of the dimensions of the raw materials used for producing the products is crucial. On the other hand, all companies usually have a huge variety of products. While utilizing a dedicated raw material with correct dimensions for producing a product will theoretically lead to the minimum possible waste, in practice, this one-to-one approach is almost impossible for the following reasons: firstly, the supply of raw material is restricted to limited specified dimensions, and secondly, dedicating a raw material to each product corresponds to a massive variety of raw materials of different quantities, which is not possible due to inventory-related restrictions. Hence, to have a standard manufacturing system with the minimum amount of incompatibility, the company needs to reduce the size of its problem through limiting the variety of them in-hand raw material in such a way that its production capabilities are not reduced. Additionally, limiting the variety of raw material is useful when suppliers offer quantity discounts where a larger purchasing discount is deliverable if a larger quantity of a single type is purchased.

- Minimizing the in-hand inventory and production surplus

Essentially, two types of inventories are available at the companies: the finished products and raw materials. Since the ordering style of the customers is highly changeable, the extra inventory of the finished products (surplus) is quite likely to remain unused for a long period of time. Apart from that, due to the vulnerability of the inventory to shrinkage, fire, and similar hazards, companies are always at risk of inventory loss. On the other hand, taking the required measures to encounter these risks is extremely costly. Therefore, companies prefer to reduce their risks by keeping their inventories at the lowest possible level.

Determining the appropriate dimensions for the raw materials, purchasing the correct quantity of raw materials, and assigning them properly for the production of products are the most important elements for fulfilling the main objectives of the companies. Indeed, the mentioned requirements are the decision variables of a subcategory of 2DCPs addresses as bin packing problem or strip packing problem in the literature.

The proposed algorithm of this study is designed to deal with this problem. The method is extendable to any other box production company as well as similar industries with minor tailoring. In this research, to evaluate the efficiency of the proposed method, it is implemented in a specific box production company as a case study. In the next section, the specification of the case study is discussed.

The Case Description and Definitions

The case discussed in this research produces over 200 different types of products including carton boxes and divider planes. The main differences among the products are associated with their dimensions and combinations of materials. The technical details are described below.

Sheet Types

The main raw sheet types utilized in the company are three- and five-layer sheets. These sheets are produced by suppliers by combining several layers of carton papers and one or more (depending on the number of plane layers) corrugated media between the papers, which is called the Flute Layer (FL). There are two major types of carton papers: Craft, denoted by (C), which is paper freshly produced from wood (virgin paper), and Liner (Li), which is recycled paper. While the papers in the outer layer of a carton sheet can be made of any material, the material type of the corrugated medium and the paper in the middle layers of a carton sheet are usually liner paper. The different combinations of paper types and medium layers provide a total number of six different carton sheets for use in the company.

- Five layers and double Craft (**C2-5**)
- Five layers and single Craft (**C1-5**)
- Five layers and liner (**Li-5**)
- Three layers and double Craft (**C2-3**)
- Three layers and single Craft (**C1-3**)
- Three layers and liner (**Li-3**)

In the next figure, the combination pattern of the carton sheets is illustrated. The outer layers of the carton sheet could be both liner, both craft, or one liner and one craft (Fig. 1).

Strength of the Boxes

The strength of a carton box is dependent on two factors: the combination of the papers and the direction of the FL. A carton box acquires the minimum necessary strength if and only if the direction of the FL is vertical with respect to the weight that the carton must carry. Consequently, rotation of the carton sheets is not allowed during the production process. On the other hand, according to a general rule, a carton sheet with more crat layers in its structure has higher strength. However, the use of more craft layers is associated with a higher production cost and therefore more expensive product.

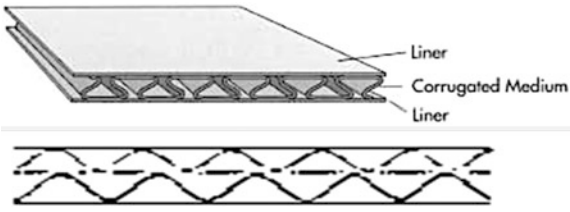

Fig. 1 3-layers and 5-layers carton sheets

Selecting the Material Type for Production

It is the customer who decides on the material combination of the carton sheets of the products; however, the company normally provides an advisory service for the customers to facilitate their decision-making process.

Dimensions of the Products

As previously mentioned, the products of the company are boxes and divider planes. The measures of a box are normally represented by its length, width, and height (a * b * c). Since the planes are two-dimensional, their measure is simply represented by length * width (a * b).

The Spread Dimension

The spread dimension of a product, represented by L * W, is the dimension of the carton sheet that is required to produce that product. The spread dimensions for boxes are calculated according to the following formulae:

$$L = [(a + b) * 2)] + 4 \tag{1}$$

$$W = b + c \tag{2}$$

For two-dimensional products, this procedure is much simpler: the required dimensions of the carton sheet for producing a plane are equal to the dimensions of the product itself. Put simply, the spread dimension of a product is equal to the minimum dimensions of the raw carton sheet capable of producing it.

Item

Each product of the company that is purchased by the customers is an item.

Object

The raw materials for the company are produced by its suppliers from different material combinations with different measures. Each variant of these raw materials is called an object, which is considered as a separate raw material.

Pattern

The first step in producing the items is to divide the objects into smaller pieces according to the items' spread dimensions. There are various strategies for dividing an object into smaller parts, each of which is called a pattern.

Constraints Related to Suppliers

As previously discussed, the aim of this study is to determine the proper dimensions of the raw materials. One of the constraints associated with this problem is the supplier restrictions in delivering the requested measures. Due to technical issues, suppliers are unable to cut the raw sheets into any desirable measures; the available lengths of a sheet from a supplier may vary between 45 to 200 based on 5 cm increments (i.e. 45, 50, 55,…, 200). Moreover, the stocks can only be cut into the following predefined widths: 90, 100, 110, 120, 140, 150, 160, and 200. The next table represents the possible measures of lengths and widths as the dimensions of an object (Table 1).

Clusters of Products

Before proceeding to the solution approach, the production data of the problem must be marshalled and categorized. In this regard, initially the data related to the item types are collected and the products with an identical material combination are placed in the same category. Based on this classification, six different clusters of products are defined: C1-5, C2-5, C1-3, C2-3, Li-5, and Li-3. It is notable that to produce the items in each cluster, the material combination of the objects must be identical to the material combination of the cluster. However, several sizes of

Table 1 Table of possible cutting measures

Possible widths							
90	100	110	120	140	150	160	180
Possible lengths	45	Possible lengths	85	Possible lengths	125	Possible lengths	165
	50		90		130		170
	55		95		135		175
	60		100		140		180
	65		105		145		185
	70		110		150		190
	75		115		155		195
	80		120		160		200

objects can be used. Selecting the proper object(s) for each cluster is one of the objectives of this problem.

Deterministic Formulation of the Problem

In this section, a deterministic formulation based on the characteristic and assumptions of the problem is proposed and explained. The following notation is used in the mathematical formulation of the above-mentioned problem:

i index for the number of products
j index for the number of available objects
m the number of items in each cluster
n the number of available objects
M a large positive value
d_i demand for item i
p the set patterns satisfying the minimum acceptable waste condition, p = {1, 2, …, P}
g_{ipj} the number of extractable items i from object j if pattern P is applied
c_{jp} unit cost of object j having pattern p applied to it
x_{pj} frequency with which pattern p is applied to object j
z_j decision variable for using object j

The following model is proposed:

$$\text{Objective function 1: } \min \sum_{j=1}^{n} z_j \tag{3}$$

$$\text{Objective function 2: } \min \sum_{j=1}^{n} \sum_{p=1}^{P} c_{jp} x_{pj} \tag{4}$$

subject to:

$$\forall i: \sum_{j=1}^{n} \sum_{p=1}^{P} \mathrm{g_{ipj}} \mathrm{x_{pj}} \geq \mathrm{d_i} \tag{5}$$

$$\forall p: \mathrm{x_{pj}} \leq \mathrm{Mz_j} \tag{6}$$

$$\mathrm{x_{pj}} \geq 0, \text{ integer} \tag{7}$$

$$\mathrm{z_j} = 1 \text{ if raw material j is used, and } 0 \text{ otherwise} \tag{8}$$

The description of the model is as follows: the objective function (3) minimizes the variety of objects (i.e., the variety of raw materials) that should be used in the production procedure. Objective function (4) minimizes the procurement cost of object j by optimizing the usage frequency of the object–pattern combination. At the same time, objective function (4) minimizes the surplus amount by justifying the purchased material at the required level. Constraint (4) guarantees that the production number of satisfies its demand. Constraint (6) denotes that there is no limitation on providing the required number of objects. Finally, the constraints (7) and (8) define the nature of the variables.

The Solution Approach

To solve this kind of problem, depending on the problem environment, various methodologies might be effective. In this study, considering the objectives of the problem, a two-phase dimension-determination method is proposed that solves the problem in several steps. The first step in approaching this problem is to categorize the products. As previously mentioned, they are divided into six different clusters: C2-5, C1-5, Li-5, C2-3, C1-3, and Li-3. Each cluster is a set of products sharing the same property of the raw material but with different dimensions. Table 2 represents a sample of uncategorized data and Table 3 represents the categorized samples.

Table 2 Sample of uncategorized data

ID code	Dimension		
G1	49.5	24.5	11
G143	7.5	3.5	10.9
G144	5	4	58
G145	6.7	6	66.5
G2	50.5	25.4	22.8
G216	50	7	0
G217	25	7	0
G218	80	7.5	0
G3	61	33.7	25
G36	42	8.6	0
G37	98.5	15	0
G38	79.5	15	0
G58	135	10	0
G59	28.5	10	0
G60	113	11	0
G71	39	11	0
G72	101	11	0
G73	14.4	13.5	9.5

Table 3 Sample of categorized data

	ID code	Dimension			Spread dimensions	
					Length	Width
C1-3	G1	49.5	24.5	11	152	35.5
	G2	50.5	25.4	22.8	155.8	48.2
	G3	61	33.7	25	193.4	58.7
C2-3	G36	42	8.6	0	42	8.6
	G37	98.5	15	0	98.5	15
	G38	79.5	15	0	79.5	15
C1-5	G58	135	10	0	135	10
	G59	28.5	10	0	28.5	10
	G60	113	11	0	113	11
C2-5	G71	39	11	0	39	11
	G72	101	11	0	101	11
	G73	14.4	13.5	9.5	62.8	23
Li-3	G143	7.5	3.5	10.9	26	14.4
	G144	5	4	58	22	62
	G145	6.7	6	66.5	29.4	72.5
Li-5	G216	50	7	0	50	7
	G217	25	7	0	25	7
	G218	80	7.5	0	80	7.5

Two-Phase Dimension Determination Method

In this approach, the complexity of the problem is decreased by determining the dimensions of the objects in two phases. The method is applicable for all clusters; therefore, to illustrate the procedure only one cluster (C1-3) is discussed as an instance. In the first phase, based on possible purchasable measures for the length of the objects, the producible products utilizing a certain length of objects are classified in the same group. In the second phase, considering the demand for the items, different combinations of the assigned lengths and available widths (as the final dimension of the objects) are investigated. The results consist of determining the best dimension of the objects as well as the optimal production plan that satisfies the requirements of the problem owners, respecting the demand for the items. In the following, the procedure used to obtain this solution is discussed.

Phase 1: Classification of the Items with the Same Object Length

Step 1. The matrix of remaining lengths is formed based on all available lengths of the objects. This matrix represents the remaining length of an object (regardless of

Table 4 The matrix of remaining length using each object

	Available lengths for C1-3 objects								
Length of items	Length of the objects								
	40	45	50	.	.	.	190	195	200
23.5	17	22	3				2	7	12
46.6	40	45	3	.	.	.	4	9	14
47.6	40	45	2				47	5	10
.		.		.				.	
.		.			.			.	
.		.				.		.	
125	40	45	50				65	70	75
125	40	45	50	.	.	.	65	70	75
135	40	45	50				55	60	65

Table 5 The assignability matrix

	Assignability matrix based on allowed remaining								
Length of items	Length of the objects								
	40	45	50	.	.	.	190	195	200
23.5	0	0	1				1	0	0
46.6	0	0	1	.	.	.	1	0	0
47.6	0	0	1				0	1	0
.		.		.				.	
.		.			.			.	
.		.				.		.	
125	0	0	0				0	0	0
125	0	0	0	.	.	.	0	0	0
135	0	0	0				0	0	0

its width) if it is utilized for delivering an integer multiple of the length of a certain item. To perform this calculation, the spread length of the products and available lengths for objects are determined. The feasible length of the objects must satisfy the following two conditions:

- It must be larger than the spread length of the product;
- The material remaining after extracting an integer multiple length of a product must be less than 5 cm.

The matrix of the remaining length in the first step is represented in Table 4.

Step 2. The matrix of the remaining lengths is handled to create the "assignability matrix". The assignability matrix is a 0–1 matrix indicating whether an item is assignable to an object. If the length of an object is suitable for extracting the length of an item, the item is considered assignable to that object and therefore the digit in the relevant intersection of the rows and columns is "1"; otherwise, it is zero (Table 5).

Table 6 Number of assignable lengths for producing an item

	Assignability matrix based on remaining									
Length of items	Length of the objects									Number of assignable objects
	40	45	50	.	.	.	190	195	200	
23.5	0	0	1				1	0	0	7
46.6	0	0	1	.	.	.	1	0	0	4
47.6	0	0	1				0	1	0	4
.		.		.				.		.
.		.			.			.		.
.		.				.		.		.
125	0	0	0				0	0	0	2
125	0	0	0	.	.	.	0	0	0	2
135	0	0	0				0	0	0	2
Productivity of the object	3	0	3	.	.	.	6	5	1	

Step 3. The length of an item might be assignable to several objects. In this step, the total number of objects that can produce an item is calculated and represented in Table 6. Additionally, in the last row of Table 6, denoted as the object's productivity, the total number of items producible by the relevant object is represented.
Step 4. The rows and columns of the assignability matrix are sorted based on decreasing order of assignable lengths and productivity of each object (the object length with more applications is shown in the first column; the object with more assignability is shown in the first row); see Table 7.

Table 7 Sorted usability matrix

	Sorted assignability matrix based on remaining									
Length of items	Length of the objects									Number of assignable lengths
	130	125	190	.	.	.	65	80	85	
35	0	0	0				0	0	0	9
27.5	0	0	1	.	.	.	0	0	0	7
37	0	0	1				0	0	0	6
.		.		.				.		.
.		.			.			.		.
.		.				.		.		.
193.4	0	0	0				0	0	0	1
107.5	0	0	0	.	.	.	0	0	0	1
107	0	0	0				0	0	0	1
Productivity of the object	9	7	6				0	0	0	

Step 5. As previously mentioned, one of the objectives of this strategy is to minimize the variety of the purchased objects. Therefore, solving a set covering problem for selecting the minimum number of objects lengths which can be used for extracting the maximum number of item lengths with minimum wastage in each cluster is a suitable approach. The following notation and formulation provide the mathematical representation of the problem:

f_j the total number of different items an object can deliver, $f_j = \{1, 2, 3, \ldots, m\}$;
a_{ij} indicates whether or not the length of item i is extractable from the length of object j;
z_j decision variable for using object j;

The mathematical model is as follows:

$$\min \sum_j f_j z_j \tag{9}$$

s.t.

$$\forall i: \sum_j a_{ij} z_j \geq 1 \tag{10}$$

$$\forall i: z_j = 0, 1 \tag{11}$$

$$\forall i, j: a_{ij} = 0, 1 \text{ and fixed} \tag{12}$$

- *Note: in this approach, by selecting the objects according to the discussed strategy, for each of them, a unique applicable pattern is determined. This determined pattern is patched to the related object and represents the same concept; therefore, they can be addresses alternatively.*

The model is described as follows: the objective function (9) selects the minimum variety of objects. Constraint (10) guarantees that all items are producible by at least one object. Finally, (11) and (12) represent the nature of the variables of the problem. The sorted assignability matrix of this problem facilitates the application of the addressed set covering problem. The procedure is as follows:

- The object with the maximum productivity value is selected; all items belonging to it are determined and permanently assigned to it.
- The assignment of the permanently assigned items to the other objects is terminated.
- The productivity of the objects is updated.
- If the assignable length for all items is one, the procedure is stopped; otherwise, steps 1 to 4 are repeated.

Tables 8 and 9 illustrate the first and last stages of this procedure.

Table 8 The first stage of the object selection procedure

	Sorted assignability matrix based on remaining									
Length of items	Length of the objects (y_j)									Number of assignable lengths
	130	125	190	.	.	.	65	80	85	
35	0	0	0				0	0	0	9
27.5	0	0	1	.	.	.	0	0	0	7
37	0	0	1				0	0	0	6
.		.		.				.		.
.		.			a_{ij}			.		.
.		.				.		.		.
193.4	0	0	0				0	0	0	1
107.5	0	0	0	.	.	.	0	0	0	1
107	0	0	0				0	0	0	1
Productivity of the object (f_j)	9	7	6	.	.	.	0	0	0	

Table 9 The final stage of the object selection procedure

	Sorted assignability matrix based on remaining									
Length of items	Length of the objects (y_j)									Number of assignable lengths
	130	190	110	.	.	.	65	80	85	
35	0	0	1				0	0	0	1
27.5	0	1	0	.	.	.	0	0	0	1
37	0	1	0				0	0	0	1
.		.		.				.		.
.		.			a_{ij}			.		.
.		.				.		.		.
193.4	0	0	0				0	0	0	1
107.5	0	0	1	.	.	.	0	0	0	1
107	0	0	1				0	0	0	1
Productivity of the object (f_j)	9	6	5	.	.	.	0	0	0	

Step 6. This step is the last step of phase 1. The items of the cluster which are assigned to a certain object are classified according to the next table (see Table 10).

Table 10 Table of classified items according to assigned objects

C1-3	Recoded product	Dimensions of the item			Spread dimension of the item		Final assigned object length
					Length	Width	
45	G9	78	20	14	200	34	200
29	G3	13.9	7.9	7.3	47.6	15.2	195
58	G15	65.5	29	21	192	49	195
54	G17	61	34	25	193.4	58.7	195
111	G1	23.5	6.5	0	23.5	6.5	190
10	G13	37	27	0	37	27	190
138	G14	37	27	0	37	27	190
31	G2	13.9	7.4	7.3	46.6	14.7	190
5	G26	95	45	0	95	45	190
141	G28	95	45	0	95	45	190
7	G18	85	40	0	85	40	175
16	G21	85	40	0	85	40	175
57	G23	85	40	0	85	40	175
50	G11	50.5	25	23	155.8	48.2	160
154	G5	21.7	15	12	77.4	26.5	155
49	G10	49.5	25	11	152	35.5	155
113	G16	45	29	22	152	51	155
93	G35	135	90	0	135	90	135
32	G6	46.3	17	17	131.4	34.8	135
94	G12	36.5	27	16	130	42	130
8	G19	125	40	0	125	40	130
15	G20	125	40	0	125	40	130
56	G22	125	40	0	125	40	130
59	G24	125	40	0	125	40	130
14	G32	125	85	0	125	85	130
55	G33	125	85	0	125	85	130
62	G34	125	85	0	125	85	130
26	G7	44.3	18	18	128.6	36	130
30	G4	7.6	7.9	7.3	35	15.2	110
4	G25	105	45	0	105	45	110
140	G27	105	45	0	105	45	110
152	G29	108	74	0	107.5	74	110
119	G31	107	80	0	107	80	110
27	G8	31.7	18	18	103.4	36	105
153	G30	91.5	74	0	91.5	74	95

Table 11 Proper dimensions of the objects and production plan obtained by software

Recoded Product code	Spread dimension		Assigned length	Available widths								Plan utilization (%)
	L	W		90	100	110	120	140	150	160	180	
G9	200	34	200				1	4993				97.14
G3	47.6	15.2	195	2741	17907		2625					96.87
G15	192	49										
G17	193.4	58.7										
G1	23.5	6.5	190	319		1	29	1	3143		10097	99.41
G13	37	27										
G14	37	27										
G2	46.6	14.7										
G26	95	45										
G28	95	45										
G18	85	40	175	1						17872		97.14
G21	85	40										
G23	85	40										
G11	155.8	48.2	160		23291							93.87
G5	77.4	26.5	155	1	1			1		2487	43583	97.63
G10	152	35.5										
G16	152	51										
G35	135	90	135	1				4040			10381	99.25
G6	131.4	34.8										

(continued)

Table 11 (continued)

Recoded Product code	Spread dimension		Assigned length	Available widths								Plan utilization (%)
	L	W		90	100	110	120	140	150	160	180	
G12	130	42	130				14211			36526	77275	93.24
G19	125	40										
G20	125	40										
G22	125	40										
G24	125	40										
G32	125	85										
G33	125	85										
G34	125	85										
G7	128.6	36										
G4	35	15.2	110	62724				2624	37249	9441		96.11
G25	105	45										
G27	105	45										
G29	107.5	74										
G31	107	80										
G8	103.4	36	105								16122	98.47
G30	91.5	74	95						25279			95.05

Phase 2: Determining the Required Objects and Their Quantities for Each Cluster

As discussed above, to specify an object for ordering, both its length and its width must be determined. Hence the appropriate lengths of the objects in each cluster are determined in the first phase of the proposed procedure. In the second phase, various combinations of the determined lengths and available widths are examined and the most profitable combination is employed for producing a specific product in a cluster. For the second phase, the main specialized cutting software that is currently in widespread use in these industries is employed. Using the software, the proper objects and their required quantity to satisfy the demand for the items in each group of products is determinable. For this purpose, all combinations of the assigned length and the available widths are elaborated. Considering the demand for the items, the optimal strategy of object selection and the order quantity is determined. This information indicates what combination of the length and width should be decided for an object and what quantity of each object must be purchased. The results are shown in Table 11. The last column of the table represents the utilization of the proposed method based on the waste of the raw material.

Conclusion

In this study, a category of cutting problem that is frequently used in box production companies and that is an NP-hard problem was investigated and formulated and a two-phase method for approaching it was introduced. The main principles of the approach were minimizing the production waste and production costs and maximizing the efficiency of the material selection for production. This method is easy to implicate, returns a very good solution, and is applicable for a wide range of similar problems in this industry with minor adaptation. Considering the environment of the problem, in this investigation, the suppliers' competitions were limited to their ability to provide the raw material, the uncertainty of the demand was neglected, and the specific restriction was applied in the determination of the proper material selection. The focus of the method was on selecting the material that would initially generate an acceptable amount of waste. This component may vary depending on different circumstances. In future development of the study, price competitive suppliers, the uncertainty of demand, and a different method of material selection (such as maximizing the useable leftovers) seem to be very interesting assumptions to be taken into consideration.

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Physical Discomfort Experienced in Traditional Education and Tablet-Assisted Education: A Comparative Literature Analysis

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Abstract With advances in technology, various forms of computers have become more involved in education. In particular, tablet computers are actively used for educational purposes nowadays. Given the fact that musculoskeletal, postural, and ocular developments of children and adolescents are still not complete, potential physical issues resulting from usage of new technologies must not be disregarded. Physical problems or challenges experienced by children and adolescent students will be involved in this research from the perspectives of traditional education and tablet-assisted education. In a sense, a comparative review of the available literature is used in the study to analyze and identify the commonalities and differences in physical problems experienced by students.

Keywords Students · Physical challenges · Traditional education
Tablet-assisted education

Introduction

Tablet personal computers (PCs) have become one of the mostly frequently used portable computing devices. In addition to increasing usage of tablet PCs, as reported by Melanson (2011), utilization of tablet PCs in education is also

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increasing, and many countries have launched initiatives for the use of tablets by children and adolescents in education (Tamim et al. 2015). In addition to reasons of widespread Internet access, and characteristics like being lightweight when compared to other IT alternatives like notebooks, laptops or desktops, increase in educational usage includes reasons as having a considerable variety of educational applications to be used, tablet-assisted systems are attractive to teachers (Henderson and Yeow 2012). Furthermore, Hashemi et al. (2011) underlined the effectiveness of mobile learning for the pedagogy and supported the idea of using mobile devices such as tablets as an educational tool.

On the other hand, Roth-Isigkeit et al. (2005) stated that 83% of a sample of 749 school-aged children and adolescents had experienced pain in the past three months. At the same time, 64% of these students reported musculoskeletal pain. Although there is no definite statistical evidence regarding the factors checked in the study, carrying school bags as a load on the back region, engagement in sedentary activities like IT usage, and having postural habits can be listed among possible factors in musculoskeletal pain. Clinch and Eccleston (2009) underline the fact that children experiencing musculoskeletal pain today will become adults who could experience more serious problems in the future, which may become a burden to their countries' health systems.

This study compares musculoskeletal, postural, and ocular problems experienced by children and adolescents in traditional education settings or traditional education activities and tablet-assisted or tablet-integrated educational settings and/or activities. The study will follow a comparative approach of a systematic literature review, with the main aim being to observe the differences between traditional and tablet-assisted education in terms of the physical problems experienced.

Literature Review

When educational activities or environments are considered, ergonomics is a critical science not only for the elimination of undesirable design elements of the environment or equipment but also for the sake of a better experience of education. Zunjic et al. (2015) discussed ergonomic aspects that affect the quality of education. Dimensions of school furniture with respect to the student population's anthropometric properties, along with other aspects of a comfortable working environment (air conditioning, illumination, etc.), improve the experience of education in the registered environments and activities. However, efforts, conditions, awareness, and limitations differ across the world and various problems such as physical, musculoskeletal, and ocular ones are experienced during educational activities (or in educational environments). Hedge (2005) also emphasized that educational environment setups are mostly not designed for children. When ergonomics is disregarded, it is hard to avoid developing lifelong incorrect habits with regard to posture or musculoskeletal health.

This review presents the posture-related, musculoskeletal, and ocular issues associated with traditional versus tablet-integrated or assisted educational activities and settings.

Physical Issues (Experienced by Students) Associated with Traditional Educational Activities and Environments

When the terminology of physical discomfort is used, it is obvious that problems are not restricted to discomfort related to posture or the musculoskeletal system but also include issues such as eye irritation or eyestrain, which are considered in this study.

Limon et al. (2004) stated that inappropriate chair height is one of the risk factors in their study, in which they scanned risk factors for 10,000 children in traditional elementary schools' settings in Israel. In another study investigating risk factors, Ismail et al. (2009) worked on risk factors associated with musculoskeletal discomfort and disorders among 229 school children in two different schools in Malaysia. They gathered information on musculoskeletal discomfort experienced by students using a modified version of the Nordic Musculoskeletal Questionnaire. In addition to records of musculoskeletal discomfort, a modified Rapid Upper Limb Assessment (RULA) study was employed to assess students' posture. Pain and discomfort experienced in the neck and shoulder regions are the most prevalent issues reported according to the results of the questionnaire. The study could not find any significant relationship between high RULA scores of students and reported musculoskeletal discomfort.

Mohd Azuan (2010) carried out a study in which 100 schoolchildren participated; in addition to considering the efforts on schoolbag load, the study used two questionnaires, one of which was the Standardized Nordic Questionnaire, to gather information on musculoskeletal discomfort experienced and children's feedback on school furniture. Statistical analyses indicated that neck pain significantly affected the overall satisfaction with furniture used in the educational environment. The results of the study imply that the most frequent types of musculoskeletal discomfort experienced by schoolchildren are neck pain and lower and upper back pain.

Although their studies did not take place during educational sessions, some studies were performed during reading activities of schoolchildren. Briggs et al. (2004) assessed postures using video images to check the angles of head tilt, neck and trunk flexion, and gaze angle. Greig et al. (2005) used surface electromyography (sEMG) as a tool for checking the cervical erector spinae (right and left) and upper trapezius muscles. The results of these two studies indicate that the type of IT used in reading tasks is associated with issues of posture, muscle activities, or gaze angles. The results of studies related to regular books (a traditional educational material) are mainly considered here. Neck flexion by schoolchildren was greatest in the traditional setup compared to the other IT types examined.

Considering reading books placed on a flat desk as the traditional approach, Briggs et al. (2004) concluded that children reading from books had more flexion in the head and neck regions and a greater gaze angle when compared to other IT types that they took into account, which had higher display positions. If the height of the display is inversely proportional to the downward gaze angle, neck flexion, and head tilt, as stated in the study by Briggs et al. (2004), it is expected that without using tablet stands to improve posture and gaze angle, reading from a tablet will lead to problems similar to those caused by reading books placed on flat desks. The higher the gaze angle, the faster the tear loss, which is likely to result in dry and irritated eyes (Anshel 1997).

Straker et al. (2009) performed an analysis of 24 children (10–12 years old) during an educational activity, namely a reading and writing task, and analyzed the postures of the children. The tasks were performed on a desktop computer and with a traditional paper-based system (book, paper, and pen combination). Posture analysis was done using video-based or photographic posture analysis methods. In addition to posture analysis, an sEMG study was conducted to assess muscle activities during the tasks. Mean postures during reading and writing activities with the traditional paper-based system were less neutral than those found with computers (with a higher display height), in agreement with the findings of Briggs et al. (2004). With regard to muscle assessment, traditional paper-based IT was associated with higher muscle activity levels.

Zovkic et al. (2011) focused on computer usage but in a traditional educational environment and identified wrist pain, dry throat, eye irritation, visual problems, headaches, and neck and back pain as problems faced by primary-school students.

Physical Issues (Experienced by Students) Associated with Tablet-Assisted Educational Activities

It may be beneficial to mention at the beginning of this section that Greig et al. (2005), Sommerich et al. (2007), and Straker et al. (2008) claimed that there is an association between tablet usage and musculoskeletal discomfort.

In their study comparing tablet-, desktop-, and paper-based IT through a set of coloring tasks, Straker et al. (2008) argued that children's use of mobile technology—such as tablet computers—has been associated with experiences of musculoskeletal discomfort. Although the study did not take the educational environment into consideration, it was performed with an educational activity, namely a coloring task. Utilizing an infrared motion analysis system for posture assessment and surface electromyography for assessment of muscle activity in the neck region, the study provides us with the information that tablet computer use by children is associated with increased muscle activity in the upper trapezius and cervical erector spinae when compared to traditional paper-based IT and traditional desktop computers.

Furthermore, muscle activities of paper-based IT and tablet computers were reported to be not significantly different. Especially, spinal postures of participants

were not statistically different when paper-based IT and tablet computer activities were compared. Spinal posture flexion during paper-based IT and tablet computer activities was higher when compared to the desktop computers (the higher display option in the study). This result also supports the results of Briggs et al. (2004) regarding display height and neck flexion.

Assuming that tablet computers are placed on a flat desk, similarly to the traditional paper–book–pen combination, a less neutral posture and increased neck activity can be expected. Therefore, it can be clearly stated that further studies on tablet-assisted education are expected to fill in this gap scientifically.

Although the subjects of elementary school age who participated in a study by Zovkic et al. (2011) were not examined for the effects of tablet usage and were not exposed to any tablet usage for educational activities at school, the researchers underlined the suggestions of Straker et al. (2008) based on the findings that tablet use was very similar to paper-based IT use. The study recommends that both tablet computers and paper-based IT should be used for moderate periods of time.

The use of computer screen devices may result in a syndrome named computer vision syndrome, which includes problems like headache, eyestrain, and neck/back pain (Yan et al. (2008). When schoolchildren are at risk of experiencing this syndrome, because their musculoskeletal and vision developments are not yet complete, it becomes a more critical issue. Therefore, the results of Sommerich et al. (2007) deserve greater emphasis. They studied tablet usage by high school students and their data collection involved filling in a questionnaire, in addition to the use of monitoring software to record the duration of tablet usage by subjects and their preferences. Although the study took place in a high school, it was not clearly stated whether the tracked tablet computer usage involved an educational purpose or not. The research pointed out that the most frequently observed types of discomfort experienced by subjects were eye and neck discomfort. Questionnaire results also reported that eyes, neck, head, right hand/wrist, and upper and lower back are the body parts in which the subjects experienced discomfort associated with using tablet computers.

The results of Kim et al. (2014) imply that prolonged use of touchscreen keyboards potentially increases the risk of experiencing musculoskeletal discomfort. The researchers suggest that the reason behind this potential risk is that touchscreen keyboards are easily activated, users cannot rest their fingers and wrists on the keyboard, and therefore some muscle groups are forced to stay motionless and experience an increased static load. The muscle groups that are most affected (as a result of this static loading) are in the wrist and shoulder regions.

Methodology

This study systematically reviewed the physical problems experienced by the young population to identify the similarities and differences in the problems experienced in traditional and tablet-assisted educational settings and activities with scientific evidence.

Justification for This Study

An interpretive analysis of the literature was required because as the tablet-children-education trilogy has not yet been thoroughly studied, this gap in the literature makes it hard to analyze the negative impacts of tablet-assisted education with respect to traditional education. Furthermore, the results of this comparative review may provide researchers with more reliable reference points that can guide future studies.

Consequently, the purpose of this study was to contribute to the body of knowledge with a literature-review-based analysis and comparison of physical discomfort (postural, musculoskeletal, or visual discomfort) experienced in traditional and tablet-assisted educational activities and environments. Thus, shedding light on the topic for the benefit of future studies with a summary work including both cases acted as a justification for this study.

Discussion and Conclusions

This comparative review has clearly put forward that if tablets are not used with a stand with an appropriate angle adjustment, musculoskeletal and posture-related problems experienced in traditional educational settings are likely to be experienced in tablet-assisted education as well. On the other hand, problems in the wrist/hand and shoulder regions and symptoms of computer vision syndrome can be attributed to physical problems related to tablet usage. Whether associated with traditional or tablet-assisted education, any physical problem of children and adolescents should be taken into account because their physical development is not yet complete.

Syazwan et al. (2011) used the Standardized Nordic Questionnaire and RULA for data collection and posture assessment of schoolchildren. Data collection was followed by an intervention that showed that the body posture of school children in their classroom settings can be improved and thus musculoskeletal discomfort and pain experienced may be reduced via some exercises and awareness of future risks regarding bad body posture.

The results of Straker et al. (2009) show that in the period of adaption to new IT, children need to be encouraged to avoid a monotonous posture and activity, while the results of Fanucchi et al. (2009) indicate that an eight-week exercise program reduced the intensity of lower back pain of 12–13 years old schoolchildren. It is obvious that proper simple physical exercises offered by specialists (like physical therapy and rehabilitation specialists or physiotherapists) to be added to school programs to reduce or eliminate physical discomfort or pain experienced by children and adolescents.

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Future Research and Suggestions Based on Maritime Inventory Routing Problem

Elifcan Gocmen and Ebru Yilmaz

Abstract The problem of the distribution of containers by ships and keeping the inventory levels within specified bounds at ports in a marine system is called the maritime inventory routing problem. The problem has been studied by both academics and practitioners. However, there are insufficient studies concerning environmental issues and ship compartment capacities. In this study, an extensive literature survey focusing on these issues is summarized and analyzed and the gaps in the field are identified. Besides, future trends, opportunities, and suggestions are presented.

Keywords Maritime inventory routing · Sustainable logistics
Ship compartment assignment

Introduction

The maritime inventory routing problem (MIRP) plays an important role in general trade. Routing of ships and maintenance of inventory levels at ports should be managed carefully to meet demand. Inventory-routing problems consider both inventory and vehicle-routing decisions simultaneously in a single model. There are many extensions and variants of these problems including, firstly, variable production and consumption rates. The other variants are multiple products and use of spot charters (Christiansen et al. 2011).

MIRP has been widely studied in the literature. In previous studies of MIRP, the sustainability and compartment capacities were not considered in detail. However, maritime transportation prompts significant fuel consumption (De et al. 2017).

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Literature on the environmental constraints, costs, and ship compartment constraints in particular have been included in this study. Environmental research has gained importance in international trade and transportation, especially in the face of current climate debates. Fuel consumption in marine transport is the basic cause of greenhouse gas emissions. Although these gases are important for the earth, they are causing temperature increases and climate changes, and as this process continues, emissions are expected to rise. In marine logistics, efforts to assess environmental impacts usually focus on strategies for reducing greenhouse gas emissions, fuel consumption optimization, low carbon transport, and energy efficient ship design.

The primary objective is to propose a systematic review of the literature studies that consider multiple containers, environmental approaches, and compartments and to present the future trends, opportunities, and suggestions.

Related Works

MIRP with multiple compartments differs from the classical MIRP in that heterogeneous goods are delivered in multiple compartments in the same ship. Fagerholt and Christiansen (2000) discuss a problem with multiple compartments. The scope of the problem is a pick-up and delivery problem. A set partitioning approach is proposed for this problem. Multiple products are distributed by ship because of a fleet including a flexible cargo. Al-Khayyal and Hwang (2007) consider the routing of heterogeneous ships. They consider a pick-up delivery for the product-dedicated compartments in a ship. Li et al. (2010) address a problem including multi-parcel ships. The ships include dedicated compartments for multiple chemicals. They propose a novel mixed integer linear programming approach. Siswanto et al. (2011) discuss an inventory routing problem with undedicated compartments to minimize the total cost. Firstly, they develop a mixed integer linear model. Then they develop a greedy heuristic. Agra et al. (2014) discuss an inventory routing problem. They consider the distribution of fuel oil products using heterogeneous ships with dedicated tanks. They determine the distribution of the products dedicated to the tank compartments using an arc load flow formulation and use different hybrid methods to obtain good results.

The researches on sustainable inventory routing problems deal with the optimization of energy consumption of transportation. Meng and Wang (2011) propose a mixed-integer non-linear model with sustainability constraints. They evaluate the service frequency and vessel speed in their model. Their study shows that a slow steaming strategy can be evaluated in the high-price scenarios or having the large ships. Norstad et al. (2011) consider slow speed, time windows, and ship capacity in a vessel-routing problem. Their study shows that slow speed minimizes the fuel consumption costs. Ronen (2011) deal with slow steaming, total operating cost, and number of ships. They propose that this strategy increases the chartering cost. De et al. (2017) study an MIRP with sustainability aspects. They integrate the slow

Table 1 Studies including sustainability and compartment capacities

Paper	Problem	Method
Perakis and Papadakis (1989)	Time-dependent environmental routing	Dynamic programming
Richetta and Larson (1997)	Waste problem of environmental routing	Simulation
Fagerholt and Christiansen (2000)	A pick-up and delivery problem for multi-compartments	A set partitioning approach
Al-Khayyal and Hwang (2007)	A pick-up delivery problem with compartments dedicated to liquid bulk products	Mixed integer linear program
Li et al. (2010)	A problem including ships with assigned compartments for multiple products	A novel mixed integer linear model
Christiansen et al. (2011)	An MIRP with heterogeneous ships and multiple compartments	Genetic algorithm
Bektaş and Laporte (2011)	A pollution routing problem	Integer programming
Siswanto et al. (2011)	MIRP for undedicated compartments	A mixed integer linear model
Norstad et al. (2011)	Slow speed, time window, and ship capacity in a vessel routing problem	Multi-start local search heuristic
Wang et al. (2011)	MIRP with sustainability constraints	Mixed-integer model
Agra et al. (2014)	A short MIRP	Hybrid methods
Kramer et al. (2015)	A pollution routing problem with ship speeds	Local search heuristic
Lam (2015)	Sustainable network problem	A hybrid methodology
De et al. (2017)	MIRP with sustainability aspects	Mixed integer non-linear model

steaming policy with ship routing. This policy is adopted to estimate the amount of fuel consumed. They present a problem including scheduling and routing constraints and develop a meta-heuristic. The approach is called particle swarm optimization. Some other studies dealing with sustainability and compartment capacities are given in Table 1.

Future Trends and Opportunities

MIRP has been widely studied. However, we believe that the problem structure can be updated by adding new trends and opportunities.

Future Trends in the Sector

- Collaboration between actors in a chain and consolidation among freight forwarders are important.
- Industry 4.0 leads to meeting new technologies, so these can be adapted to the maritime processes such as GPS and RFID.
- Decision support systems can be used to integrate the inventory routing based on sustainability.
- The maritime inventory routing problem faces a dynamic environment. However, most existing research neglects stochastic travel times and stochastic demands. Future studies can use queuing models and fuzzy approaches to overcome the uncertain conditions.
- The speed of ships and wave conditions can be considered in the studies. This leads to travel at the optimum speeds and a reduction in energy consumption.

Future Trends in the Literature

- Most publications present one-level distribution for MIRPs. Multi-echelon distribution systems are more efficient for minimizing energy consumption.
- Most papers that tackle fuel consumption assume that the fuel tank capacity is adequate to complete the tour. So, recharging stations must be considered to charge the ship's tanks.
- The number of studies that take into account perishability is limited in MIRPs.
- Additionally, in the future, studies can be extended by including fleet-planning approaches. Efficient load plans, fleet sizes, and fleet reduction or expansion decisions may contribute to sustainable advantages.
- A few papers aim to minimize the cost, but profit maximization must be targeted to control demand and price flexibility.
- More advanced heuristics combining classical heuristics and optimization can be used for more complex MIRPs.

Some suggestions considering current trends are given in Table 2.

Results

The paper has proposed a study of combined MIRPs based on sustainability and compartment capacities. The inventory routing problem has been studied many times in previous maritime studies. However, the number of studies that take into account the sustainability and compartment capacities is limited. The literature

Table 2 Suggestions for MIRPs

Existing papers	Suggestions
One-mode transportation	Intermodal transportation
	Logistics hub design
Design of transportation based on time and cost	Environmental and reliability conditions for the design
Deterministic demands	Stochastic demands
	Dynamic logistics network with demand changes
Mathematical programming approaches for routing and scheduling of ships	Scheduling with uncertain times and demands
Inventory routing with time windows	Multi-period, multi-product, multi-compartment inventory routing
Mathematical-heuristic approaches	Queue models, fuzzy approaches
Inventory routing considering fuel consumption	Inventory routing with ship speeds, ocean conditions, waves

work reviewed in this paper is based on the problem type and the method in Table 1. The existing papers are presented and suggestions are discussed in Table 2. Future trends are suggested, considering both the maritime sector and the literature research. Many papers about maritime inventory-routing problems have been studied in the literature generally. However, MIRP integrated approaches including both sustainability and compartment capacities have not been sufficiently considered. Therefore, in this paper, this problem is highlighted. The importance of integrating the inventory and routing in this sector is seen and an environmental focus and richer models with new constraints will be more important tomorrow.

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Lean Transformation Integrated with Industry 4.0 Implementation Methodology

Sule Satoglu, Alp Ustundag, Emre Cevikcan and Mehmet Bulent Durmusoglu

Abstract Succeeding a cultural and people-oriented transformation, lean producers adopt the philosophy of doing more with less by eliminating non-value-added activities from production processes to maintain effectiveness, flexibility, and profitability. In the context of Industry 4.0, new solutions are available for combining automation technology with lean production. Moreover, when effective usage of resources (finance, labor, material, machine/equipment) is concerned, it is obvious that Industry 4.0 should be applied to lean processes. In this context, this paper attempts to emphasize the interaction between lean production and Industry 4.0 and proposes a methodology that provides guidance for Industry 4.0 in a lean production environment. Moreover, Industry 4.0 technologies and automation-oriented lean production applications are also included.

Introduction

Lean manufacturing, which evolved from the conceptualization of the Toyota Production System by Taichii Ohno's initiatives at Toyota Motor Company, can be described as a multi-faceted production approach comprising a variety of industrial practices directed towards identifying value-adding processes from the purview of the customer and to enable the flow of these processes at the pull of the customer through the organization (Sanders et al. 2016).

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From a technological point of view, lean production can be regarded as a complement to automation. Zuehlke (2010) suggested that the complexity of the production systems should be reduced by lean practices and stated that relying too much on technology cannot always improve the performance but may make the system more complicated. Lean production suggests five different levels of automation that should be considered when deciding on an appropriate automation strategy, as shown in Table 1 (Rother and Harris 2001). Meanwhile, there is a great divide between level-three and level-four automation. When making the jump to level-four automation, the cost (maintenance, engineering, machines, etc.) often increases while flexibility can decrease.

In fact, applications for the integration of Industry 4.0 into lean production already exist and have been described by the term "lean automation". Lean automation aims for higher changeability and shorter information flows to meet future market demands. Contrary to popular belief, lean production does not exclude automation. According to the automation principle of lean production, repeated and value-adding tasks should be automated. With the term "Low Cost Intelligent Automation (LCIA)", it is suggested that standardized, automated, flexible, and cost-efficient solutions should be favored over customized solutions (Takeda 2006). However, LCIA only focuses on mechanical and electrical systems and does not consider information and communication technology. Both lean production and Industry 4.0 favor decentralized structures over large, complex systems and both aim for small, easy-to-integrate modules with a low level of complexity (Takeda 2006; Kolberg et al. 2016).

Taking into account the above-mentioned manners, this paper emphasizes the relationship between Industry 4.0 and lean manufacturing and proposes a methodology that provides a waste-hunting environment for Industry 4.0 applications. The rest of the paper is organized as follows. In Section "Literature Review", relevant literature is reviewed. The proposed methodology is presented in Section "The Proposed Methodology". Cases combining lean production and automation or Industry 4.0 are described in Section "Automation-Based Lean Production Applications". Finally, the conclusions are presented in Section "Conclusion".

Table 1 Levels of lean automation

Level	Loading machine	Machine cycle	Unloading machine	Transferring part
1	Operator	Operator	Operator	Operator
2	Operator	Automatic	Operator	Operator
3	Operator	Automatic	Automatic	Operator
The great divide (cost and flexibility change drastically)				
4	Automatic	Automatic	Automatic	Operator
5	Automatic	Automatic	Automatic	Automatic

Literature Review

Some research has been performed to emphasize the interaction between lean manufacturing and Industry 4.0. For example, Sanders et al. (2016) analyzed the link between Industry 4.0 and lean manufacturing and investigated whether Industry 4.0 is capable of implementing lean. A methodology has been proposed to integrate lean manufacturing and Industry 4.0 with respect to the supplier, customer, and process as well as human and control factors. The authors also stated that researches and publications in the field of Industry 4.0 hold answers to help overcome the barriers to implementation of lean manufacturing. Similarly, Rüttimann and Stöckli (2016) discussed how lean manufacturing has to be regarded in the context of the Industry 4.0 initiative. Sibatrova and Vishnevskiy (2016) suggested the integration of lean management and foresight while considering the conditions of trends in Industry 4.0 and human and time resources. Doh et al. (2016) not only reviewed the relevant literature from the industrial revolution to the new Industry 4.0 but also considered the need for the use of automation in lean production systems and supply chain characterization with the aim of developing a framework for the integration of information systems and technologies. Blöchl and Schneider (2016) devised a new simulation game with a learning focus on lean logistics with Industry 4.0 components to teach the adequate application of Industry 4.0 technology in production logistics. Veza et al. (2016) carried out an analysis of global and local enterprises based on a literature review and questionnaires in order to develop a Croatian model of the Innovative Smart Enterprise (HR-ISE model). In that study, a selection of six basic lean tools is made and the foundations of a generic configuration of the HR-ISE model are defined. Rauch et al. (2016) presented an axiomatic design-oriented methodology that can be regarded as a set of guidelines for the design of lean product development processes. Linked with Industry 4.0, these guidelines show how a lean and smart product development process can be achieved by the use of advanced and modern technologies and instruments. Similarly, Synnes and Welo (2016) discussed organizational capabilities and tools required to enable transformation into Industry 4.0 through integrated product and process design. Biedermann et al. (2016) stated that maintenance needs to change to meet the requirements of Industry 4.0 and emphasized the necessity of knowledge and data management for improving predictive maintenance performance. Diez et al. (2015) proposed a novel lean shop floor management system, namely the Hoshin Kanri Tree (HKT). The authors also noted that the standardization of communication patterns by HKT technology should bring significant benefits in value stream performance, speed of standardization, and learning rates to the Industry 4.0 generation of organizations.

The Proposed Methodology

First, some brief information about the basic concepts of lean philosophy and lean production systems will be presented. Lean philosophy primarily aims at the elimination of all activities that consume time and resources but do not add value to the physical completion of the products (Womack and Jones 2010). These activities are called waste, or *muda* in Japanese, and are termed as non-value adding activities. Here, the value is defined from the end customers' point of view and is product specific. Hence, a value-adding activity is one that contributes to the physical completion of the product and that the customer may want to pay for (Womack and Jones 2010). According to lean philosophy, the intention is to eliminate wastes. However, sometimes some of the wastes seem to be inevitable with the current technologies or manufacturing assets (Womack and Jones 2010). For instance, while switching from one product to another, a setup time can be unavoidable. Besides, there are other wastes that can be immediately eliminated by implementing lean tools and techniques.

According to lean philosophy, there are seven traditional wastes or non-value adding activities that are common within manufacturing systems. These are over-production, transportation, motion, waiting, inventory, unnecessary processing, and defective parts/products (Ohno 1988). Later, Womack and Jones proposed that products or services that do not meet the customer expectations should be regarded as a kind of waste (Womack and Jones 2010). Overproduction waste includes producing items for which there is no order or requirement (Liker 2004). This is the worst kind of waste, since it causes other wastes to occur. Due to overproduction, a large amount of inventory accumulates, an excess amount of staff is employed, excess storage space is occupied, and so on. Inventory waste is linked to overproduction and also includes excess raw material, work-in process, and finished goods inventory holding. Besides, excess inventory hides problems within the production system such as frequent machine breakdowns, long setup times, and defective parts.

There are several lean tools and techniques that can be utilized for waste elimination. The lean tools and techniques and the wastes that they help eliminate are shown in Table 2.

On the other hand, there exist various advanced Industry 4.0 technologies and cyber-physical systems that can be employed for waste elimination in advanced manufacturing systems. The most fundamental technologies and the associated waste types that these technologies help reduce are depicted in Table 3.

The methodology for implementing these technologies integrated with lean tools is discussed. Figure 1 illustrates this projected relationship between the lean tools and techniques and the advanced technologies. The figure is like a ladder, implying that the lean tools and techniques should be implemented in a sequential manner. First, the layout of the manufacturing system should be converted into a cellular manufacturing system that aims to produce product families through the use of autonomous and dedicated cells that are equipped with all required resources

Table 2 The seven wastes versus lean tools/techniques

	Cellular manufacturing	Setup reduction	Quality control	TPM	Production smoothing	Kanban	WIP reduction	Supplier development	Jidoka	CIM
Overproduction	√	√				√	√	√		
Transportation	√									
Motion	√								√	√
Waiting	√	√		√	√	√		√	√	√
Inventory	√	√	√		√	√	√	√		
Unnecessary processing		√								√
Defectives		√	√	√				√	√	√

Table 3 Seven wastes and advanced Industry 4.0 technologies

	Additive manufacturing (3-d printing)	Augmented reality	Simulation and virtualization	Adaptive robotics	IoT	Data Analytics	Cloud computing
Transportation		√	√	√		√	
Motion		√		√			√
Waiting	√		√	√	√	√	√
Inventory	√				√	√	
Unnecessary processing	√		√	√			√
Overproduction	√				√	√	
Defectives	√	√	√	√	√	√	

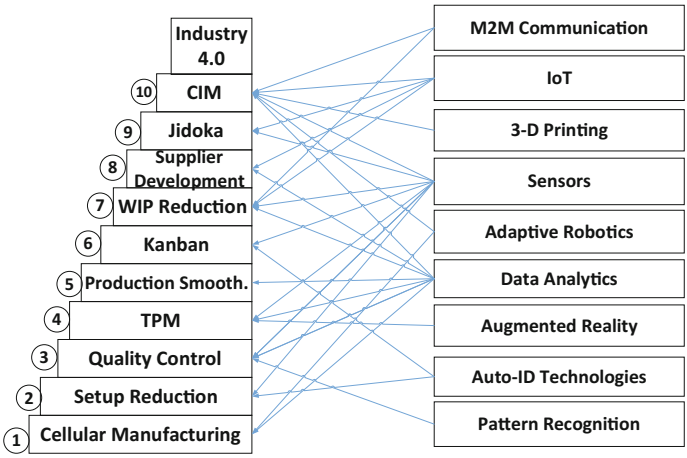

Fig. 1 Lean tools and Industry 4.0 technologies ladder

(Durmusoglu and Satoglu 2011). Besides, adaptive robotics can be employed for enhanced material handling and parts loading–unloading. For setup reduction purposes, sensors that detect the components of the machines such as dies, blades, and so on can speed up the internal setup operations and protect the operators from accidents. Besides, adaptive robotics can also be implemented for setup reduction.

Quality control and foolproof mechanisms (*poka yoke*) are other important aspects of lean production systems. To prevent the production of defective parts and products, pattern recognition augmented reality technologies and sensor applications can be utilized.

Total Productive Maintenance (TPM) aims to improve the overall equipment effectiveness of the machines, which includes reduction of time, speed, and quality losses (Ahuja and Khamba 2008). Augmented reality can be utilized to guide the operators in the performance of maintenance activities. Besides, sensors that keep track of vibration, noise, and heat help operators to detect abnormal conditions before failure.

Production smoothing is a production scheduling activity that aims to produce the same quantities of a part or product on a daily or hourly basis, as far as possible. Data analytics is a suitable tool for analyzing the demand frequency coming from customers.

Kanban is a lean production tool where pull-production control is performed. However, thanks to advanced auto-ID technologies, instead of scanning the barcodes of many kanbans, RFID tags are detected by readers and quick communication between the stages can be achieved.

Better M2M Communication, IoT, sensors and data analytics should be used to reduce Work-in Process (WIP) among machines. Besides, by means of data analytics, the cycle times and failure characteristics of the machines can be analyzed and the buffer area capacities among the machines can be adjusted.

For supplier development purposes, better data analytics should be employed for better analysis of demand data. To achieve better coordination and communication among the supplier and customer parties, IoT technologies should be employed.

Jidoka means automation with a human touch (Liker and Morgan 2006). In other words, the manufacturing system employs automation technologies under the supervision of the workers. So, while implementing *jidoka*, sensors and IoT can be employed.

While converting system into a computer-integrated manufacturing system, M2M communication, sensors, IoT, 3-D printing, adaptive robotics, and data analytics can be employed to obtain more benefit from the advanced manufacturing technologies.

Automation-Based Lean Production Applications

Industry 4.0 technologies and automation can be applied to several methods of lean production. The following section describes examples of possible combinations.

E-Kanban Systems. The digitalization of the kanban system has already been known for several years. Conventional, physical cards for an order-oriented production control are replaced by virtual kanban (Lage and Filho 2010). Depending on the implementation of this so called e-kanban system, missing or empty bins are recognized automatically via sensors.

Automation in Error-Proofing. Magna T.E.A.M. Systems makes widespread use of bar-coding technology to eliminate human error and production mistakes. Operators scan bar codes wrapped around their wrists to ensure that they are assembling the correct product on high-mix production lines. All operators use bar codes to log into their workstations so that there is a record of who is building what part. Electronic work instructions displayed at every workstation address error proofing and serve as a visual aid to operators (Weber 2016).

***Chaku Chaku* Lines**. In 2012, the University of South Denmark, together with the toy manufacturer Lego A/S, developed approaches for integrating automation technology in U-shaped assembly stations, also known as *chaku chaku* lines. In particular, human–machine interaction was the focus of this project. As a result, they developed a local order-management system that shifts typical tasks of ERP systems to employees on *chaku chaku* lines (Bilberg and Hadar 2012). Moreover, the ongoing research project "Lean Intelligent Assembly Automation" also addresses *chaku chaku* lines (Kolberg and Zühlke 2015).

iBin System. In 2013, Würth Industrie Services GmbH & Co. KG presented the optical order system iBin as an extension for kanban bins (Fig. 1). A camera in the module detects the charging level of the bin and iBin wirelessly reports the status to an inventory control system. Besides, iBin is also able to send orders automatically to suppliers. As a result, buffer stock can be reduced and spare parts can be scheduled in an order-oriented way (Würth Industrie Service GmbH & Co. KG 2013).

QR Code Integrated Milk-Run System. Wittenstein AG and BIBA—Bremer Institut für Produktion und Logistik GmbH, among others, are working on a flexible

material supply system for production lines through the state-funded project "CyProS". Instead of using fixed intervals, an IT system calculates round-trip intervals for the transport system based on real-time demands. In the first prototype, collection of data during this so-called milk run is done by scanning QR codes. Interaction with employees of the transport system is realized by conventional tablet PCs (Kolberg and Zühlke 2015).

Pick-by-Vision. In the DHL application, warehouse workers see the physical reality of the aisles and racks in front of them just as they could if they were not wearing head-mounted displays, but this is augmented by a superimposed AR code in the form of a graphical work instruction, which appears after they scan the barcode at the storage location with their smart glasses. This code tells the workers where to go, how many items to pick, and even where to place them in their trolleys. When the pilot project is complete, DHL evaluates the operational suitability and economic feasibility of adopting augmented-reality vision picking. Meanwhile, its trends-research team has already identified other logistics activities that could be enhanced by a judicious dose of AR technology (Url-1).

Augmented Reality-Based Work Standardization. The project "MOON" (asseMbly Oriented authOring augmeNted reality) is being developed by Airbus Military. MOON uses 3D information from the industrial digital mock-up to generate assembly instructions and their deployment by applying augmented reality technology. A prototype was developed for the electrical harness routing in Frame 36 of the Airbus A400M (Servan et al. 2012).

Plug'n'Produce Workstations. Industry 4.0 could furthermore support lean production's requirement for a flexible, modular production. For several years, SmartFactoryKL has demonstrated modular workstations based on standardized physical and IT interfaces, which can be flexibly reconfigured to new production lines via Plug'n'Produce. According to the Single-Minute-Exchange-of-Die (SMED) principle, the setup time should be reduced to less than 10 min (Kolberg et al. 2016).

Automatic Mold-Change System: At K 2016 in Dusseldorf, Staubli of Germany (U.S. office in Duncan, S.C.) demonstrated complete hands-off mold changing in less than 2 min, and company spokespersons said the system could reduce that to 1 min. A mold table on rails carried a preheated mold into position beside the press. A sensor in the cart read the mold setup parameters from a chip in the mold. For the mold already in the press, all power and data connections were disconnected automatically within 3 s (Url-2).

Digitized *Heijunka*. Besides the flexible material supply system, Wittenstein AG digitized the Heijunka-Board. *Heijunka*, also known as levelling, describes a method for converting customer orders into smaller, recurring batches (Verein Deutscher Ingenieure e.V. 2013) (Kolberg et al. 2016).

Predictive Maintenance. Condition monitoring, data analytics, and early prediction of failures increase the uptime and overall equipment effectiveness (Bal and Satoglu 2014). For this purpose, predictive maintenance practices in manufacturing facilities have increased. In the oil and gas industry, where equipment is in remote

locations, oil fields have been digitized by means of sensors. The name of the software platform is MAPR Distribution Including Hadoop® (MAPR 2015).

Conclusion

The approach used in this paper answers a significant part of this question and illustrates that lean manufacturing and Industry 4.0 are not mutually exclusive but can be seamlessly integrated with each other for successful production management. This paper analyzes the researches and publications concerned in the field of Industry 4.0 and identifies how they act as supporting factors for implementation of lean manufacturing.

Industry 4.0 will not solve the problems of mismanaged and weakly organized manufacturing systems. Its tools should be applied to lean activities that are performed successfully before automatization. In addition, effective information flow should be maintained effectively before introducing ICT. In this context, keeping the data in the correct and current manner is a critical success factor in both Industry 4.0 and lean production.

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Selecting the Best Strategy for Industry 4.0 Applications with a Case Study

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Abstract In this paper, we try to find the best strategy for Industry 4.0 implementation. For this aim, we determine the aggregated strategies for applying this concept and criteria that are used to select the best strategy. With the criteria set out in this context, basic strategies should be applied as a priority, considering for example human resources, work organization and design, information systems, and effective use of resources, and the development of new business models and standardization are specified. Since this selection is a process in which many different measures need to be considered, multi-criteria decision-making (MCDM) methods based on AHP-VIKOR methodologies have been applied to find the best strategy. Fuzzy set theory was beneficial for coping with uncertainties in the selection process.

Keywords Fuzzy sets · Industry 4.0 · Multi-criteria decision making
Strategy selection

Introduction

The world has changed as fast as it has ever existed since the industrial revolution. This revolution has been followed by second and third generations, called Industry 2.0 and Industry 3.0, in order to able to meet the increases in demand that have accompanied human population growth. From that moment, investments in industry and industrial products and their returns have reciprocally increased in excessive amounts. Today, we are taking steps to transition to a new concept called Industry 4.0 in order to bring this development further to meet the demands of the growing human population. This concept aims to introduce technical advances such as wireless network systems, cyber-physical systems, the Internet of Things, and cloud computing in industry. Not only scientists but also politicians have been evaluating

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this transition process since the 2000s. As a result of this evaluation process, many strategies have been suggested to select in a systematic way. Since this process considers many criteria, both qualitative and quantitative, which are used for comparison of strategy alternatives, it is very difficult for experts to make decisions. In order to deal with this multi-expert and multi-criteria environment, we will decide how many criteria exist in it, build a set of possible strategies, collect the appropriate information about strategies with respect to criteria, and evaluate them to reach the goal by using multi-criteria decision making (MCDM) (Tzeng and Huang 2011). This kind of evaluation requires the utilization of expert systems so that data can be expressed more explanatory to handle uncertainties, and thereby more knowledgeable decisions can be taken. There are many models dealing with the uncertainty of strategy problems in the literature. Among these models, stochastic selection models (Klein et al. 2009), heuristic optimization models (Beloglazov et al. 2012), simulation models (Goh et al. 2007), and fuzzy MCDM (Kaya and Kahraman 2011; Opricovic and Tzeng 2004) are the most frequently applied techniques. In this paper, an integrated fuzzy MCDM methodology is suggested for the Industry 4.0 strategy selection problem. There are several integrated fuzzy MCDM methodologies in the literature, such as fuzzy Analytic Network Process (ANP) and the fuzzy Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE) (Vinodh et al. 2014); fuzzy Analytic Hierarchy Process (AHP) and fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) (Chen and Chen 2010); fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) and Fuzzy ANP and Fuzzy TOPSIS (Gorecky et al. 2017). In this paper, a fuzzy MCDM methodology consisting of AHP and VIKOR methods is used to determine the best Industry 4.0 strategy. For this aim, the criteria weights have been calculated by using fuzzy AHP and fuzzy VIKOR has been used to determine the best strategy. The rest of this paper is organized as follows: Section "Literature Review" presents the literature review concerning Industry 4.0. Section "The Proposed Methodology" presents the proposed model. Section "Real Case Study" describes a real case study for the selection of the most appropriate Industry 4.0 strategy. Finally, the obtained results and future research suggestions are discussed in Section "Conclusion and Suggestions for Future Work".

Literature Review

Industry 4.0 has drawn much attention by academicians and researchers in recent years and the number of studies has increased dramatically. Some of the studies of Industry 4.0 can be summed up as follows. Gorecky et al. (2017) presented the design, implementation, and presentation of a virtual training system, VISTRA, for future factories (Grundstein et al. 2017). They selected the automotive industry

because it is one of the leading industries adopting future factory concepts and technologies such as cyber-physical systems and the Internet of Things. Grundstein et al. (2017) performed a study of the autonomous production control (APC) method in job shop manufacturing (Barbosa et al. 2017). This control method integrates all control tasks (order release, sequencing, and capacity control) to meet due dates. They compared the APC method with other method combinations and found that the APC method has the potential to meet the due dates better. Barbosa et al. (2017) studied two key concepts of Industry 4.0 vision, namely Cyber Physical Systems (CPSs) and Intelligent Product (IP). They suggested that the integration of these two approaches is beneficial for future smart industries. They presented the integration of these approaches via two real world cases. Fleischmann et al. (2017) mentioned new methodologies for monitoring systems based on CPSs and presented a condition monitoring system for a handling unit in a test cell. Kolberg et al. (2016) presented an ongoing work concerning the digitization of lean production methods using CPS. Lean production is inadequate for meeting the market demand for customized products. Industry 4.0 technologies are combined with lean production, which is called lean automation. They gave the example of a kanban method to explain their work. Sepulcre et al. (2016) mentioned that the Industry 4.0 concept targets the interconnection and computerization of traditional industries to improve their adaptability and utilize their resources efficiently. Oesterreich and Teuteberg (2016) reviewed applications of technologies related to Industry 4.0 in the construction industry. They evaluated the literature from different perspectives like political, economic, social, technological, environmental, and legal ones and gave recommendations for future research. Chang and Wu (2016) mentioned that Industry 4.0 offers smart productivity based on the industrial Internet of Things, big data, and CPSs in manufacturing industries. Rennung et al. (2016) analyzed the service industry from the perspective of Industry 4.0. They interviewed experts and evaluated the applicability of scientific approaches to service networks for the project “Industry 4.0”. Veza et al. (2015) studied a partner-selection problem. They used the PROMETHEE method to evaluate virtual enterprises. The problem was applied to a production network of smart factories in Industry 4.0. Forstner and Dümmler (2014) claimed that the smart factory is the central element of Industry 4.0 and established a foundation value to enable the integration of value chains across companies.

The Proposed Methodology

We apply a fuzzy MCDM approach to detect the best strategy for applying the Industry 4.0 concept. The following subsections explain the adopted methodology in the fuzzy environment.

Fuzzy Set Theory

Fuzzy set theory was introduced by Zadeh (1965) as a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function that assigns to each element a grade of membership varying in a closed interval ranging from zero to one.

Fuzzy Analytic Hierarchy Process

The AHP was proposed by Saaty (1980) to solve complex multi-criteria decision problems (Rezaie et al. 2014; Kaya and Kahraman 2014) and is based on the concept of simplifying complex decision problems into elements (Zare et al. 2016). In this paper, Buckley's fuzzy AHP (1985) is used to determine the weights of criteria in order to select the best strategy in Industry 4.0 (Hsieh et al. 2004; Kahraman et al. 2014).

Fuzzy VIKOR

VIKOR was developed by Opricovic and Tzeng to find a compromise solution for MCDM issues. This method has been applied to many areas such as risk assessment (Gupta et al. 2016), machine selection (Wu et al. 2016), plant location selection (Gul et al. 2016), supplier selection (Kaya and Kahraman 2010), and so on. VIKOR is an MCDM method that ranks alternatives and determines the compromise solution that is the closest to the "ideal" (Opricovic and Tzeng 2004). The steps of the fuzzy VIKOR methodology are as follows (Tuzkaya et al. 2010; Kaya and Kahraman 2010):

n represents the number of feasible alternatives, $A_i = \{A_1, A_2, \ldots, A_n\}$ and $\tilde{x}_{ij}$ is the rating of alternative A_i with respect to criterion j.

Step 1: Construct the fuzzy multi-criteria decision-making problem in matrix format:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{11} & \ldots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \ldots & \tilde{x}_{2n} \\ \vdots & \vdots & & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \ldots & \tilde{x}_{mn} \end{bmatrix} \tag{1}$$

Step 2: Determine the best $\tilde{f}_j^* = (l_j^*, m_j^*, u_j^*)$ and worst $\tilde{f}_j^- = (l_j^-, m_j^-, u_j^-)$ values of all criterion functions, $j = 1, 2, \ldots, m$.

$\tilde{f}_j^* = \max_i \tilde{x}_{ij}, \tilde{f}_j^- = \min_i \tilde{x}_{ij}$, if the jth criterion belongs to the benefit criteria,

$\tilde{f}_j^* = \min_i \tilde{x}_{ij}, \tilde{f}_j^- = \max_i \tilde{x}_{ij}$, if the jth criterion belongs to the cost criteria.

Step 3: Compute the normalized fuzzy difference $\tilde{d}_{ij}$, j = 1, …, m and i = 1, …, n.

$$\tilde{d}_{ij} = (\tilde{f}_j^* \Theta \tilde{x}_{ij})/(\tilde{f}_j^* \Theta \tilde{f}_j^-) \tag{2}$$

if the jth criterion belongs to the benefit criteria,

$$\tilde{d}_{ij} = (\tilde{x}_{ij} \Theta \tilde{f}_j^*)/(\tilde{f}_j^* \Theta \tilde{f}_j^-) \tag{3}$$

if the jth criterion belongs to the cost criteria.

Step 4: Calculate the values $\tilde{S}_i = (S_i^l, S_i^m, S_i^u)$ and $\tilde{R}_i = (R_i^l, R_i^m, R_i^u)$, j = 1, 2, …, m by using the equations below:

$$\tilde{S}_i = \sum_{j=1}^{m} \oplus (\tilde{w}_j \otimes \tilde{d}_{ij}) \tag{4}$$

$$\tilde{R}_i = \max_j (\tilde{w}_j \otimes \tilde{d}_{ij}) \tag{5}$$

where $\tilde{S}_i$ refers to the measure of separation of A_i from the fuzzy best value and $\tilde{R}_i$ to the measure of separation of A_i from the fuzzy worst value.

Step 5: Defuzzify the values of $\tilde{S}_i$ and $\tilde{R}_i$ by using the graded mean integration approach; for triangular fuzzy numbers, the fuzzy number $\tilde{C} = (c_1, c_2, c_3)$ can be transformed into a crisp number by employing the equation below:

$$P(\tilde{C}) = C = \frac{c_1 + 4c_2 + c_3}{6} \tag{6}$$

Step 6: Calculate the values Qi, i = 1, 2, …, n by using the equation below:

$$Q_i = v(S_i - S^*)/(S^- - S^*) + (1 - v)(R_i - R^*)/(R^- - R^*) \tag{7}$$

where $S^* = \min S_i$, $S^- = \max_i S_i$, $R^* = \min R_i$, and $R^- = \max_i R_i$ and $v \in [0, 1]$ represents the weight for the decision-making strategy of maximum group utility, whereas $1 - v$ means the weight of the individual regret.

Step 7: Rank the alternatives according to the values of S, R, and Q in decreasing order.

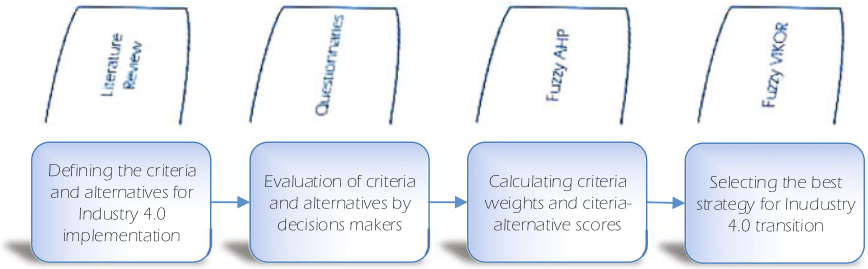

Fig. 1 Flowchart of the proposed methodology

Step 8: Propose a compromise solution, called alternative $A^{(1)}$, which is the best ranked solution according to the measure Q(minimum) if the following two conditions are satisfied:

Condition 1 The acceptable advantage $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$, where $A^{(2)}$ is the alternative with second position in the ranking list according to Q and DQ = 1/(n − 1).

Condition 2 For acceptable stability in decision making, alternative $A^{(1)}$ must also be the best ranked according to S and/or R.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives $A^{(1)}$ and $A^{(2)}$ if only the condition C2 is not satisfied, or
- Alternatives $A^{(1)}$, $A^{(2)}$,…, $A^{(n)}$ if the condition C1 is not satisfied; $A^{(n)}$ is determined by the relation $Q\left(A^{(n)}\right) - Q\left(A^{(1)}\right) < DQ$ for the maximum n (the positions of these alternatives are "in closeness").

A flowchart of our suggested methodology can be seen in Fig. 1.

Real Case Study

This paper aims to find the best strategy for the implication of the Industry 4.0 initiative of companies. In the selection process, fuzzy MCDM methodology is applied to obtain results that are closer reality. First of all, the criteria that are used to evaluate the strategies for Industry 4.0 are defined. Figure 2 shows the hierarchy of criteria and alternatives that are considered in the scope of this paper. Ten criteria and five alternatives are determined for this study. Then, the weights of the criteria are calculated to find their importance levels in the decision-making process. In this phase, fuzzy AHP methodology with the evaluations obtained from three experts is used. These experts are the people who study Industry 4.0 in their academic fields. They were asked to evaluate the criteria according to a scale presented on a

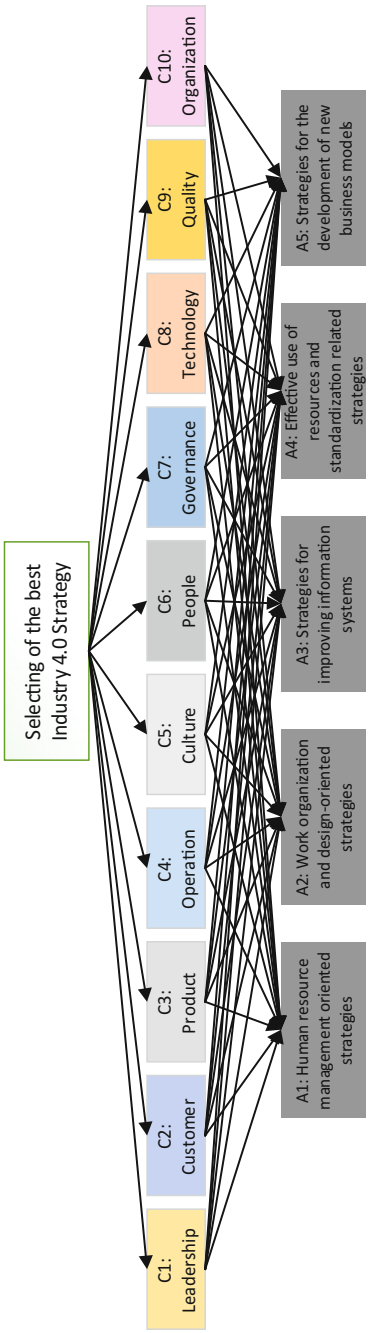

Fig. 2 Hierarchical representation of the criteria and alternatives

Table 1 Weights of each criterion

Criterion	Weights
*C*1	(0.134, 0.199, 0.268)
*C*2	(0.072, 0.112, 0.170)
*C*3	(0.063, 0.072, 0.087)
*C*4	(0.066, 0.095, 0.140)
*C*5	(0.048, 0.072, 0.106)
*C*6	(0.027, 0.034, 0.058)
*C*7	(0.077, 0.094, 0.124)
*C*8	(0.077, 0.097, 0.123)
*C*9	(0.109, 0.140, 0.169)
*C*10	(0.062, 0.084, 0.117)

questionnaire. After that, we checked the consistency of evaluations for each expert. If there was any inconsistent evaluation, the questionnaires were sent back to the experts for reevaluation. This process was repeated until all the evaluations were consistent, which meant that the consistency ratio was lower than 0.1.

The fuzzy AHP process is conducted to calculate the criteria weights. Table 1 shows the weights in triangular fuzzy numbers. According to the results, criterion 1, "*Leadership*", was determined as the most important criterion. The least important one was "C_6: *People*".

After obtaining the criteria weights, fuzzy VIKOR steps were initiated. Firstly, experts were consulted again to score the alternatives according to the criteria. Linguistic expressions were converted to triangular fuzzy numbers according to the scale presented in the proposed methodology section. Then three decision makers' evaluations were aggregated and the best and worst values for each criterion were revealed. Then the S, R, and Q values for each alternative were calculated. Table 2 shows the S, R, and Q values.

When we analyze the results, we can see that the alternative that has the minimum Q value is Alternative 3. This alternative also takes the minimum S and R values, which means that Condition 1 is satisfied. When we look at the acceptable advantage, $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) \geq DQ$, where $A^{(2)}$ is the alternative with second position in the ranking list according to Q,

Table 2 Resulting values for each alternative

Alternative	*S* Value	*R* Value	*Q* Value
*A*1	1.044	0.409	0.560
*A*2	1.232	0.423	0.775
*A*3	0.804	0.169	0.000
*A*4	0.991	0.362	0.444
*A*5	1.279	0.560	1.000

$$DQ = 1/(n-1) = 1/(5-1) = 0.25$$
$$Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right) = 0.444 - 0.000 = 0.444$$

Because the value of $Q\left(A^{(2)}\right) - Q\left(A^{(1)}\right)$ is bigger than DQ, we also claim that the best alternative is found as to be Alternative 3, "*Strategies for improving information systems*". The worst alternative is the one that does not need to be considered in the first stages, Alternative 5, "*Developing new business models*".

Conclusion and Suggestions for Future Work

In this paper, we aimed to find the best strategy for transition to Industry 4.0 by using a fuzzy MCDM with the integration of fuzzy AHP and VIKOR methodologies. To this end, criteria and alternatives were determined from experts' ideas and a literature review. The criteria used to evaluate the strategies were weighted by using fuzzy AHP methodology and the impacts of alternatives on criteria were provided by experts for application to fuzzy VIKOR. The most important criterion in the decision-making process was determined to be leadership. As a result of the work, it emerged that the best alternative was the strategies designed to improve information systems. It is not surprising that the alternative of developing information systems, which is also referred to as the Internet of Things, takes first place in the adoption of Industry 4.0. The last alternative was found to be developing new business models. The development of new business models is also very important in the implementation of this concept, but it does not appear to be a priority strategy.

As suggestions for future papers, different MCDM methods can be used, extensions of fuzzy sets can be considered, or the criteria and alternatives can be divided in more detail.

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Musculoskeletal Discomfort Experienced by Children and Adolescents During the Use of ICT: A Statistical Analysis of Exposure Periods and Purposes

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Abstract The risk of development of musculoskeletal discomfort problems among children and adolescents is high as the development of their musculoskeletal system is still continuing. Therefore, it is very important to learn the habits and attitudes of children and adolescents, the location and duration of the use of these technologies, and the relationship between musculoskeletal discomforts. This study aims to investigate the relationship between duration of daily exposure of children and adolescents to Information and Communication Technology (ICT) devices and the musculoskeletal discomfort experienced. A two-part questionnaire, which are adopted by Dutch Musculoskeletal Discomfort Questionnaire (DMQ) and the Student Specific Cornell Musculoskeletal Discomfort Questionnaire (SS-CMDQ), was used to gather data from children and adolescents in public and private secondary and high schools in Northern Cyprus. The survey findings showed that the participants experienced discomfort mostly in the neck, upper back, lower back, and shoulders. The correlation analysis indicated that there is a relationship between prolonged use of ICT devices for many hours and musculoskeletal discomfort. Also, it was found that there is a significant relationship between daily use of desktop, laptop, or tablet computers for different purposes (activities) and musculoskeletal discomfort. The musculoskeletal discomfort was observed to occur mostly due to the use of ICT devices for communication, surfing the Internet, reading, and writing. The results of the analysis showed that shoulder, upper back, upper arm, forearm, and hand muscles are affected by the use of ICT devices.

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Information communication technology

Introduction

Information and Communication Technology (ICT) devices, such as laptops, desktops, tablet computers, smartphones, and gaming devices, have become an indispensable part of daily life. Nowadays, children and adolescents start using these devices at a very early age. Thus, society becomes technologically well-equipped as a result of engaging with such devices from an early age. However, as the development of the musculoskeletal system of children and adolescents is ongoing, the risk of developing musculoskeletal discomfort problems increases. Poor habits in the use of ICT devices result in musculoskeletal discomfort problems from early ages. If they are disregarded, more serious consequences are inevitable. Therefore, it is very important to learn the habits and attitudes of children and adolescents, the location and duration of the use of these technologies, and the relationship between musculoskeletal discomforts. If these relationships are understood, recommendations could be made for the development of healthy habits when using these technologies to avoid musculoskeletal discomfort at early ages. This study aims to gather data about the habits and experiences of musculoskeletal discomfort of children and adolescents while using ICT devices and to investigate the relationship between the daily use of such technologies for different activities and musculoskeletal discomfort experienced in their body regions.

Literature Review

For many years, many researchers have been investigating the physical effects of computer use on the musculoskeletal systems of children. The aim of the majority of studies was to investigate muscle activities related to computer use by children and to learn the risk factors resulting in musculoskeletal discomfort. Another aim of these studies was to investigate differences and similarities between muscle activities when using old technology systems and computer-based technology (Oates et al. 1998; Leaser et al. 1998; Ciccarelli et al. 2006; Breen et al. 2007; Straker et al. 2008a, b; Maslen and Straker 2009; Straker et al. 2009; Brink et al. 2009; Harris 2010; Zovkic et al. 2011).

Recent studies on ergonomics and physiotherapy have found that the use of ICT by children and adolescents is associated with the musculoskeletal discomfort they experience (Harris and Straker 2000; Greig et al. 2005; Sommerich et al. 2007; Straker et al. 2008b). Moreover, these studies showed that discomfort occurring in the neck region is one of the signs of musculoskeletal disorder.

Harris and Straker (2000) mentioned that children's use of portable computers with prolonged poor posture leads to musculoskeletal discomfort. They found an association between musculoskeletal discomfort and duration of exposure to information technology. Zovkic et al. (2011) indicated that health problems are exacerbated by prolonged computer use. Among the health problem recorded were wrist pain, drowsiness, dry throat, eye irritation, nose irritation, visual problems, headaches, and neck and back pain. Straker et al. (2015) conducted a study to analyze the muscular activities of children using tablet computers and other activities (playing with toys and watching TV). The results indicated that the use of desktop computers by children increased the risk of musculoskeletal discomfort. Tablet computers introduced even less movement and muscle activity, in addition to bad spinal posture, compared to other children activities. Woo et al. (2016) showed that children and adolescents experienced a risk factor for musculoskeletal discomfort similar to that of adults when they used computer devices.

However, very few studies have investigated the relationship between duration of daily exposure of children and adolescents to ICT and musculoskeletal discomfort. The aim of this study is to fill this gap and learn about the experiences of musculoskeletal discomfort among children and adolescents.

The study also looks at the correlation between subjects' musculoskeletal discomfort and ICT use for different daily activities such as communication, gaming, watching films, studying at school, studying outside school, surfing the Internet, reading, and writing.

Method

A two-part questionnaire comprising the Dutch Musculoskeletal Discomfort Questionnaire (DMQ) and the Student Specific Cornell Musculoskeletal Discomfort Questionnaire (SS-CMDQ) were used to gather data from children and adolescents in public and private secondary and high schools in Northern Cyprus.

In the first part, a questionnaire that was designed by modifying the DMQ (Hildebrandt et al. 2001) was used to collect data on the children's and adolescents' demographic variables, attitudes and habits related to ICT use, and experiences when using these devices as well as information related their lifestyles.

In the second part, the SS-CMDQ (Erdinç and Ekşioğlu 2009a, b), which is a modified version of the Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) (CUergo 1999), was used to learn about frequency of pain or discomfort during the past week and to check whether the academic activities of respondents were interrupted by any discomfort experienced.

The research was approved by the Scientific Research Ethics Committee (Eastern Mediterranean University, decision number 2014/04-01). In addition, this study was granted by the General Secondary Education Department of the Ministry of Education to gather data from schools in northern Cyprus.

According to the *Statistical Yearbook* (Ministry of Education of the Turkish Republic of Northern Cyprus, Department of Common Services for Education, 2014), 18,249 students were enrolled in northern Cyprus in public and private secondary and high schools at the time of the study. By using Yamane's formula, a sample size of 391 respondents was found with a 95% confidence level and 5% sampling error. Five-hundred questionnaires were distributed and 406 completed questionnaires were collected, giving a response rate of 81%. The questionnaires were filled in during computer classes or in classrooms; filling them in took each respondent approximately 20–30 min. Two versions of the questionnaires (Turkish and English) were used because of the different nationalities of students in the sample.

The collected data were analyzed using SPSS for Windows (version 21.0); bivariate correlation analysis was used to investigate the significant relationships between the musculoskeletal discomforts experienced by participants in regions of their bodies. The following variables were tested:

- Total hours of daily exposure of children and adolescents to ICT devices.
- Cumulative years of exposure to desktop, laptop, or tablet computers.
- Average number of hours of daily exposure of children and adolescents to desktop, laptop, or tablet computers.
- Use of desktop, laptop, or tablet computers for communication, gaming, watching films, studying outside school, studying at school, surfing the Internet, reading, and writing.
- Many hours of daily smartphone usage.

In the analyses, Spearman correlation coefficients were utilized.

The responses of the subjects who filled in the second part of the questionnaire to state how often aches, pains, and discomfort were experienced in 20 body regions were used to analyze musculoskeletal discomfort they experienced in their body regions.

The first part of the questionnaire aimed to investigate the purposes for which the respondents used these devices and the duration of use. The correlation between uses desktop, laptop, or tablet computer usage for communication, gaming, watching films, studying outside school, studying at school, surfing the Internet, reading, and writing and musculoskeletal discomfort experienced in their body regions was checked. In addition, the average number of hours of daily use of desktop, laptop, or tablet computers and total number of hours of daily use of ICT devices were calculated. These new variables were used to investigate the relationship between musculoskeletal discomfort and long periods of use of these devices. The questionnaire was used to determine whether the total duration (in years) of use of desktop, laptop, or tablet computers is related to musculoskeletal discomfort. The questionnaire was also utilized to find out the smartphone use behaviors of the respondents.

Results

Among the 406 participants, 50.7% were male and 49.3% were female. The participants were aged between 11 and 20 years. It was stated by 43.8% of participants that they performed at least one of the activities for more than 3 h per day using one of the ICT devices. In addition to daily desktop, laptop, or tablet computer use, 43% of participants mentioned that they used their smartphones for many hours in their daily lives. An interesting result is that 70.8% of the participants used at least two different types of devices in their daily lives. Table 1 presents the percentages and numbers regarding participants' preferences for devices.

The participants also indicated the type of device, duration of daily use, and the purpose of use in the questionnaire. Table 2 presents a summary of participants' responses regarding the purpose of using desktop, laptop, or tablet computers.

Another result related to total years of ICT device use was that most of the participants indicated that they had been using ICT devices for at least one year. It was stated by 55% of participants that they had been using desktop computers for at least a year, while 67.5% reported that they had been using laptop computers for at least a year, and 58% stated that they have been using tablets for at least a year.

Musculoskeletal discomfort experienced by participants was determined through the second part of the questionnaire. The participants stated that they mostly experienced musculoskeletal discomfort in the neck (42.36%), upper back (41.12%), lower back (38.67%), and right shoulder (22.41%) regions.

Five different correlation analyses were conducted to test the hypothesis. It was found that there was a weak but significant relationship between musculoskeletal discomfort experienced in their body regions and total hours of daily exposure of children and adolescents to ICT devices. The results indicated that the participants who used devices for less than 1 h per day experienced discomfort in their upper arms (both left and right). In addition, there was no significant relationship for those participants who used devices for 1–2 h daily. The participants who used ICT devices for 2–3 h per day felt more discomfort in their thigh (left) and shoulders (both left and right).

Table 1 Statistics drawn from the question "Do you use a tablet, laptop, or desktop PC or all of them in your daily life?"

Computer usage preferences of the respondents in daily life	Percentage (%)	Number
Tablet only	8.9	36
Laptop only	15.0	61
Desktop only	5.4	22
Desktop and laptop	9.9	40
Laptop and tablet	20.2	82
Desktop and tablet	11.1	45
All	29.6	120

Table 2 Average number of hours of daily laptop, desktop, or tablet computer usage

Purpose	Device	None	Less than 1 h	1–2 h	2–3 h	More than 3 h
Communication	Laptop	42.86%	28.82%	17.00%	5.42%	5.91%
		174	117	69	22	24
	Desktop	66.50%	17.73%	10.59%	2.96%	2.22%
		270	72	43	12	9
	Tablet	43.10%	21.43%	13.30%	10.10%	12.07%
		175	87	54	41	49
Gaming	Laptop	52.96%	23.15%	14.04%	5.17%	4.68%
		215	94	57	21	19
	Desktop	65.27%	23.15%	9.85%	4.43%	7.39%
		265	53	40	18	30
	Tablet	46.31%	21.92%	15.76%	7.88%	8.13%
		188	89	64	32	33
Watching films	Laptop	44.09%	18.72%	17.73%	11.82%	7.64%
		179	76	72	48	31
	Desktop	68.47%	11.08%	10.34%	6.16%	3.94%
		278	45	42	25	16
	Tablet	63.55%	13.79%	13.55%	4.43%	4.68%
		258	56	55	18	19
Studying outside school	Laptop	52.46%	25.62%	16.26%	3.45%	2.22%
		213	104	66	14	9
	Desktop	71.67%	13.79%	8.37%	3.45%	2.71%
		291	56	34	14	11
	Tablet	65.52%	19.95%	7.64%	3.94%	2.96%
		266	81	31	16	12
Using laptop, desktop, or tablet at school for lectures	Laptop	72.41%	16.01%	7.64%	1.97%	1.97%
		294	65	31	8	8
	Desktop	62.56%	24.88%	8.87%	2.22%	1.48%
		254	101	36	9	6
	Tablet	79.31%	13.05%	4.68%	0.99%	1.97%
		322	53	19	4	8
Using laptop, desktop, or tablet for surfing the Internet	Laptop	46.80%	21.92%	16.50%	6.90%	7.88%
		190	89	67	28	32
	Desktop	68.97%	11.58%	11.08%	3.20%	5.17%
		280	47	45	13	21
	Tablet	45.07%	17.49%	18.23%	8.87%	10.34%
		183	71	74	36	42

(continued)

Table 2 (continued)

Purpose	Device	None	Less than 1 h	1–2 h	2–3 h	More than 3 h
Reading	Laptop	75.37%	14.78%	6.16%	2.71%	0.99%
		306	60	25	11	4
	Desktop	82.02%	12.32%	3.69%	1.23%	0.74%
		333	50	15	5	3
	Tablet	62.32%	19.95%	12.32%	2.22%	3.20%
		253	81	50	9	13
Writing	Laptop	66.50%	20.94%	8.37%	1.97%	2.22%
		270	85	34	8	9
	Desktop	78.57%	11.82%	6.90%	1.23%	1.48%
		319	48	28	5	6
	Tablet	74.63%	13.05%	7.88%	1.72%	2.71%
		303	53	32	7	11

The correlation analyses also showed that there was a weak but significant correlation between cumulative years of exposure to tablet computers and discomfort experienced in the (left) shoulder region. Furthermore, cumulative years of exposure to desktop computers and discomfort experienced in the upper back region were also weakly correlated. There was no significant relationship between cumulative years of exposure to laptop computers and musculoskeletal discomfort experienced in the body regions of participants.

The third correlation analysis tested the relationship between average number of hours of daily exposure of children and adolescents to desktop, laptop, or tablet computers and musculoskeletal discomfort experienced in their body regions. The results indicated that there was a weak correlation between average number of hours of daily exposure of children and adolescents to desktop and laptop computers and some body regions. However, there was no correlation between the average number of hours of daily exposure of children and adolescents to tablet computers and musculoskeletal discomfort experienced in their body regions. The correlation and significant values are shown in Table 3.

Table 4 illustrates the results of the correlation analysis to test whether there were significant correlations between desktop, laptop, or tablet computer usage for communication, gaming, watching films, studying outside school, studying at school, surfing the Internet, reading, and writing and musculoskeletal discomfort experienced in body regions. The results obtained from the analysis showed that there were weak but significant correlations between the variables.

The results also proved that there was no correlation between musculoskeletal discomfort experienced in body regions and many hours of daily smartphone use.

Table 3 Summary of correlations and significant values

Device	Body region	Spearman's rho correlation
Laptop	Lower back	0.117*
	Hips/buttocks	0.216**
	Knee (right)	0.145*
	Knee (left)	0.131*
	Lower leg (right)	0.153**
	Lower leg (left)	0.130*
Desktop	Upper arm (right)	0.144
	Upper arm (left)	0.158
	Thigh (left)	0.142

*$p < 0.05$; **$p < 0.001$

Discussion

The current study analyzed the relationship between duration of daily exposure of children and adolescents to ICT and musculoskeletal discomfort experienced. The participants indicated that frequently felt discomfort, which occurred mostly in the neck, upper back, lower back, and shoulder regions. The results of Sommerich et al. (2007) and Straker et al. (2008a, b), who investigated children's and adolescents' use of ICT, also support these findings.

This study showed that there is a relationship between the average number of hours of daily exposure of children and adolescents to desktop and laptop computers and discomfort experienced in the lower back, upper arm, thigh, lower leg, hip, and knee regions. Korpinen et al. (2015) pointed out that pain, numbness, and aches were mostly experienced in the hip and lower back regions. In addition, Zovkic et al. (2011) showed that prolonged computer usage increases health problems such as wrist pain, drowsiness, dry throat, eye irritation, nose irritation, visual problems, headaches, and neck and back pain. The results of this study also provided similar findings.

An important finding of the current research was that there is a significant relationship between daily use of desktop, laptop, or tablet computers for different purposes (activities) and experiencing musculoskeletal discomfort. This result was also verified by Lin et al. (2015), Sobhy et al. (2015), and Kingston et al. (2016). Lin et al. (2015) showed that prolonged touch-typing affects the upper extremities and neck. Kingston et al. (2016) pointed out that reading tasks performed using tablet computers affected the wrists, elbows, and shoulders. Sobhy et al. (2015) investigated wrist and neck discomfort experienced during tablet usage for the purpose of gaming. The results showed that the prolonged use of tablets for gaming increased muscle activity and that there was a relationship between gaming activities and discomfort experienced in the neck and wrist.

Table 4 Summary of correlations between ICT usage and musculoskeletal discomfort experienced by participants

		Communication	Studying outside school	Surfing the Internet	Reading	Writing
Tablet	Shoulder (right)			0.126*	0.174**	
	Shoulder (left)			0.128*	0.141*	
	Upper back				0.182*	
	Upper arm (right)	0.133*	0.118*			
	Upper arm (left)					0.154**

		Communication	Gaming	Studying outside school	Surfing the Internet	Reading
Laptop	Shoulder (right)		0.138*			
	Shoulder (left)				0.118*	
	Forearm (right)		0.175**			
	Hand/fingers (right)		0.127*			
	Hand/fingers (left)		0.160**			
	Hips/buttocks			0.166**		0.216**
	Knee (right)		0.149**	0.164**		
	Knee (left)	0.230**				
	Lower leg (right)	0.138*			0.136*	0.133*
	Lower leg (left)		0.137*		0.157**	

		Communication	Gaming	Watching Films	Studying outside school	Surfing the Internet
Desktop	Shoulder (left)			0.202*	0.150*	
	Shoulder (right)			0.130*		
	Upper arm (right)	0.133*		0.195*		
	Upper arm (left)	0.138*		0.212*		
	Lower back			0.130*		
	Forearm (left)			0.139*		
	Wrist (left)			0.138*		

(continued)

Table 4 (continued)

		Communication	Gaming	Watching Films	Studying outside school	Surfing the Internet
	Hand/fingers (right)			0.142*		
	Hand/fingers (left)				0.174*	
	Hips/buttocks		0.141*			0.172**
	Thigh (right)					0.191**
	Thigh (left)					0.235**
	Lower leg (left)	0.140*		0.144*		0.139*

*$p < 0.05$; **$p < 0.001$

Conclusion

In this study, the relationship between duration of daily exposure of children and adolescents to ICT and musculoskeletal discomfort was investigated. The survey findings showed that the participants felt discomfort mostly in the neck, upper back, lower back, and shoulders. The correlation analysis indicated that there is a relationship between prolonged duration of ICT device use and musculoskeletal discomfort. Musculoskeletal discomfort mostly occurred due to the use of ICT devices for communication, surfing the Internet, reading, and writing. The results showed that the shoulder, upper back, upper arm, forearm, and hand muscles are affected by use of these ICT devices.

This research illustrated that there is a significant relationship between prolonged usage of ICT devices and musculoskeletal discomfort. However, there is a need for further research to understand the musculoskeletal discomfort experienced. In addition, not only the musculoskeletal discomfort experienced but also the effects of using this technology for many years on the motor skills of children and adolescents should be examined.

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A Closed-Loop Reverse Supply Chain Network Design for Waste Electrical and Electronic Equipment

Gokhan Aldemir and Hur Bersam Bolat

Abstract Nowadays, firms are choosing strategies that increase their economic performance as well as their competitiveness in the field of social responsibility. Interest in the effective reuse of resources and/or manufactured products continues to increase in all companies as a result of global climatic changes, population growth, rapid urbanization, and the reduction of natural resources. This study proposes a sustainable multi-period reverse logistics network design to minimize the waste of electric and electrical equipment, which is the one of the most crucial sectors in terms of waste management. This study contributes to filling the gap in the literature on mathematical closed-loop reverse logistics network design by including multi-product, multi-objective, and multi-period parameters in the model for all three dimensions of sustainability for decision making. The proposed model is optimized with mixed integer linear programming. It is applied to a sample data set and sensitivity analysis is done with crucial decision variables to reveal the model limitations. The study ends by presenting the future directions, giving some helpful recommendations for other researchers on this topic.

Keywords Closed loop supply chain · Network design · Sustainable supply chains

Introduction

Sustainable development is one of the most important issues of the last decade. For the first time, this concept has emerged in a narrow sense as economic and environmental compatibility in the Brundtland Commission Report. Supply chain

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sustainability is the management of environmental, social, and economic impacts and the encouragement of good governance practices throughout the lifecycle of a good or service. The objective of supply chain sustainability is to create, protect, and increase long-term environmental, social, and economic value for all stakeholders involved in bringing products and services to a market (UN Global Compact Supply Chain Report, 2008). The topic of sustainable development has gained importance in many different fields, such as sustainable municipality, sustainable agriculture, sustainable architecture, sustainable production, and so on.

Industries in developed countries set up fully fledged systems to follow these regulations, implementing environmentally friendly strategies to reduce their carbon footprints (Xu et al. 2013). These systems are all about recovery options. In the past, companies thought that recovery options, such as recycling, would incur great costs. It was difficult to strike a balance between environmental issues and production costs. Today however, recovery options are considered to represent an economic gain by a lot of companies. Moreover, pricing is no longer a unique competitive strategy since customers give today value and prefer environmentally friendly products. In other words, recovery options are considered by manufacturers due to customer demand, regulations, and economic return.

The aim of this study is to put forward a sustainable closed-loop supply chain network design to minimize the waste of electric and electrical equipment, which is the one of the most crucial sectors in terms of waste management. The study uses the multi-period, multi-product reverse logistics concept. There are many studies in the literature about closed loop supply chain network design, but few take into account all three dimensions of sustainability (economic, environmental, and social). Also, there are still fewer studies of sustainability that use quantitative models in the literature. Therefore, this study contributes to filling the gap in the literature on mathematical closed-loop reverse supply chain network design models in multi-product, multi-objective and multi-period aspects for all three dimensions of sustainability for decision making.

Literature Review

Sustainable business is defined by its aspects to balance triple bottom lines (TBLs, i.e., profit, planet, and people). In sustainable business design, consideration of the interaction between the core business and external environment, which does not seem to affect the profit of the core business but is required to clarify its de-liberate environmental and social value statement, is decisive (Kondoh et al. 2014).

Sustainability, the consideration of environmental factors and social aspects, in supply chain management (SCM) has become a significant topic for researchers and practitioners. The application of operations research methods and related models, that is, formal modeling for closed-loop SCM and reverse logistics, has been thoroughly examined in previously published research (Brandenburg et al. 2014).

Combining environmental and social perspectives with financial aspects, known as the TBL dimensions of organizational sustainability, has continually gained relevance generally for managerial decision making and specifically for SCM and operations management (Carter and Rogers 2008).

Sustainable supply chain management (SSCM) is defined as the management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking into account goals from all three dimensions of sustainable development, that is, the economic, environmental and social ones, which are derived from customer and stakeholder requirements (Seuring and Müller 2008).

SSCM is defined as "the strategic, transparent integration and achievement of an organization's environmental, social and economic goals in the systematic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its chains" (Carter and Rogers 2008). Besides, SSCM is mainly intended to improve the business and environmental performance in a supply chain network (Tseng et al. 2014).

For CLSCM, quantitative models are frequently applied and practical (Fleischmann et al. 1997). In contrast, the majority of models employed for SSCM are more conceptual. Recently, the quantity of formal modeling efforts has improved (Brandenburg et al. 2014).

It can be seen from the literature that reverse-oriented CLSCM models are widely accepted but a significant number of forward SCM models for sustainability also exist (Min and Kim 2012).

To help catalyze further research in this field, which has several opportunities to enhance organizational, industrial, and commercial sustainability, further understanding of the common and unique modeling characteristics is required. Some reviews of SSCM are present now but most of them are descriptive (Brandenburg et al. 2013).

Chaabane et al. (2011) propose a bi-objective mathematical model as an example of Sustainable Supply Chain Network Design (S-SCND). The objective of economic sustainability is to minimize the total logistics cost of the supply chain, while the objective of environmental sustainability is to minimize the total quantity of greenhouse gas (GHG) emissions. This article shows that S-SCND provides long-term competitive advantage through the alignment of economic, social, and environmental goals.

The study of Diabat et al. (2014) identifies influential enablers for SSCM by using structural modeling with 13 enablers. They designate five enablers, namely adoption of safety standards, adoption of green practices, community economic welfare, health and safety issues, and employment stability, for the Indian textile sector. The study shows that safety perspective enablers provide additional motivation when compared to the other enablers for SSCM adoption.

Garg et al. (2015) investigate a multi-criteria optimization approach to manage environmental issues in CLSC-ND. They formulate a bi-objective non-linear programming problem, and in order to solve it they propose an interactive multi-objective programming approach algorithm. Their model determines the

optimal flow of parts and products in the CLSC network and the optimum number of trucks hired by facilities in the forward chain of the network.

Chaabane et al. (2011) propose a comprehensive methodology to address sustainable supply chain design problems where carbon emissions and total logistics costs, including the selection of suppliers and sub-contractors, technology acquisition, and the choice of transportation modes, are considered in the design phase. The proposed methodology provides decision makers with a multi-objective mixed integer linear programming model to determine the trade-off between economic and environmental considerations.

He et al. (2006) review the implementation of strategies of WEEE treatment and the recovery technologies of WEEE. They present the current status of WEEE and corresponding responses adopted so far in China. The concept and implementation of scientific development is critical to the sector of electronics as one of the important industrial sectors in China's economy. To achieve this objective, it is significant to recycle WEEE sufficiently to comply with the regulations regarding WEEE management and to implement green design and cleaner production concepts within the electronics industry in accordance with the upcoming EU and Chinese legislation in a proactive manner.

Yang et al. (2008) also study WEEE flow and mitigating measures in China. They identify the sources and generation of WEEE in China and calculate WEEE volumes. The results show that recycling capacity must increase if the rising quantity of domestic WEEE is to be handled properly. Simultaneously, suitable WEEE treatment will generate large volumes of secondary resources. They describe the existing WEEE flow at the national level and future challenges and strategies for WEEE management in China.

Walther and Spenger (2005) analyze the impact of the WEEE directive on reverse logistics in Germany. They think that essential changes in the field of treatment of electronic products in Germany are expected due to the new regal requirements owned. On the other hand, the consequences in terms of changes of organization and material flows of the German treatment system are currently unknown. Their contribution is to predict relevant changes in this context. That sets the framework for a deduction of recommendations for political decision makers and actors of the treatment system.

Wu and Barnes (2016) present a new model for partner selection for reverse logistic centers in green supply chains. The applicability of the model is demonstrated by means of an empirical application based on data from a Chinese electronic equipment and instrument manufacturing company.

Zandieh and Chensebli (2016) investigate the reverse logistics network design problem, including collection and inspection, recovery, and disposal centers, considering a mixed integer linear programming model. The NP-hardness of this problem has been proved in many papers, so a novel meta-heuristic solution method aimed at minimization of total costs fixed opening cost of collection and inspection, recovery and disposal centers, and transportation cost of products between opened centers using priority-based encoding presentation is proposed. Comparison of

outputs from their algorithm and a modified genetic algorithm shows the excellence of this new solution method.

John (2017) develop a mathematical model for the network design of a reverse supply chain in a multi-product, multi-period environment. The studied algorithm achieves a reduction of the total cost of emissions.

Mathematical Model

Sets

P Set of product types
Q Set of raw material types
T Set of time periods (years)
M Set of manufacturing facilities
D Set of existing distribution facilities
C Set of existing and potential collection centers
R Set of existing and potential recovery facilities
B Set of customer locations (buyers)
K Set of transportation modes
L Set of all locations
U Set of all nodes

Parameters

D_{jpt} demand for product $p \in P$ by the customer $j \in B$ in time $t \in T$
A_{qp} amount of product required $p \in P$ to produce one unit of product $q \in Q$
G_{jpt} end-of-life products $p \in P$ generated at the customer point $j \in B$ in time $t \in T$
F_{qp} amount of product generated $p \in P$ from one unit of product $q \in Q$
V_p volume of product $p \in P$
Cap_j capacities of facilities of node $j \in U$
$CCap_j$ campaign capacity of node $j \in D$
Cap_k capacity of transportation mode $k \in K$
CO_{2k} amount of CO_2 generated per kilometer during transportation by using transportation mode $k \in K$
β required percentage recovery from collected parts at potential and existing recovery centers
α conservation of mass ratio
dis_{ij} distance between node $i \in U$ and node $j \in U$, i ≠ j
S_j increase in social utility when a decision is taken to open node $j \in C\, or\, R$

Costs:

FC_j fixed cost of opening a new collection center or new recovery center $j \in C \, or \, j \in R$

E_{pj} unit recovery cost of product $p \in P$ in an existing or potential recovery center $j \in C \, or \, j \in R$

TC_{pk} unit transportation cost per kilometer of product $p \in P$ when using transportation mode $k \in K$

PC_{qm} unit cost of purchasing raw material $q \in Q$ for manufacturing facility $m \in M$

Decision variables:

$$y_{jt} \begin{cases} 1, \text{if a decision is made to open the collection center or recovery} \\ \quad \text{center } j \in C \; or \; j \in R \text{ time } t \in T \\ 0, \text{ otherwise} \end{cases}$$

$$w_{ijkt} \begin{cases} 1, \text{ if a decision is made that transportation mode } k \in K \text{ will be used} \\ \quad \text{between nodes i and j } \in U \text{ in time } t \in T \\ 0, \text{ otherwise} \end{cases}$$

z_{ipt} *amount of* product $p \in P$ manufactured in facility $i \in M$ in time $t \in T$

H_{iqt} amount of raw material $q \in Q$ purchased from suppliers for manufacturing facility $i \in M \; t \in T$

x_{ijkt} amount of product $p \in P$ or raw material $q \in Q$ which moves from node i to node $j \in U$ with transportation mode $k \in K$ in time $t \in T$

A multi-objective mathematical model is shown by Eqs. (1)–(16) according to the defined parameters and decision variables, and the flow of products and raw materials is shown in Fig. 1.

$$\begin{aligned} \textbf{\textit{Min}} \Bigg\{ & \sum_{j \in R \cup C} FC_j y_{jt} + \sum_{q \in Q} \sum_{t \in T} \sum_{J \in M} PC_{qj} H_{qjt} \\ & + \sum_{t \in T} \sum_{i \in U} \sum_{j \in U} \sum_{k \in K} \sum_{p \in P} TC_{pk} x_{ijpkt} dis_{ij} SS_{ij} \\ & + \sum_{t \in T} \sum_{k \in K} \sum_{p \in P} \sum_{i \in C} \sum_{j \in R} E_{pj} x_{ijpkt} \Bigg\} \end{aligned} \tag{1}$$

$$\textbf{\textit{Min}} \left\{ \sum_{t \in T} \sum_{i \in U} \sum_{j \in U} \sum_{k \in K} SS_{ijk} dis_{ij} w_{ijkt} CO_{2k} \right\} \tag{2}$$

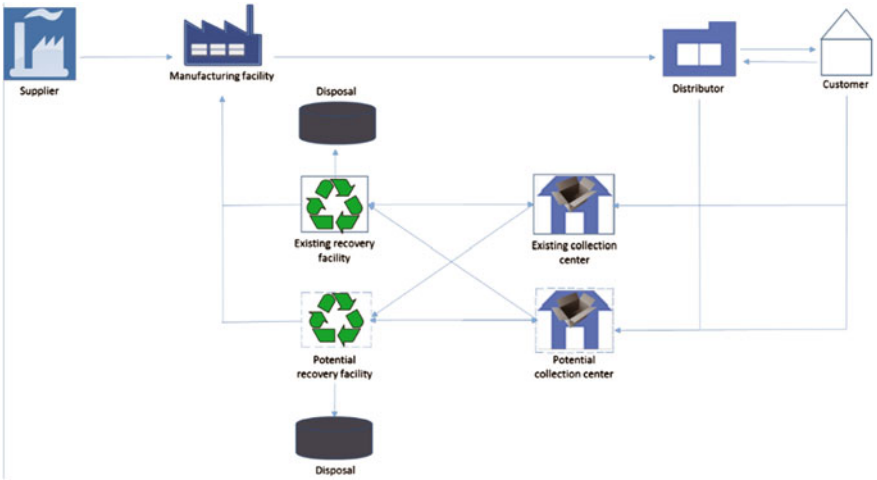

Fig. 1 Forward and reverse flow of the products and raw materials

$$\boldsymbol{Max}\left\{\sum_{j\in R\cup C} S_j y_{jt}\right\} \tag{3}$$

$$\sum_{p\in P} 0.0192 x_{ijpkt} V_p SS_{ij} \le Cap_k w_{ijkt} \tag{4}$$

$$\sum_{k\in K}\sum_{p\in P}\sum_{i\in U-B} x_{ijpkt} V_p \le Cap_j y_{jt} \tag{5}$$

$$\sum_{i\in D} x_{ijpt} \ge D_{jpt} \tag{6}$$

$$y_{jt} = 1 \tag{7}$$

$$\sum_{p\in P}\sum_{k\in K}\sum_{b\in B} x_{ijpk} V_p \le CCap_j \tag{8}$$

$$\sum_{i\in U} \alpha_{ip} x_{ijp} = \sum_{m\in U} x_{jmp} \quad \forall j \in U, i \ne j,\ j \ne m \tag{9}$$

$$\sum_{i\in C}\sum_{p\in P}\sum_{k\in K}\sum_{j\in R} x_{ijpkt} \ge \beta \sum_{j\in C\cup D}\sum_{i\in B}\sum_{p\in B}\sum_{k\in K} x_{ijpkt} \quad \forall t \in T \tag{10}$$

$$\sum_{i\in U}\sum_{k\in K} \alpha x_{impkt} = \sum_{j\in U}\sum_{k\in K} x_{mjpkt} \quad \forall p \in P \text{ and } t \in T \tag{11}$$

$$\sum_{j\in D\cup C}\sum_{k\in K} x_{ijpkt} = G_{ipt} \quad \forall i \in B,\ p \in P \text{ and } t \in T \tag{12}$$

$$\sum_{k\in K}\sum_{i\in R} x_{imqkt} + H_{mqt}/F_{qp} \geq \sum_{k\in K}\sum_{j\in D} x_{mjpk(t+1)} \quad \forall_{T,P,Q,M} \tag{13}$$

$$\sum_{m\in M}\sum_{k\in K} x_{jmqkt}/A_{pq} \leq \sum_{i\in M}\sum_{k\in K} x_{ijpkt} \quad \forall_{j\in R,q\in Q,p\in P \text{ and } t\in T} \tag{14}$$

$$H_{iqt}, x_{ijpkt} \geq 0 \tag{15}$$

$$w_{ijkt}, y_{jt}\ 0 \text{ or } 1,\ \text{binary} \tag{16}$$

The first objective function minimizes the fixed cost of opening a new recovery and collection center, the cost of raw material purchased from suppliers, the total transportation cost among nodes, and the cost of recovery. The second objective function minimizes the total amount of CO_2 generated by transportation, while the third objective function maximizes the increase in social utility when a decision is made to open a new node. Constraints (4), (5), and (8) are capacity constraints for transportation modes, recovery and collection centers, and the campaign capacity for retailers. In constraint (4), 0.0192 is equal to 1/52. Constraints (9) and (11) take into account the conversation of mass before and after the recovery center and collection center. Constraint (10) takes into account the collection targets of recovery centers defined by the government in the regulation. Constraints (13) and (14) define the relation between the amount of raw materials and the amount of products. The last two constraints provide non-negativity for the decision variables.

Analysis of the Model

Testing the Model with Sample Data

In this section, the mathematical model is tested with a sample data set on an Intel® Core™ i7-5500U processor computer with ZIMPL and SCIP solver software. Table 1 shows all manufacturing facilities, distribution centers, buyer points, existing and potential collection centers and recovery facilities, and the capacities and fixed costs per year of potential collection centers and recovery facilities.

Table 2 shows the product and raw material types and their unit volumes, and Table 3 lists the unit cost of raw materials from the supplier.

Table 4 shows the first year's demand and the number of end-of-life products that the customers have on hand. The demand and number of end-of-life products are assumed to increase by 20% every year to show the applicability of the multi-period aspect of the mathematical model.

Table 1 Facilities, capacities, and fixed costs

Facility number	Center name	Capacity	Fixed cost per year of facility
1	Manufacturing facility	100,000	–
2	Manufacturing facility	500,000	–
3	Distribution center	170,000	–
4	Distribution center	185,000	–
5	Distribution center	124,000	–
6	Distribution center	280,000	–
7	Buyer	–	–
8	Buyer	–	–
9	Buyer	–	–
10	Buyer	–	–
11	Buyer	–	–
12	Buyer	–	–
13	Buyer	–	–
14	Existing collection center	10,000	–
15	Potential collection center	12,000	1,000
16	Potential collection center	35,000	750
17	Potential collection center	22,000	1,200
18	Potential collection center	20,000	2,000
19	Potential collection center	25,000	1,300
20	Potential collection center	13,000	800
21	Potential collection center	27,000	1,250
22	Existing recovery center	12,000	–
23	Existing recovery center	13,000	–
24	Potential recovery facility	15,000	1,200
25	Potential recovery facility	14,500	2,000
26	Potential recovery facility	1,600	900
27	Potential recovery facility	2,000	950
28	Potential recovery facility	5,000	1,100
29	Potential recovery facility	35,000	2,700
30	Potential recovery facility	15,500	1,700
31	Potential recovery facility	9,900	1,300

Table 2 Volumes of products and raw materials

Product/raw material type	Volume
1	1
2	2
3	1
4	3
5	1
6	2
7	3

Table 3 Unit cost of raw materials

Raw material type	Unit cost
5	0.75
6	0.6
7	0.53

Table 4 Demand and number of end-of-life products

Buyer number	Product type	Demand	Number of end-of-life products
7	2	2,500	1,000
7	3	3,750	2,500
8	1	2,750	500
8	2	1,500	500
8	3	2,500	1,750
9	3	2,000	1,000
9	4	1,750	1,750
10	3	5,000	2,500
10	1	4,000	1,000
10	4	2,750	1,250
11	1	6,000	1,500
11	2	3,500	500
12	4	2,000	600
12	3	3,000	500
13	1	2,700	600
13	4	4,400	1,500

Table 5 Information about transportation

Transportation mode	Vehicle capacity	CO_2 generated	Cost per unit
1	2,500	10	0.15
2	3,500	13	0.16
3	4,000	15	0.2

The transportation modes, their capacities, the amount of CO_2 generated by using them, and the unit transportation costs of products are summarized in Table 5.

Table 6 shows the relationship between raw materials and products based on their production and recovery requirements.

The time horizon is 8 years, and α and β are set as 0.95 and 0.60. The three-objective model is applied with four types of products, three types of raw materials, and 31 facilities, and the objective value is found to be 1,776,910.

Table 6 Relationship between raw materials and products

Product type	Raw material type	Generated amount of product (F)	Required amount of raw material (A)
1	5	2	1
1	6	3	2
2	5	5	3
2	7	3	2
3	5	2	1
3	6	3	1
3	7	5	3
4	7	4	2

Sensitivity Analysis

After the application of the model, sensitivity analysis is carried out between increased demand and recovery centers and increased demand and collection centers. The aggregate demand (demand of all buyers) is 48100 in the first year and increases by 20% every year during eight years. Figures 2 and 3 show the required number of recovery centers and collection centers.

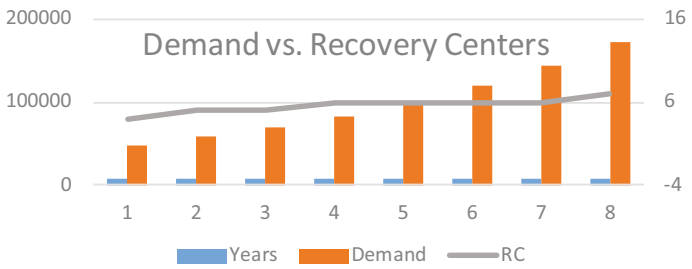

Fig. 2 Sensitivity analysis between demand and recovery centers

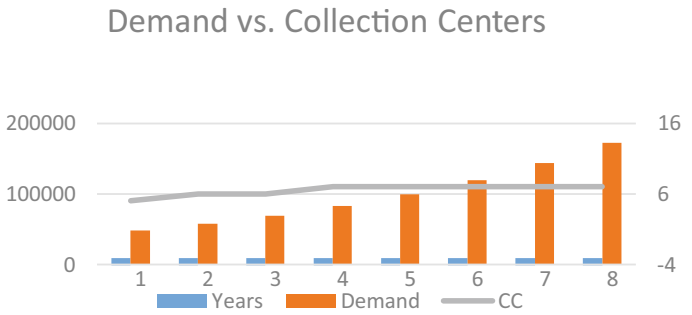

Fig. 3 Sensitivity analysis between demand and collection centers

Conclusion and Recommendations

Sustainability and sustainable development are gaining in importance day by day, and therefore the encouragement of governance practices to promote them should be continued among all nations, companies, SCM, life cycles of products or services, and so on. Sustainable supply chain management (SSCM) is the management of all flows of information, capital, and material as well as cooperation among companies along the supply chain while taking into account goals from all three dimensions of sustainability, that is, economic, environmental, and social, which are derived from the requirements of all stakeholders in the supply chain. In sustainable supply chains, environmental and social criteria need to be fulfilled by the members to remain within the supply chain, while it is expected that competiveness will be maintained through meeting customer needs and related economic criteria.

This study aims to put forward a sustainable multi-period supply chain network design for minimizing the WEEE, which is the one of most crucial sectors in terms of waste management. This study contributes to filling the gap in the literature on mathematical closed-loop reverse supply chain network design models in multi-product, multi-objective, and multi-period aspects of all three dimensions of sustainable development for decision makers.

In a future study, the model should be tested with real data. Moreover, the model can be integrated with collection and recovery centers owned by the government so that companies can compare these options. The main limitation of the model is the lack of a detailed analysis of the social dimension of sustainability. Researchers should find new and real indicators to define the social dimension of sustainability, especially for SSCM. Also, supply chains and sectors are different from each other, so sectorial snapshots are required, it can be succeeding with the new models for the other sectors.

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Analyzing the Recycling Operations Data of the White Appliances Industry in the Turkish Market

Alperen Bal, Peiman Alipour Sarvari and Sule Itir Satoglu

Abstract There is legislation that makes manufacturers responsible for incorporating recycling of waste electric and electronic equipment (WEEE). The white appliances industry is one of these sectors and in many countries, particularly those that are members of the European Union, there are regulations to guarantee the recycling of white appliances. This paper aims to investigate the data analysis of the white appliances industry in terms of reverse logistics operations. The most important usage and logistics operation data of a white appliances manufacturer are identified and evaluated by using data-mining methods. Important factors for types of white appliances are analyzed with respect to the lifespans of products, regional data, transaction times, campaign period, and choice of new products. A neural network is applied for prediction importance and ANOVA and Pearson correlation tests for region, lifespan, and brand of new product data are performed using SPSS. The results demonstrated that customers are prone to buying the same brand when they are delivering waste white appliances. Besides analysis of the campaign time, important inferences for strategic planning could be drawn from the lifespan and regional data.

Keywords ANOVA · Big data · Data analytics · Neural networks
Recycling · Reverse logistics · WEEE

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Introduction

Product recovery has gained considerable attention within the context of sustainability. Also governmental regulations and customer perspectives on environmental issues have motivated the organization of product recovery systems in companies. The first legislation on environmentally conscious manufacturing (ECM) drew the attention of both researchers and practitioners at the beginning of the 1990s. Recent governmental regulations in Turkey have also set out collection targets for electrical and electronic equipment (EEE) manufacturers as well as defining the formation of product recycling and remanufacturing procedures. Table 1 gives collection targets for EEE manufacturers in proportion to the total product produced in five categories. In this context, manufacturers are working toward establishing reverse logistics networks, while some of them have already done so.

Governmental regulations also oblige manufacturers to report the data of all operations to the Ministry of Environment and Urbanization. Therefore, collection of the data has become a very critical issue for reporting and also a very good resource for gaining remarkable inferences for manufacturing and logistics operations as well as managerial and marketing perspectives. The vast availability of data, on the other hand, has stimulated researchers to find more effective segmentation tools in order to discover more useful information about their markets and customers due to the inefficient performance of traditional statistical techniques (or statistics-oriented segmentation tools) when handling such voluminous data (Sarvari et al. 2016). For this reason, data mining has been seen as a solution to this problem. In fact, big data has attracted a great deal of attention because it provides the ability to derive patterns, increase profit margins, find potential markets, and carry out various predictions for the service and manufacturing sectors (LaValle et al. 2011). In supply chain management and logistics, Wang et al. (2016) reviewed big data analytics by investigating research and applications. Logistics data are generated from different sources in distribution networks such as

Table 1 WEEE collection targets according to 2012 regulations (Ministry of Environment and Urbanization, Turkey 2012, Regulation No. 28300)

Collection category	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)
1. Refrigerators/coolers/ air-conditioners	1.25	2.25	4.25	8.50	8.50	17.00
2. Large house appliances	2.50	3.75	8.00	16.00	16.00	32.50
3. Televisions and monitors	1.50	2.50	5.50	11.00	11.00	21.50
4. IT and telecommunications and consumer equipment	1.25	2.00	4.00	8.00	8.00	16.00
5. Small household appliances, toys, and electrical and electronic tools	0.75	1.50	2.75	5.50	5.50	11.00

forecasting of the supply capacities of suppliers, demand at demand points, or shipping costs (Najafi et al. 2013).

Big data has been used both in research to validate existing theories and in industry to help business organizations make better decisions (Muhtaroglu et al. 2013), especially in logistics and supply chain management (Wamba et al. 2015). However only 20% of companies make use of big data analytics (Jain et al. 2017). This indicates that there is a big potential to be understood and worked upon in big data analytics implementation in reverse logistics.

In this research, collected data for waste white appliances are analyzed. Figure 1 explains the waste collection network. Initially the customer goes to the vendor of the white appliance manufacturer. After purchasing a new product, service comes for installation. In the meantime, the waste white appliance is taken back from the customer. So collected WEEEs are taken by a third-party logistics-provider company from the service to the recycling facility. The data for WEEEs are monitored throughout the reverse logistics system. In the following sections, we introduce the background of the methods that are used, present the application in detail, and examine the research questions. Lastly, we discuss the results of the analysis.

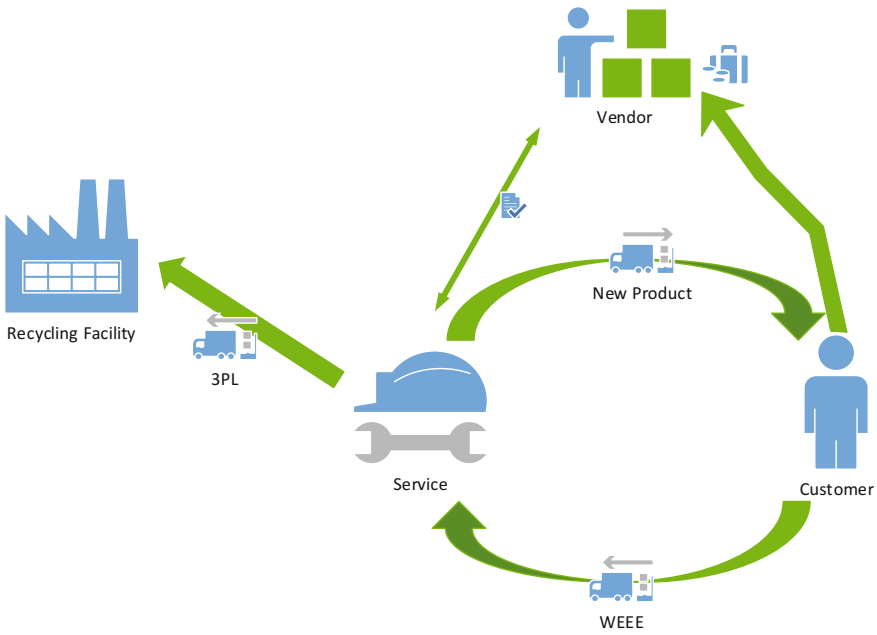

Fig. 1 Reverse logistics process for collecting waste white appliances

Research Framework

Big Data

The term "big data" has become popular recently; it refers to massive datasets with a large structure that are hard to handle using conventional database management systems and traditional data-processing tools (Akoka et al. 2017). "Big Data represents the Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value" (De Mauro et al. 2015). In the context of waste white appliances, this involves a number of applications that can be expected to benefit from large-scale capture and analysis of data from these WEEEs.

The CRISP-DM (Cross-Industry Process for Data Mining) methodology is an industry-proven way to guide data-mining efforts that provides a structured approach to planning a data-mining project. This methodology consists of six phases that cover the full data-mining process.

Business understanding. In this phase, business objectives are determined, the situation is assessed, data-mining goals are determined, and a project plan is produced.
Data understanding. The second stage addresses the acquisition of data resources and understanding the characteristics of those resources. It comprises the initial data collection, data description, data exploration, and data quality verification.
Data preparation. This includes selecting, cleaning, constructing, integrating, and formatting data.
Modeling. In this part, sophisticated analysis methods are used to obtain information from data. Modeling includes selecting modeling techniques, generating test designs, and building and assessing models.
Evaluation. After the model has been chosen, data-mining results can be evaluated to achieve the business objectives. This phase includes evaluating the results, reviewing the data-mining process, and determining the next steps.
Deployment. In this stage, the evaluation results are taken and new knowledge is integrated into the everyday business process to solve the original business problem. Elements of this phase include plan deployment, monitoring and maintenance, producing a final report, and reviewing the project.

Neural Networks

Neural networks take biological systems as a model and aim to simulate their behavior. Neural networks have been used for prediction purposes for both classification and regression of continuous target attributes (Tobergte and Curtis 2013).

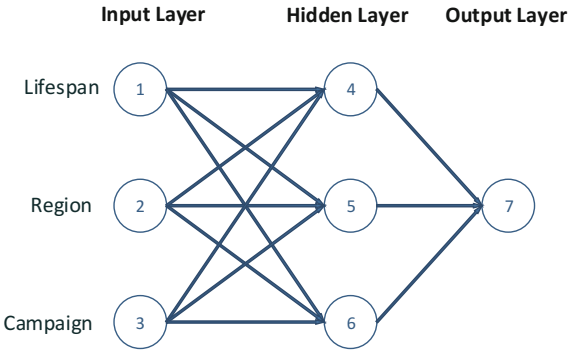

Fig. 2 A neural network with an input layer, one hidden layer, and an output layer

A neural network consists of nodes and arcs. Nodes represent neurons in the biological analogy and arcs correspond to dendrites and synapses. Each arc is related to a weight, whilst each node is defined by an activation function. The weights of the arcs adjust the values received as inputs by the nodes along the incoming arcs. The neural network learns through being trained. It makes an adjustment whenever it makes an incorrect prediction. The learning process occurs by examining individual records, generating a prediction for each record, and making adjustments to the weights (Fig. 2).

Application

The initial dataset used in this study is obtained from a database of the recycling system of a white appliance manufacturer and consists of approximately half a million cases of collected WEEEs. The data include 1. and 2. group of WEEE (see Table 1). To be more precise, five groups of white appliances, namely refrigerators, washing machines, drying machines, dishwashers, and ovens, are included in the data. Data analysis was performed using the statistics software IBM SPSS Modeler and IBM SPSS 23 (Table 2).

In the model, we wanted to focus on the predictor fields that matter most and least. The dependent variable was the product group and the independent variables were the same product, campaign, lifespan, region, and transaction hour. A maximum training time criterion was considered as the stopping rule. In addition, the dataset was divided into training and test groups. The training data comprised 80% of the whole dataset and the remaining 20% were used as the test data. According to the results, being the same product was the most important predictor for our model (0.41). After that, campaign (0.25), lifespan (0.21), region (0.08), and transaction hour (0.04) were the other predictors, respectively (Fig. 3).

Table 2 The field variables of the dataset

Field variable	Remarks
Campaign	The type of campaign giving special offers or discounts to customers who return their waste white appliances. Campaign times generally start from the close of the third quarter and end at the close of the year
Lifespan	A record of the production year of the collected waste white appliances is always taken. Therefore, the lifespan of these products is obtained considering the collection time
Product group	Five groups of white appliances, namely refrigerators, washing machines, drying machines, dishwashers, and ovens
Region	Ten different regions exist countryside in a logistics manner
Same product	The question of whether or not the newly sold white appliance or small household appliance is the same type of product. In other words, if a certain type of washing machine is sold and exactly the same type of washing machine is collected as the WEEE of the same brand then we have the same product
Transaction hour	The time at which a customer delivers a waste white appliance and receives a new white appliance or small household appliance

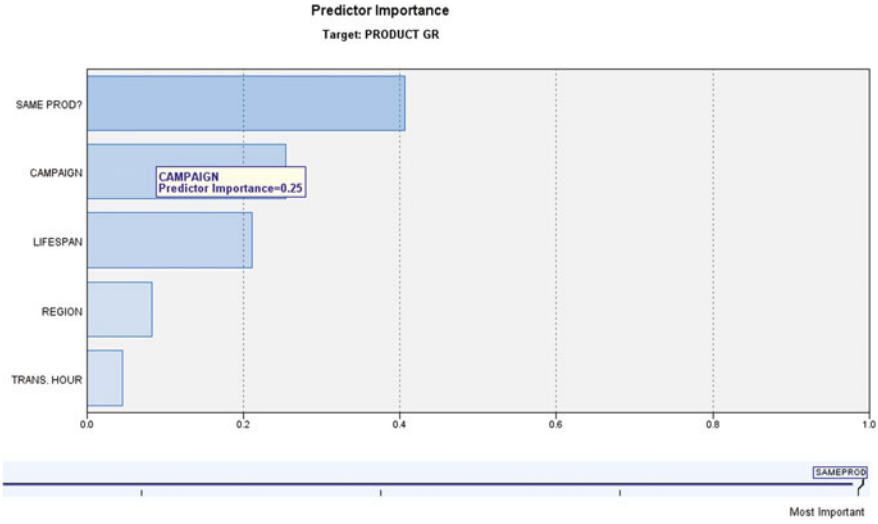

Fig. 3 Importance factors for product groups of waste white appliances

Research Question

The campaign is found to be the second most important predictor for the product groups. Therefore, we wanted to see whether a relationship between the number of waste white appliances collected and the campaign period exists. The transaction

Table 3 Pearson correlation test between transaction date and campaign time

		Trans. date	Campaign
Trans. date	Pearson correlation	1	0.983**
	Sig. (two-tailed)		0.000
	N	633,525	322,334
Campaign	Pearson correlation	0.983**	1
	Sig. (two-tailed)	0.000	
	N	322,334	322,334

**The correlation is significant at the 0.01 level (two-tailed)

date are considered to measure the effect of the campaign period since all cases are recorded in the transaction time (Table 3).

H_0: $\rho = 0$
H_A: $\rho \neq 0$

We can conclude that the result of the Pearson correlation test indicates a quite strong positive linear relationship between the transaction date and the campaign period for waste white appliances. This means that customers are prone to delivering their waste white appliances especially during the period of the campaign. On the other hand, when we look at the number of waste white appliances collected during a three-year period, we can clearly see from Fig. 4 that the increases at the end of each year indicate a seasonal effect (Fig. 5).

Meanwhile it is also important to see whether there are differences in customer behavior by region. Therefore, firstly we questioned whether brand preferences differ between regions. Afterwards we also questioned whether the lifespans of

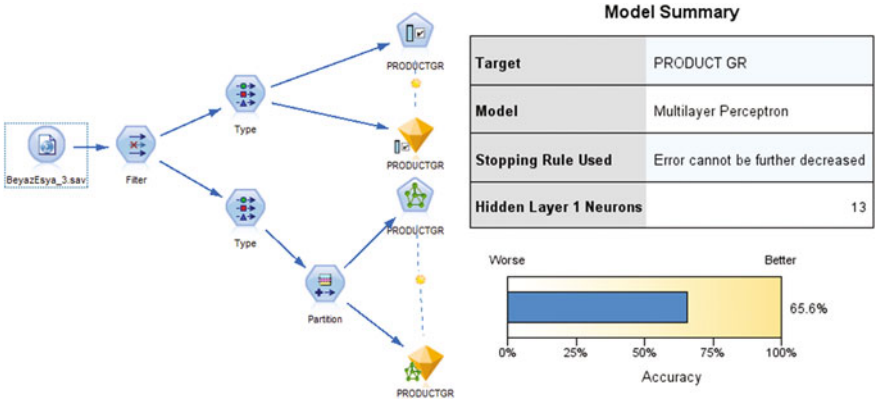

Fig. 4 Application design and model summary

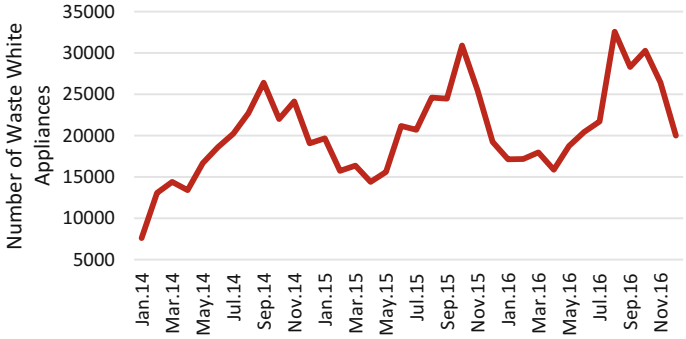

Fig. 5 Number of waste white appliances collected monthly

Table 4 ANOVA test result for brand of new product

	Sum of squares	Df	Mean square	F	Sig.
Between groups	1844.370	9	204.930	216.670	0.000
Within groups	262955.880	608029	0.946		
Total	264800.249	608020			

white appliances differ between regions. The following variance analyses were used to test our hypotheses regarding these questions.

H_0: On average, brands of new white appliances do not differ between regions.
H_A: On average, brands of new white appliances differ between regions.

According to the results of the F-test carried out with a 95% confidence interval, the significance value for the brand of new product was found to be $p = 0.000 < 0.05$. With regard to the brand of new product, hypothesis H_A is accepted (Table 4). In other words, brand preference differs significantly by region. Also, when we look at the brand preference table (Table 5), we can see that the upper-mass brand preference increases especially in the west of Turkey. In other words, more lower-mass brands are preferred by customers, especially in the East Anatolia region.

H_0: On average, the lifespans of waste white appliances do not differ between regions.
H_A: On average, the lifespans of waste white appliances differ between regions.

According to the results of the F-test for the lifespan of waste white appliances with a 95% confidence interval, the significance value was found to be $p = 0.000 < 0.05$. With regard to the lifespan of waste white appliances, hypothesis H_A is accepted (Table 6). In other words, the lifespans of waste white appliances differ significantly between regions. Also, Table 7 shows the average lifespan of

Table 5 Proportion of brand segments according to region

	Lower mass/upper mass
East Marmara region	0.067
North Aegean region	0.078
Central Anatolia region	0.114
Thrace region	0.116
Southeastern Anatolia region	0.133
Black Sea region	0.140
West Aegean region	0.146
Central Aegean region	0.157
West Mediterranean region	0.182
East Anatolia region	0.190

Table 6 ANOVA test result for lifespan of waste white appliances

	Sum of squares	df	Mean square	F	Sig.
Between groups	54283.137	9	6031.460	486.735	0.000
Within groups	3635717.567	633,516	12.392		
Total	3690000.705	633,525			

Table 7 Average lifespan of waste white appliances by region

	Lifespan
Southeastern Anatolia region	6.25
Black Sea region	6.31
West Aegean region	6.45
Central Aegean region	6.67
East Anatolia region	6.95
West Mediterranean region	6.97
Thrace region	6.98
East Marmara region	7.09
North Aegean region	7.09
Central Anatolia region	7.55

white appliances. It can be seen that white appliances have the longest lifespans in the Marmara and Central Anatolia regions.

Results and Conclusion

This study considers waste white appliances, a type of WEEE that is a cause of great concern all over the world. In order to understand the big data of reverse logistics operations, three-year product records were analyzed using different tools

in SPSS. The main purpose of the work was to understand customer behavior according to different variables. Also, the results can lead the way for companies in a strategic manner. Initially, the most important factors wanted to be seen for product groups. Predictor importance results showed that being the same product was the most important predictor. This indicates that customers mainly prefer to buy the same brand again when they want to buy a new white appliance. This also indicates customer loyalty, considering one of the most dominant brands of the Turkish market. The second most important predictor for the product groups was campaigns. The Pearson correlation test results showed a strong positive linear relationship between campaign period and collected waste white appliances. Lifespan and region were the third and fourth most important predictors for the product groups, respectively. Therefore, we questioned whether there were differences in lifespan and choice of brand between regions. The results of both analyses indicated that significant differences exist. Also, the tables of lifespan and brand preferences show differences between regions. These results give a good indication of which regions prefer lower-mass or upper-mass brands. Besides, the lifespan of products can be a good indicator for forecasting sales.

With regard to future study, we would like to extend our research by rule mining since association rules can help companies to make strategic decisions on reverse logistics or marketing. Besides, demand for waste products has increased by approximately 10%, and seasonal effects exist. Thus forecasting future demand can be beneficial as well.

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Application of Q-R Policy for Non-smooth Demand in the Aviation Industry

Merve Sahin and Fahrettin Eldemir

Abstract In the aviation industry, maintenance and inventory holding costs of spare parts give managers an opportunity to decrease their operational costs. Therefore, highly accurate demand forecasting is an indispensable entity in spare-parts inventory management. In the literature, traditional demand forecasting methods and measures are insufficient due to the variability of demand quantity and the uncertainty of demand occurrence times. When comparing the demand forecasting methods, MAPE and RMSE measures are usually preferred and these methods often give misleading results when inventory cost minimization is considered. In this paper, a cost-based performance measure and a newly generated joint performance measure, GMEIC, are employed to compare the traditional forecasting methods with the methods generated for non-smooth demand. The methodology applied in this paper consists of data classification, parameter tuning, and ordering decisions based on (Q, R) inventory policy and inventory cost evaluations. In order to measure the performances of the employed forecasting methods for non-smooth demand data, 632 different items were selected from the inventory of Turkish Airlines Technic MRO. It was observed that traditional forecasting methods did not perform better than the forecasting methods developed for non-smooth demand data when the inventory costs were taken into account as the performance measure.

Keywords Spare parts · Inventory cost · (Q, R) policy · Intermittent data

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Introduction

Irregular demand patterns make demand forecasting challenging and forecast errors can lead to substantial costs because of unfulfilled demand or obsolescent stock. A common problem in the case of irregular demand patterns is the need to forecast demand with the highest possible degree of accuracy and to set the inventory policy parameters based on that information. The accuracy of forecasting methods is closely related to the characteristic of demand data (Boylan et al. 2008). The need to produce more accurate time series forecasts remains an issue in both conventional and soft computing techniques; therefore, innovative methods have been developed in the literature for intermittent demand. Exponential smoothing methods and variations are often used for smooth demand patterns as well as to forecast spare parts requirements (Snyder et al. 2002). However, variability and the uncertainty of occurrence of these parts raise challenges when traditional forecasting methods are used. Exponential smoothing methods, however, place some weight on the most recent data regardless of whether there is zero or nonzero demand. As such, it underestimates the size of the demand when it occurs and overestimates the long-term average demand. Consequently, biased forecasting methods cause unreasonably high stocks.

Typical high-performance companies such as Turkish Airlines tend to improve robust demand forecasting techniques and processes, leading to smaller inventories and better customer satisfaction. There is scope to increase the performance of inventory planning systems, and modifications are required for the interaction between forecasting and stock control in terms of their effects on system performance.

In the literature, non-smooth demand data are categorized into three types: erratic, lumpy, and intermittent. When demand data contain a large percentage of zero values with random nonzero demand data with small variation, the demand is referred to as intermittent. If the variability of demand size is high but there are only a few zero values, it is called erratic demand. If both the variability of demand size and the time periods between two successive nonzero demands are high, it is called lumpy demand. The demand data type is smooth when both variability and time periods between two successive nonzero demands are low.

The categorization scheme is based on the characteristics of demand data that are derived from two parameters: the average inter-demand interval (ADI) and the squared coefficient of variation (CV^2). ADI is defined as the average number of time periods between two successive demands, which indicates the intermittence of demand,

$$\mathrm{ADI} = \frac{\sum_{i=1}^{\mathrm{N}-1} t_i}{N-1} \tag{1}$$

where N indicates the number of periods with nonzero demand and t_i is the interval between two consecutive demands. CV^2 is defined as the ratio of the variance of the

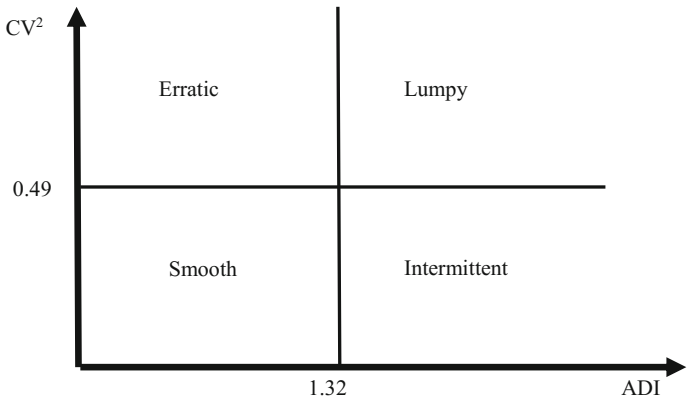

Fig. 1 Syntetos and Boylan's data categorization scheme

demand data divided by the square of average demand, which standardizes the variability of demand.

$$\mathrm{CV}^2 = \frac{\sum_{i=1}^{n} \left(D_i - \overline{D}\right)^2}{(n-1)\overline{D}^2} \tag{2}$$

where n is the number of periods, and D_i and $\overline{D}$ are the actual demand in period i and average demand, respectively. Cut-off values for Syntetos and Boylan's categorization scheme are given in Fig. 1 (Syntetos and Boylan 2005a). The cut-off values are ADI = 1.32 and $\mathrm{CV}^2 = 0.49$.

Due to excessive stocks and low customer service levels, lumpy demand presents the biggest challenge with regard to spare parts in forecasting and inventory management (Altay and Litteral 2011).

As far as intermittent demand forecasting is concerned, stock control does not determine the consequences of employing specific estimators. A limited number of researchers considering forecast accuracy that it is to be differentiated from the stock control performance of the utilized estimators (Eaves and Kingsman 2004; Strijbosch et al. 2000).

Recent empirical research on the performance of various intermittent demand forecasting approaches was conducted by Willemain et al. (2004) and Syntetos and Boylan (2005b). Thus, stock-holding cost and service level measures are of utmost importance in evaluating the performance of an inventory management system. Since the inspirational work of Croston in the area of forecasting for intermittent demand (Croston 1972), more than a few researches have been conducted on forecasting implication to inventory management, although these items comprise a substantial portion of the inventory population in parts (Porras and Dekker 2008).

Forecasts are used to determine inventory control parameters and to compare the average inventory or service levels (Syntetos and Boylan 2008). This type of

performance measure sometimes hurts comparison but reveals that Croston-type methods outperform traditional methods. No studies have found consistent superior performance from either Croston-type or traditional methods. Most studies show that Croston-type methods perform better on average (Willemain et al. 1994; Ghobbar and Friend 2003; Regattieri et al. 2005), but some findings show that the traditional methods can still provide better results (Eaves 2002).

(Q, R) Policy with Non-smooth Demand

In maintaining the operational sustainability of airline companies and their Maintenance and Repair Operations (MRO), which are rigidly tied to the available spare parts, stock control and ordering policies for those spare parts have great importance. When one considers the minimization of inventory costs of spare parts, forecasting with high accuracy is a challenging task since demand data for spare parts generally show a non-smooth pattern. Croston's method and Syntetos' method, which were developed for non-smooth demand data, are employed in this study in order to provide comparisons of their cost performances with exponential smoothing and a naive approach.

Croston's Method

Croston's (1972) paper on intermittent demand is the pioneering paper that addressed sporadic demand forecasting. He proposed a forecasting procedure that independently updates the demand interval between two nonzero demand values and also the demand size. The forecast for the demand per period is then calculated as the ratio of the forecasts of demand size and demand interval. Croston's method forecasts the nonzero demand size and the inter-arrival time between successive demands using exponential smoothing individually. Both forecasts are updated only after demand occurrences. The following notation is employed:

Y(t) is the estimate of nonzero demand size at time t,
P(t) is the estimate of the mean interval between nonzero demands at time t,
X(t) is the actual demand at time t, and Q is the time interval since the last nonzero demand,
α is the smoothing constant and F(t) is the estimate of demand per period at time t.

Croston's forecasting method updates values of Y(t) and P(t) according to the procedure shown in Fig. 2.

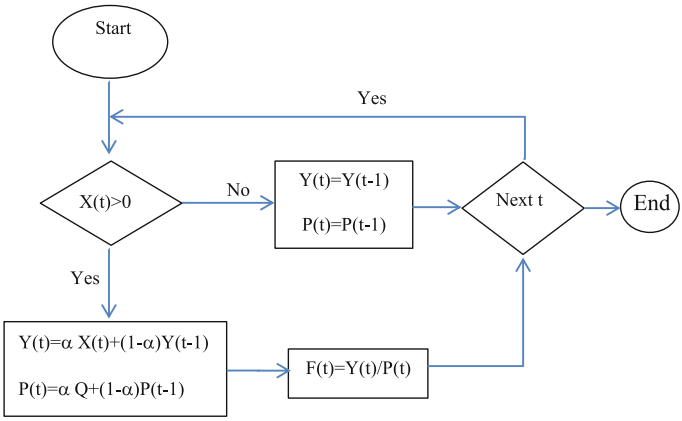

Fig. 2 Algorithm used in Croston's method

Croston's method finds the forecast of the demand for the period t as follows:

$$F(t) = \frac{Y(t)}{P(t)} \tag{3}$$

Syntetos' Method

Modifications to Croston's method were later developed by other researchers. Syntetos and Boylan showed that the initial Croston technique is biased (Syntetos and Boylan 2001). They corrected the biasness by multiplying the forecast for the demand per period by $(1 - \alpha/2)$, which is defined as the correction factor. If the demand occurs, estimates are updated as in Croston's method. Otherwise, the estimates remain the same. Their forecast of the demand for the period t is:

$$F(t) = \left(1 - \frac{\alpha}{2}\right)\frac{Y(t)}{P(t)} \tag{4}$$

(Q, R) Policy Basics

When the level of on-hand inventory decreases to point R, an order amount Q is supposed to be placed. Q is the order quantity that is added to the inventory and R is the reorder level in units of inventory.

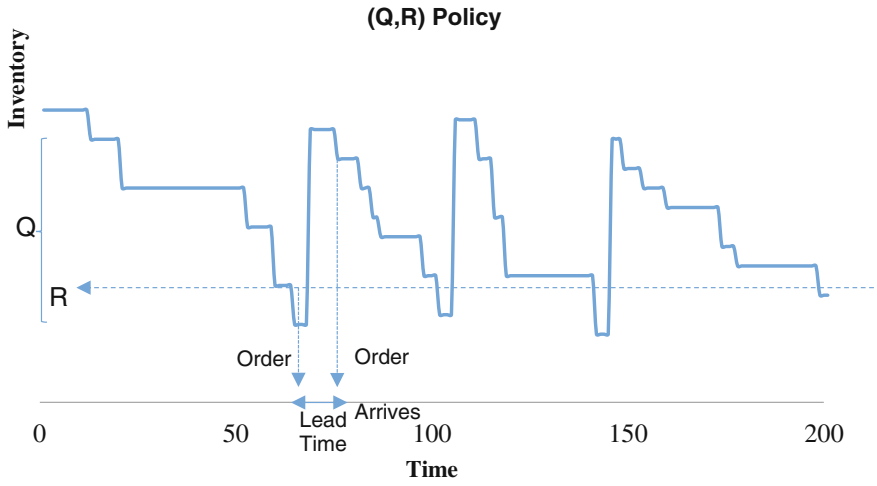

Fig. 3 (Q, R) policy inventory system

The ordering policy in this inventory system is given as below:

Q Order amount
R Reorder point
K Ordering cost per order
h Holding cost ($h per unit held per year)
p Penalty cost ($p per unit of unsatisfied demand)
λ Mean demand unit per year
τ Lead time

Therefore:

$\lambda\tau$ Expected demand over lead time

The expected average annual inventory costs by employing optimal values of (Q, R) decision variables are minimized (Fig. 3).

Inventory costs:

$$\text{Holding cost} = h\left(\frac{Q}{2} + R - \lambda\tau\right) \tag{5}$$

$$\text{Ordering cost} = K\lambda/Q \tag{6}$$

Let "D" be the observed demand over lead time. The expected number of shortages occurring in one cycle is:

$$N(R) = E(\max(D - R, 0)) = \int_{R}^{\infty} (x - R) f(x) dx \tag{7}$$

The expected number of stock-outs incurred per unit of time (per year) is:

$$\frac{n(R)}{T} = \lambda n(R)/Q \tag{8}$$

$$\text{Stock-out cost} = p\lambda \text{n(R)/Q} \tag{9}$$

$G(Q, R)$ is the total expected cost of holding, ordering, and stock-out costs.

$$G(Q, R) = h\left(\frac{Q}{2} + R - \lambda\tau\right) + \frac{K\lambda}{Q} + p\lambda n(R)/Q \tag{10}$$

Solving Q and R Iteratively

In order to minimize $G(Q, R)$ for each item in the stock, the derivative of the cost function with respect to Q and R individually should be equalized to zero to satisfy the necessary conditions for minimization.

$$\frac{\partial G(Q, R)}{\partial Q} = 0, \ \frac{\partial G(Q, R)}{\partial R} = 0 \tag{11}$$

By solving two equations simultaneously, Q and R can be expressed as follows:

$$Q = \sqrt{\frac{2\lambda(K + pn(R))}{h}} \tag{12}$$

$$1 - F(R) = Qh/p\lambda \tag{13}$$

To solve Q, $n(R)$ is needed. To solve R, the order quantity Q is needed. Since both Q and R require the other parameter, the iterative procedure will help to obtain the solutions. Arbitrarily selecting a Q value or an R value can start the iteration. Then a check should be performed to determine whether the solutions converge to meaningful results.

For the initial Q_0 value, the Economic Order Quantity (EOQ), which is the most convenient starting point, can be selected.

$$Q_0 = \text{EOQ} = \sqrt{\frac{2\lambda K}{h}} \tag{14}$$

If the demand during the lead time is assumed to be normally distributed with mean μ and standard deviation σ, then the value of R_0 can be found from Eq. (13) by using a Z table (cumulative standard normal probability table).

$$R = \mu + z\sigma \tag{15}$$

Once R has been obtained, $n(R)$ can be calculated by using the standardized loss function $L(z)$ as follows:

$$n(R) = \sigma L\left(\frac{R-\mu}{\sigma}\right) = \sigma L(z) \tag{16}$$

where $L(z)$ is

$$L(z) = \int_z^\infty (t-z)\phi(t)\mathrm{dt} = \int_z^\infty t\phi(t)\mathrm{dt} - \mathrm{z}(1-\Phi(z)) = \phi(z) - \mathrm{z}(1-\Phi(z)) \tag{17}$$

$\phi(\mathrm{z})$ is the standard normal probability density function and $\Phi(\mathrm{z})$ is the standard normal probability cumulative density function.

Geometric Mean of the Expected Inventory Costs (GMEIC)

Since there are multiple items in the stock, a performance measure that will collectively calculate the performances of the forecasting methods is needed. Regardless of the variability of the items in the stock, the geometric mean (based on products) of the expected costs (based on time) may be employed by using the expected costs as follows:

$$GMEIC = \left(\prod_{j=1}^{N}\left(h_j\left(\frac{Q_j^*}{2} + R_j^* - \lambda_j\tau j\right) + \frac{K_j\lambda_j}{Q_j^*} + \mathrm{p}_j\lambda_j\mathrm{n}\left(R_j^*\right)/Q_j^*\right)\right)^{1/N} \tag{18}$$

Methodology

The following steps are taken when determining the best strategy in order to lower the inventory costs:

- The spare parts demand data are categorized.
- 24 months' data are used for initialization.
- The last 36 months' data are used for validation purposes.
- Demand forecasting methods are selected (naïve, exponential smoothing, Croston and Syntetos; a constant smoothing factor α of 0.2 is used).
- The future (hidden) demand is forecasted.
- Ordering times and amounts are determined.
- Inventory holding costs, ordering costs, and stock-outs are calculated.
- The results of the naïve, exponential smoothing, and Croston and Syntetos methods are compared.
- The results are compared to select the most appropriate method.

The following steps are followed to obtain the Q and R values and compare the inventory costs of the forecasting methods employed.

1. Calculate the Q_0 (EOQ) using Eq. (14).
2. Calculate F(R) and R using Eqs. (13) and (15).
3. Find the corresponding z value.
4. Find the loss function value for the corresponding z using Eq. (17).
5. Calculate n(R) using Eq. (16).
6. Calculate Qi using Eq. (12).
7. Repeat Steps 2–6 until Q and R converge to Q* and R* respectively.
8. The last Q* value is taken to define the order amount for the month considered.
9. F(R*) is employed to calculate the reorder point (R*) value.

Case Study

In this study, a spare parts demand dataset is employed to perform comparisons of forecasting methods in the light of the inventory costs of Turkish Airlines Technic MRO. Accurate demand forecasting for stock-keeping units has a high importance in the aviation industry as the absence of any small part can lead to very high downtime costs. The minimization of inventory costs by keeping the availability of service parts as high as possible is a fundamental dilemma that needs to be investigated with new approaches.

Turkish Airlines Technic MRO is a notable aircraft maintenance, repair, and overhaul services company in the region. Turkish Airlines Technic MRO provides maintenance operations to its customers (business partners, airlines, etc.) for approximately all aircraft components (4,000 Boeing and 4,000 Airbus parts) from two wide- and narrow-body hangars and one VIP and light-aircraft hangar in Istanbul.

In this study, real datasets for spare parts that belong to the Turkish Airlines Technic MRO inventory are employed. These spare parts (except for one) were selected from non-smooth demands that have ADIs greater than 1.32 or CV^2 values

above 0.49. The data cover 106 monthly periods from 2008 to 2013. Descriptive statistics of the non-smooth demand dataset are given in Table 1.

Examples of non-smooth demand data from each demand category are given in Fig. 4. Data are taken from the MRO inventory of service parts of Turkish Airlines are given in monthly form for the last two years.

In our case, 632 demand data from the Turkish Airlines Technic MRO inventory are selected for the purpose of classification (Table 2).

Table 1 Descriptive statistics of demand data for spare parts

	Num of occur. N_i	Average demand $\overline{X}_i$	ADI	Demand per period	Standard deviation of sets	CV^2
Mean	46.5	9.05	3.08	6.01	9.29	0.80
Minimum	8	1	1	0.10	0	0
First quart.	25	1.73	1.63	0.48	0.96	0.30
Median	39	2.88	2.72	1.09	2.22	0.51
Third quart.	65	5.98	4.24	3.13	5.65	0.89
Maximum	106	934.01	13.25	934.01	880.65	17.19
Count	632	632	632	632	632	632

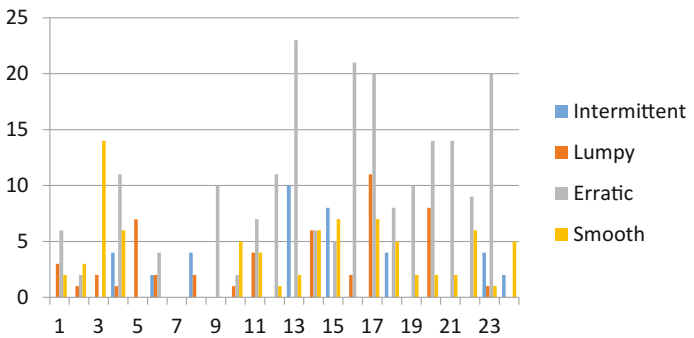

Fig. 4 Different types of non-smooth demand data (monthly)

Table 2 Spare-parts demand dataset classification

	Count of data type
Erratic	60
Intermittent	278
Lumpy	269
Smooth	25
Grand total	632

In this section, the inventory cost performances of the forecasting methods are investigated. Cost-based inventory performance results are given with the application of (Q, R) policy based on the exponential smoothing, Croston, Syntetos, and naive forecasting methods. The following assumptions are made:

1. The lead time is fixed as 1 month.
2. Demand is random and the system is continuously reviewed.
3. The penalty cost is taken as five times the part price.
4. The holding cost is taken as 0.2* part price.
5. The ordering cost is taken from the Turkish Airlines Technic MRO inventory cost system.
6. The demand during the lead time is a continuous random variable D with a probability density function. Let $\mu = E(D)$ and $\sigma = \sqrt{var(D)}$ be the mean and standard deviation of the demand during the lead time.

The iterative methodology given in Section "Methodology" is applied to obtain results. The inventory costs and GMEIC are the performance measures used to compare the intermittent demand forecasting methods.

Cost Results

Comparative results are given in Table 3 for the demand data for 632 spare parts. Of the 631 data, 278 had intermittent characteristics. Of these 278 intermittent data, 119 (43%) are best forecasted by Syntetos' method. Even with the smoothed data, 44% of the time, the performance of the Syntetos method is better than that of the other methods. The smoothing parameter (α) is selected as 0.2 for the exponential smoothing, Croston, and Syntetos methods.

Looking at the best performance is insufficient to help us compare the performance of non-winning methods. In this case, the GMEIC can be employed. The GMEIC results obtained from 632 different items are given in Table 4.

Table 3 Comparative results for data types and forecasting methods

Data type	Croston	Exponential smoothing	Naive method	Syntetos	Grand total
Erratic	14	9	11	26	60
Intermittent	58	58	43	119	278
Lumpy	62	55	37	115	269
Smooth	3	8	3	11	25
Grand total	137	130	94	271	632

Table 4 GMEIC results of spare-parts demand dataset

	Naive method	Exponential smoothing	Croston	Syntetos
GMEIC	962.82	896.91	883.84	863.31

Conclusion

Service parts inventory management is a challenging task when it comes to considering costs. Selection of a forecasting method with high accuracy is crucial, since the data are in a very unusual form. Traditional time series forecasting methods generally perform poorly when applied to non-smooth demand. In this study, we investigated the implications of forecasting methods for inventory costs. It can be concluded that the choice of forecasting method has an impact on the decisions regarding inventory costs and thus on the performance of the system.

Initially, historical demand data of Turkish Airlines Technic MRO spare parts are classified according to their properties such as the average inter-demand interval (ADI) and the coefficient of variation based on the Syntetos scheme. Four different groups of spare parts were determined based on that classification, namely intermittent, lumpy, smooth, and erratic. Then, spare parts demand forecasting models and a (Q, R) ordering policy for stochastic demand during lead time were applied. The comparison was executed on 607 non-smooth and 25 smooth real demand data series. In order to compare the forecasting methods while considering inventory costs, a newly generated accuracy measure (GMEIC) was employed. It was observed that the Syntetos method outperformed the other methods.

In a supply chain, random occurrences of demand are studied to manage the inventory system and the planned customer service at minimum cost. The inventory of a product may experience stock-out or over-stocking if the actual demand does not match the demand forecast. If the inventory quantity is determined based on the improved forecast, the inventory cost of a product may be reduced. The focus of this research is on demonstrating the inventory cost reductions that can be achieved through the application of an appropriate demand forecast. The best forecast for the product may be selected by comparing the inventory costs derived from several forecasts.

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A Closed-Loop Sustainable Supply Chain Network Design with System Dynamics for Waste Electrical and Electronic Equipment

Gokhan Aldemir, Tugce Beldek and Dilay Celebi

Abstract Supply chain management covers the management of all activities starting from the supply of the raw material to the delivery of the final product to the end user. In the rapidly evolving and globalizing world, limited resources and increasing competitiveness are pushing both nations and organizations to make a difference in the context of supply chain management. The importance of the concept of the sustainability has become more widely recognized among nations and organizations recently. Recovery options are considered to be an economic gain by many companies. Moreover, pricing is no longer a unique competitive strategy since customers give today value and prefer environmentally friendly products. In other words, recovery options are considered by manufacturers due to customer demand, regulations, and economic return. This study puts forward a sustainable supply chain network design with a system dynamics model to minimize the waste of electric and electrical equipment, which is the one of the most crucial sectors in terms of waste management. This study contributes to filling the gap in the literature concerning the mathematical closed-loop reverse supply chain network design model from a system dynamics perspective rather than by using deterministic and static models proposed in the literature. The proposed model is visualized with the program AnyLogic. It constitutes a general framework with crucial variables of electrical and electric equipment supply chains. The results show the states of these variables by year, which can provide a decision-support system for policy making. The study ends by suggesting future directions and giving some helpful recommendations for other researchers on this topic.

Keywords Closed-loop supply chain · Network design · System dynamics

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Introduction

Supply chain sustainability is the management of environmental, social, and economic impacts and the encouragement of good governance practices throughout the lifecycle of a good or service. The objective of supply chain sustainability is to create, protect, and increase long-term environmental, social, and economic value for all stakeholders involved in bringing products and services to a market (UN Global Compact Supply Chain Report 2008). Negative effects arise from many factors, such as solid waste, chemicals mixed with water, and gases produced by manufacturing facility activities that have been neglected for many years. By the end of the 1990s, protecting natural resources and the environment became a significant issue in both national and international arenas (Büyüközkan and Vardaloğlu 2008). Both technological improvements and a growing world population have sped up the rate of production and consumption of products as well as increasing the demand for raw materials as a result. For this reason, pollution levels have increased, which has led to resource scarcity and global warming. This has caused many enterprises and companies to worry about environmental and economical sustainability, so much so that many countries have developed new regulations related to green issues. That is why supply chain managers need to identify and use economic and environmental sustainability applications (Green et al. 2012). The supply chain and logistics management approach of companies is affected by the sustainable development concept and the traditional problem-solving approach is about to give way to the new sustainability-based approach.

Industries in developed countries have set up fully fledged systems to follow these regulations, implementing environmentally friendly strategies to reduce their waste (Xu et al. 2013). These systems are all about recovery options. In the past, companies thought that recovery options such as recycling would incur great costs. It was difficult to strike a balance between addressing environmental issues and production costs. Today however, recovery options are considered to represent an economic gain by many companies. Moreover, pricing is no longer a unique competitive strategy since customers give today value and prefer environmentally friendly products. In other words, recovery options are considered by manufacturers due to customer demand, regulations, and economic return.

The Aim of the Study

The aim of this study is to put forward a dynamic and sustainable supply chain network design to minimize waste electric and electrical equipment (WEEE), which is the one of the most crucial sectors in terms of waste management. The study is based on the multi-period, multi-product reverse logistics concept. There are many studies in the literature on closed-loop supply chain network design, but only a few take into account the dynamic perspective with regard to the important variables of

the supply chain. Therefore, this study contributes to filling the gap in the literature on the mathematical closed-loop reverse supply chain network design model from a system dynamics (SD) perspective rather being based on the deterministic and static models proposed in the literature and to create a general dynamic framework for that chain.

The Scope of the Study

This study includes six parts: the introduction, literature review, analysis of WEEE management in Turkey and other countries, the SD model and its application with illustrative data, the results, and the conclusion together with recommendations for future study. In the literature review, supply chain management (SCM), the concept of sustainability, dimensions of sustainability, and sustainable supply chain management (SSCM) will be defined first, and then quantitative studies related to the sustainability concept will be discussed. In addition, sustainability will be examined and compared across different sectors. The definitions of closed-loop supply chain and reverse logistics will be included. Then, studies that provide examples of closed-loop supply chain and reverse logistics network design models with multi-product, multi-period, and/or multi-echelon concepts will be explained.

In the analyses of WEEE management, information from Turkey's waste management directive will be presented to set specific parameter values that are used in the model of WEEE management. Moreover, the targets for collection and recovery by year will be investigated in this section.

In the section on the dynamic model, the parameters, costs, and decision variables will be defined first. Then, the general framework of the model will be explained. The aim of study will be to minimize and visualize the total investment with the first costs of new collection centers and new recovery centers, costs of collection and recovery of products, and the cost of acquisition of raw material from suppliers and third parties by year. After that, the data will be explained for the application of the model.

The results of the illustrative data and its comment will be analyzed in the results and discussion section.

Finally, the conclusion and recommendations section will contain some critical points to offer helpful information for further studies.

Literature Review

SSCM is defined as the management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking into account goals from all three dimensions of sustainable development, that is, economic, environmental, and social ones, which are derived from customer and

stakeholder requirements. In sustainable supply chains, environmental and social criteria need to be fulfilled by the members to remain within the supply chain, while it is expected that competiveness will be maintained through meeting customer needs and related economic criteria. This definition is rather broad and joins together those given for sustainability and SCM. It is also able to integrate green or environmental SCM as one part of the wider field (Seuring and Müller 2008).

Sustainability, the consideration of environmental factors and social aspects, in SCM has become a significant topic for researchers and practitioners. The application of operations research methods and related models, that is, formal modeling for closed-loop SCM and reverse logistics, has been thoroughly examined in previously published research (Brandenburg et al. 2014).

Combining environmental and social perspectives with financial aspects, known as the triple-bottom-line (TBL) dimensions of organizational sustainability, has continually gained relevance generally for managerial decision making and specifically for SCM and operations management (Carter and Rogers 2008).

It can be seen from the literature that reverse-oriented CLSCM models are widely accepted but a significant number of forward SCM models focusing on sustainability also exist (Min and Kim 2012).

By using reverse logistics, used materials are converted into new products and materials that have market value through reuse, remanufacture, refurbishment, and recycling. Therefore, a typical supply chain becomes a closed loop under favor of reverse logistics (Hervani et al. 2005). Therefore, closed-loop SCM consists of both forward and reverse flows. Forward supply chains start with the raw material that ends up at the customer, while reverse supply chains define the collection of the end-of-life products from customers followed by their recovery, recycling, or reuse in dependence on their quality; if they do not reach the required quality level, they will be disposed of (Guide et al. 2003).

Jindal et al. (2015) propose a network design for a multi-product, multi-time, multi-echelon closed-loop supply chain framework in an uncertain environment. The proposed CLSC network is represented by a fuzzy mixed integer linear programming (MILP) model to decide on the optimal location and allocation of parts at the facility, inventory level of the parts, number of products to be remanufactured, and number of parts to be purchased from external suppliers in order to maximize the profit of the organization.

Easwaran and Üster (2010) consider a multi-product closed-loop logistics network design problem with hybrid manufacturing/remanufacturing facilities and finite capacity hybrid distribution/collection centers to serve a set of retail locations. In their model, hybrid production plants, hybrid collection centers, hybrid distribution centers, and hybrid remanufacturing centers are opposed to separate plants. They determine the locations of facilities in both forward and reverse channel networks and incorporate processing and storage capacity restrictions.

Qiang et al. (2014) propose a two-period CLSC network model with manufacturers that compete with one another to serve the consumers of various demand markets. Manufacturers decide on the production quantity and remanufacturability level in the first period. They assume that those manufacturers who are proactive in

the product remanufacturability design will incur a higher production cost for the new product but will reap the benefit by having a lower production cost for the remanufactured product in the second period. Consumers are assumed to be conscious of the price and quality of the product and therefore discount their willingness to pay for the remanufactured product. In spite of being proactive in product remanufacturability design, the market share of the new product decreases for competitors who are reactive in choosing the design, and the former product is more profitable due to the capture of additional market share by the refurbished product. Also, they find that if all customers have a higher willingness to pay for the refurbished product, being proactive is less promising.

Garg et al. (2015) investigate a multi-criteria optimization approach to manage environmental issues in CLSC-ND. They formulate a bi-objective non-linear programming problem, and in order to solve it they propose an interactive multi-objective programming approach algorithm. Their model determines the optimal flow of parts and products in the CLSC network and the optimum number of trucks hired by facilities in the forward chain of the network. They carry out numerical experimentation with the proposed model to validate its applicability with the help of data from a real-life case study. The case presented in the paper is based on a geyser manufacturer, and the application of the model to this case provides them with the underlying tradeoffs between the two objectives. The model also results in the very interesting fact that with the implication of the extended supply chain, a firm can create a green image for its product, which eventually results in an increase in demand while significantly reducing the use of transportation in both directions.

He et al. (2006) review the implementation of strategies for WEEE treatment and the technologies for recovery of WEEE. It presents the current status of WEEE and corresponding responses adopted so far in China. The concept and implementation of scientific development are critical to the electronics sector as one of the important industrial sectors in China's economy. To achieve this objective, it is significant to recycle WEEE sufficiently to comply with the regulations regarding WEEE management and to implement green design and cleaner production concepts within the electronics industry in line with the upcoming EU and Chinese legislation in a proactive manner.

Yang et al. (2008) also study WEEE flow and mitigating measures in China. They identify the sources and generation of WEEE in China and calculate WEEE volumes. The results show that recycling capacity must increase if the rising quantity of domestic WEEE is to be handled properly. Simultaneously, suitable WEEE treatment will generate large volumes of secondary resources. They describe the existing WEEE flow at the national level and future challenges and strategies for WEEE management in China.

Walther and Spengler (2005) analyze the impact of the WEEE directive on reverse logistics in Germany. They think that essential changes in the field of treatment of electronic products in Germany are expected due to the new regal requirements owned. On the other hand, the consequences in terms of changes of organization and material flows of the German treatment system are currently

unknown. Their contribution is to predict relevant changes in this context. That sets the framework for a deduction of recommendations for political decision makers and actors in the treatment system.

Forrester (1961) introduced SD in the 1960s as a modeling and simulation methodology for dynamic management problems. Since then, SD has been applied to various business policies, strategies, and environmental problems (Sterman 2000). However, according to Dekker et al. (2004), only a few strategic management and environmental problems in CLSC have been analyzed and reported in the literature. Specifically, Spengler and Schröter (2003) present a CLSC using SD. Georgiadis et al. (2004) present the loops of product reuse with a major influence. Van Schaik and Reuter (2004) present an SD model focused on cars showing that the realization of the legislation targets imposed by the EU depends on the product design. SD is a powerful methodology for obtaining insights into the problems of dynamic complexity. Sterman mentioned that "whenever the problem to be solved is one of choosing the best from among a well-defined set of alternatives, optimization should be considered. If the meaning of best is also well-defined and if the system to be optimized is relatively static and free of feedback, optimization may well be the best technique to use". Bloemhof-Ruwaard et al. (1995) state that the latter conditions are rarely satisfied for environmental management and supply chain systems (Georgiadis et al. 2005). The system under study in this paper is dynamic and full of feedbacks, promoting SD as an appropriate modeling and analysis tool.

Analysis of WEEE Management in Turkey

The first study of WEEE in Turkey was done by the Ministry of Environment and Urban Planning with a regulation for the limitation of some certain hazardous substances in 2009. The regulation was published in the *Official Gazette* on May 30, 2009 and entered into force in 2009. The purpose of this regulation was to establish guidelines for the restriction of the use of certain hazardous substances found in electric and electronical goods, determination of the applications to be exempted from this limitation, and recovery or disposal of WEEE in order to protect the environment and human health (Ministry of Environment and Urban Planning 2008).

The Waste of Electric and Electrical Controlling Regulations were enacted by the Ministry of Environment and Urban Planning with the post in the *Official Gazette* on May 22, 2012 (Ministry of Environment and Urban Planning 2012). The purpose of the regulations was the same as that of the regulation published in 2009. Companies that had letters of conformity collected 4000 tons of WEEE in 2009, while they collected only 1818 tons of WEEE in 2006. The household WEEE collection targets are shown in Table 1.

Table 2 shows the recycling targets and Table 3 shows the recovery targets according to the categories of types of equipment.

Table 1 Household WEEE collection targets

	EEE category	Waste collection target by year (kg/capita-year)				
		2013	2014	2015	2016	2018
1	Refrigerators/cooling/air-conditioning appliances	0.05	0.09	0.17	0.34	0.68
2	Large white appliances (with the exception of refrigerators/cooling/ air-conditioning appliances)	0.1	0.15	0.32	0.64	1.3
3	Televisions and monitors,	0.06	0.10	0.22	0.44	0.86
4	IT and telecommunications equipment, and consumer equipment (with the exception of televisions and monitors)	0.05	0.08	0.16	0.32	0.64
5	Lighting equipment	0.01	0.02	0.02	0.04	0.08
6	Small household appliances, electrical and electronic tools, toys, sports and leisure equipment, monitoring and control tools	0.03	0.06	0.11	0.22	0.44
Total household WEEE (kg/capita-year)		0.3	0.5	1	2	4

Table 2 Recycling targets

	Year	
	2013	2018
Electrical and electronic equipment category		(%) by weight
Large household appliances (%)	65	75
Small household appliances (%)	40	50
IT and telecommunications equipment (%)	50	65
Consumer equipment (%)	50	65
Lighting devices and equipment (%)	20	50
Gas discharge lamps	55	80
Electrical and electronic tools (%)	40	50
Toys, leisure, and sports tools (%)	40	50
Medical devices (%)	–	–
Monitoring and control devices and tools (%)	40	50
Automatic dispensers (%)	65	75

Model Structure

In this study, a sustainable supply chain model for refrigerators is designed with AnyLogic (Fig. 1). SD is a way to understand the entire behavior of actors in the long term.

At a random moment, a decrease means the total amount of goods divided by their lifespan. This means that it is e-waste after a few years. Refrigerators will become e-waste after an average lifespan of five years. It is assumed that the

Table 3 Recovery targets

	Year	
	2013	2018
Electrical and electronic equipment category		(%) by weight
Large household appliances (%)	75	80
Small household appliances (%)	55	70
IT and telecommunications equipment (%)	60	75
Consumer equipment (%)	60	75
Lighting devices and equipment (%)	50	70
Gas discharge lamps	70	80
Electrical and electronic tools (%)	50	70
Toys, leisure, and sports tools (%)	50	70
Medical devices (%)	–	–
Monitoring and control devices and tools (%)	50	70
Automatic dispensers (%)	70	80

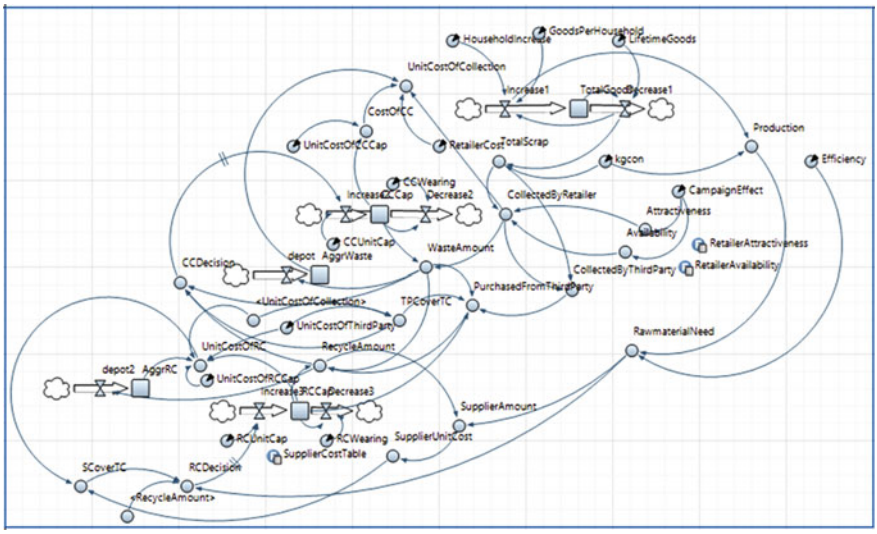

Fig. 1 System dynamics model conducted using AnyLogic

household amount will increase every year and as a result they will buy refrigerators for each. When production increases due to demand, the total amount of scrap will also increase year by year. For the production facility, regulation requirement is a must so that a specific amount (in kilograms) of e-waste has to be collected. The producer can collect end-of-life products via its retailers or from third-party firms.

If the producer wants to collect WEEE from its retailers, it has to carry out a campaign to make customers bring their end-of-life products to buy a new one,

maybe at a lower price. For this reason, retail attractiveness is defined, which comes with the campaign rate. By the time the retailer collects the WEEE, it will reach its capacity, so another parameter, namely retailer availability, is used. To calculate the total amount of WEEE collected from the retailer, we can multiply the total scrap, attractiveness, and availability. Also 50% of the rest, which is coming from the difference between total scrap and "collected by the retailer", will be collected by third parties.

When we consider the capacity of the collection center, the amount of waste must be the minimum out of the collected amount and the capacity. By using this formula, if more capacity is needed, the results will show that a capacity increase is essential and a new collection center may need to be opened. The capacity of the collection center has a wearing ratio that will decrease year by year as 0.0001. There is unit cost for the collection center, which is fixed as 80 TL/ton. From the beginning, the model shows that 1000 WEEE is collected.

There is also a unit cost of the collection center, which is defined by dividing the total of cost of the collection center and multiplication of the retailer cost and collected by retailer to aggregate waste amount. The decision of the collection center (CCDecision) can be calculated by multiplying the waste amount and the third party cost and dividing it to amount recycled. The amount recycled must be at least 50% for the recycling center to be efficient. Also, it is important to define a "delay" after the decision of the collection center is given because of the time needed to build it up.

If the third party cost changes over time, the producer can change the amount of waste it collects from the retailer. The most important thing is for the company to provide the required amount, which is already certain due to the WEEE regulation.

The same loop is designed with the same parameters for the recycling center. At this time, we have to consider both recycling and collection costs together.

There is a table defining the supplier cost that gives data about quantity discounts. With this cost table, the producer will decide to purchase raw material from suppliers or to recycle its scrap for use as a raw material. It will compare costs to enable it to make a decision about this purchasing action.

To represent a pull system, if there is demand, production will be carried out. Production requires raw material, so the material needed will be bought or recycled.

Simulation Results

The simulation was run without any errors in AnyLogic software. Sample data were used to test the model and the data information of parameters is given in the section on the model structure. Graphs are taken as a result to make comments on the capacity of the recycling center and collection center (Fig. 2).

In this model, the decision to open a new collection or recycling center is made due to capacity. The model shows crucial conclusions regarding two big dilemmas. First it selects its own collection system rather than working with a third-party

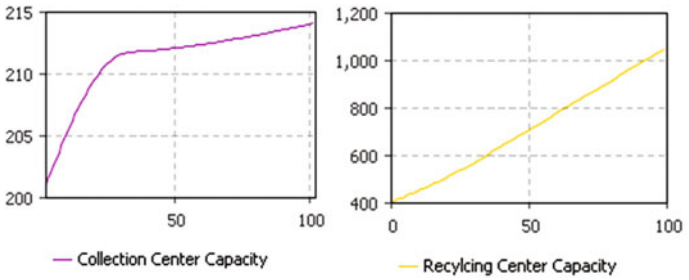

Fig. 2 Time plots for collection and recycling centers

logistics firm. Secondly, it suggests opening recycling centers to obtain raw materials rather than purchasing them from suppliers. These preferences result in a decrease in the unit costs of collection centers and recycling centers year by year, which can be seen from Fig. 3.

When increasing the capacity of collection and recycling centers, decreasing unit cost is a big benefit for the producer.

Conclusions and Future Study

Nowadays, firms are choosing strategies that increase their economic performance as well as increasing their competitiveness in the field of social responsibility. Interest in the effective reuse of resources and/or manufactured products continues to increase in all companies as a result of global climatic changes, population increase, rapid urbanization, and the reduction in the availability of natural resources. Due to customer demand, governmental regulations, and economic returns, manufacturers consider recovery options.

SD is a method that allows a whole system to be controlled over time to see whether or not it is sustainable. This model shows a WEEE collection system for a white appliances manufacturer. This study will give an idea for collection and recycling of e-waste, making it possible to obtain benefits such as reaching

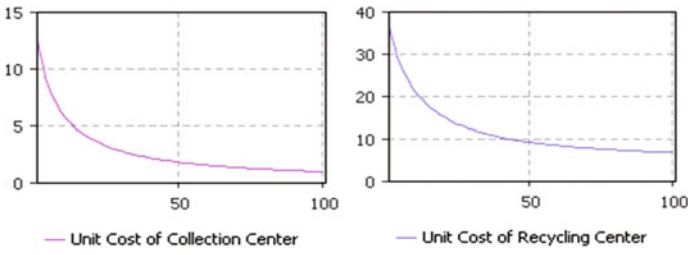

Fig. 3 Time plots for the unit cost of collection and recycling centers

governmental targets, reducing cost by using recycled material as a raw material, and having an environmentally friendly image.

If the investment cost is implemented in this model as a fixed cost of collection and recycling centers, opening a new facility can be considered instead of increasing the capacity. This model is specified for refrigerators but with a change in the life cycle parameter it can be generalized for many kinds of electrical and electronic equipment. Also, it can be extended to more areas and facilities for different producers in different countries according to their own regulations. This model is a basis framework for a closed-loop sustainable supply chain network design.

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Part II
Engineering and Technology Management

The Relationships Among the Prominent Indices: HDI-GII-GCI

Basak Cetinguc, Eyup Calik, Lutfihak Alpkan and Fethi Calisir

Abstract Several global indices have been used to classify and to analyze the states of countries. Comparison can be performed not only based on country but also annually for each country. In this study, three prominent indices, the Global Competitiveness Index (GCI), the Global Innovation Index (GII) and the Human Development Index (HDI) were investigated to examine the relationships between them by employing the PLS-SEM method. According to the results, HDI has an influence on GII while GCI is affected by GII. The results also demonstrated that GII has a full mediating effect on the relationship between HDI and GCI. Moreover, findings indicated that countries should improve their innovativeness by taking human capital into consideration to gain competitive advantages.

Keywords Index · HDI · GCI · GII · PLS-SEM · Mediating Relationship

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Introduction

Since ancient times, economies have been challenged to have a competitive advantage over other economies. Over the years, several indices have been created based on different facets of development or economic performance to classify the countries. These indices were an important tool for economies to benchmark themselves compared to other economies in a given year or observe the changing rankings of each economy year to year. In the meantime, each economy can monitor its own trends specifically to identify weaknesses and strengths in each designated sub-index. In the study reported in the present paper, we focus on three prominent indices: The Global Competitiveness Index (GCI), the Global Innovation Index (GII) and the Human Development Index (HDI). The global competitiveness index is used as a tool to evaluate the level of competitiveness; the global innovation index is an instrument to monitor overall innovativeness of countries; the human development index measures parameters of human development and it is widely used to assess the social development of a society (Sirotin and Arkhipova 2014). The aim of the present study is to investigate the relationships among these three indices.

The remaining sections of this paper are organized as follows. Section "Literature Review" covers the literature review of these concepts. Section "Methodology" presents the methodology followed. Finally, findings and conclusion are presented in Section "Findings and Conclusion".

Literature Review

In this part of the paper, the three indices mentioned above will be discussed briefly. Furthermore, past research regarding the interactions between these indices is reviewed.

Human Development Index

The Human Development Index (HDI) has been presented by the United Nations Development Program (UNDP) to assess the level of human development among countries on the basis of composite measurements since 1990. The index started with 144 countries and the last index that is produced in 2015 included 188 countries from all over the world. To measure human development, three dimensions are taken into consideration as long and healthy life, knowledge, and a decent standard of living. Long and healthy life estimation is determined by life expectancy at birth; in other words, the number of years a newborn infant could expect to live if the conditions of age-specific mortality rates remain the same throughout the

infant's life. Knowledge is measured by expected years of schooling and mean years of schooling. Lastly, the decent standard of living dimension is measured by gross national income per capita. After the measurements of these indicators, the average of them is calculated, giving each country a score between 0.00 and 1.00. There is a classification among countries according to the scores they gained. These classes are very high human development [1.00–0.80], high human development (0.80–0.70], medium human development (0.70, 0.55] and low human development (0.55, 0.00]. Moreover, there are also sub-indices such as the Gender Development Index (GDI), the Inequality-adjusted Human Development Index (IHDI), the Gender Inequality Index (GII), and the Multidimensional Poverty Index (MPI) to help to analyze specific areas of curiosity based on descriptive data.

Global Innovation Index

The Global Innovation Index examines innovation progress of countries worldwide along various dimensions. The first GII was conceived in 2007 by INSEAD as a tool to sort out how countries cope with the challenge of innovation (https://www.globalinnovationindex.org/userfiles/file/GII-2007-Report.pdf). After the first edition, 8 more editions were published. The last three editions were presented by a partnership of INSEAD, Johnson Cornell University and the World Intellectual Property Organization (WIPO).

It is important to point out that GII is an evolving measure that is affected by available data and trending concepts; ever changing and developing needs encourage measurement of innovativeness of countries with different indicators. 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.

The GII consists of two sub-indices: the Innovation Input Sub-Index and the Innovation Output Sub Index. The Input Sub-Index is designed to assess if the countries provide an environment conducive to innovation. Institutions, human capital and research, infrastructure, market sophistication and business sophistication are the indicators to evaluate the conditions. The Innovation Output Sub-Index includes knowledge and technology outputs and creative outputs and is designed to capture how given conditions and opportunities turn into 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 (https://www.globalinnovationindex.org/gii-2016-report).

Global Competitiveness Index

Since 1979 the annual Global Competitiveness Report has been presented by The World Economic Forum to shed light on the factors that countries encounter to

achieve competitive advantage. The number of evaluated countries changes year to year due to available data; 138 countries were ranked in 2016–2017 Report whereas 140 economies were listed in the 2015–2016 Report. Altogether there are 12 pillars under three sub-indices to measure competitiveness of economies according to their key factors. The Basic Requirement Sub-Index is a helpful tool for factor-driven economies and its pillars are (1) institutions, (2) infrastructure, (3) macroeconomic environment, and (4) healthy and primary education; the Efficiency Enhancer Sub-Index assesses economies efficiency based on 6 pillars: (5) higher education and training, (6) goods market efficiency, (7) labor market efficiency, (8) financial market development, (9) technological readiness, and (10) market size; the Innovation and Sophistication Sub-Index involves (11) business sophistication and (12) innovation pillars. Innovation-driven economies can use this sub-index as a guide to success. After gathering sub-scores from these three sub-indices, each economy has its own score ranging from 1 to 7.

The Relationships Among Indices

Nasierowski (2016) examined several composite indexes (The World Competitiveness Report Index, the Human Development Index, the Knowledge Economy Index, the Innovation Union Scoreboard, the Global Innovation Index and the Global Competitiveness Report Index) in order to determine their relationships by employing Pearson correlations. He found a strong relationship between the HDI and GII, the HDI and GCI, and the GII and GCI. Fonseca and Lima (2015) also found a high positive correlation between the GII and the GCI. Similarly, Pearson correlation analysis was conducted to capture the relationships among these indices and sub-indices of HDI and GCI. Her calculations were divided into three main parts. In the first part, the correlation between the HDI and GCI was examined. In the second part, the relationship between the GCI and the pillars forming the HDI was investigated. The last part of her study examined the relationship between GCI and GII. All factors mentioned in her study had strong positive correlations (Onyusheva 2015).

There are few studies in the literature that have examined causal relationships among these three indices. Sirotin and Arkhipova (2014) investigated the causal relationship between the GII and the HDI. They found that the best economies according to the GII also had the highest scores on the HDI. On the other hand, Taranenko (2013) used a regression model to show a positive impact of GII on GCI. Similarly, Cvetanovic et al. (2014) examined the relationship between the GII and the GCI of six Western Balkan countries and found GII has a positive but weak influence on GCI.

Although there are several studies on causal and non-causal relationships among indices, a model has not been proposed to test these relationships simultaneously. Moreover, no mediational analyses have been conducted. Therefore, a structural equation model (SEM) was developed in order to analyze the causal relationships

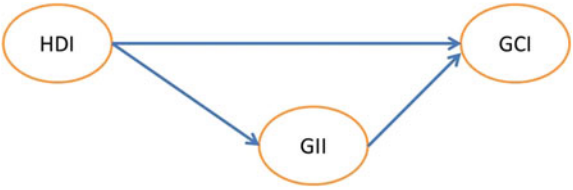

Fig. 1 The model of the study

between these indices with mediating relationships being considered. The model is shown in Fig. 1.

Methodology

In order to explore the interactions in the model, the data were collected from the websites of the corporations. We gathered the latest available data from each index, and the year 2015 was the last year for all of them. Each index includes a different number of countries depending on the responses to the distributed questionnaires. Economies were included in the data of this study if they were listed for more than two indices. After all the eliminations due to the restrictions, 99 economies remained. Different scales were used in each index; consequently, this may cause interpretive problems. In order to evaluate the data on the same scale, normalization was conducted for each of the indices. Finally, all the data ranged between 0 and 1.

The aim of this research to examine causal relationships among the HDI, GII and GCI. To examine the causal relationships among these constructs, simultaneous analysis is required. Partial Least Squares-SEM (PLS-SEM), which is a second-generation technique, was chosen for the analyses for the following reasons. Comprising both a structural and measurement model, PLS-SEM is a nonparametric method (Hair et al. 2011). Moreover, PLS-SEM does not require any distributional assumptions. Hair et al. (2014) suggest using PLS-SEM when the literature is not sufficiently developed. Furthermore, he and his colleagues mention that PLS-SEM is preferable when the main aim is to examine the explanatoriness of a structural model. However, PLS-SEM does not have a goodness of model fit measure to test theory; therefore, confirmation is limited (Hair et al. 2011).

Many researchers from various backgrounds have been conducting PLS-SEM in their research. Some examples of recent studies using PLS-SEM include Calabrò et al. (2017), Moreira et al. (2017), Pai et al. (2014), Vanalle et al. (2017), Wong (2013).

Analysis

In this study, Smart PLS 2.0 software was employed. Structural and measurement models are the elements of PLS-SEM. Additionally, measurement models are divided into two groups, reflective measurement models and formative measurement

Table 1 The statistical significance of the relationships

	Mean	Std. error	t-stats	p-values	Supported/not supported
HDI → GII	0.834	0.029	28.841	0.000	Supported
HDI → GCI	0.264	0.154	1.714	0.087	Not supported
GII → GCI	0.605	0.151	3.895	0.000	Supported

models. In this study, the measurement model is a reflective measurement model that is used when the indicators are caused by the constructs. Reflective measurement models have their own requirements for validity and reliability, and these include a composite reliability higher than 0.70, indicator loadings higher than 0.70, above 0.50 for the average variance extracted (AVE), and discriminant validity that is measured by Fornell-Lacker criterion (Hair et al. 2011). We employed PLS-SEM with a maximum number of 300 iterations and mean replaced missing values. Since our constructs were measured by creating a latent variable with one indicator, the required reliability and validity criteria have all been fulfilled. Composite reliability, indicator loadings and discriminant validity of all constructs were equal to 1. Based on AVE of the highest values, the discriminant validity requirement was also satisfied.

In order to test robustness of the structural model, R^2 values and path coefficients' significance were examined. R^2 values were found to be 0.675 for GCI and 0.693 for GII. Hair and his colleagues suggest that above 0.50 values of R^2 are moderate (2011). A bootstrapping procedure was conducted with 5000 subsamples and mean replacement to estimate significance of relationships, and findings can be seen in Table 1. The significance of relationships is supported if the t-statistics are above 1.96 for a two-tailed test (Hair et al. 2014, p. 186). In other words p values below 0.05 indicate significance.

It was found that the relationships between HDI-GII and GII-GCI is supported, while the relationship between HDI-GCI is not supported. To examine the mediating effect of GII, direct effects between HDI-GCI and HDI-GII-GCI were investigated. Figures 2 and 3 show the models of direct effects.

Fig. 2 Model of direct effects of HDI on GCI

Fig. 3 Model of simultaneous direct effects

Table 2 Direct effects of HDI on GCI

	Mean	Std. error	t-stats	p-values	Supported/not supported
HDI → GCI	0.753	0.047	15.912	0.000	Supported

Table 3 Direct effects of HDI on GII and GII on GCI

	Mean	Std. error	t-stats	p-values	Supported/not supported
HDI → GII	0.834	0.029	28.335	0.000	Supported
GII → GCI	0.809	0.045	18.077	0.000	Supported

Direct effects are significant, as seen in Tables 2 and 3; thereby we can conclude that GII has a full-mediating effect on the relationship between HDI and GCI.

Findings and Conclusion

This study is aimed at investigation of the relationships among three prominent global indices. The literature was reviewed to identify the likely nature of these interactions. Even though some studies addressed the relationships between indices, simultaneous analysis of relationships among these three indices was not found in the literature. This paper filled the gap in the literature by introducing a PLS-SEM methodology to clarify simultaneous interactions. According to the results, the Global Innovation Index is influenced positively by the Human Development Index, while the Global Innovation Index has a positive effect on Global Competitiveness Index. Moreover, the Global Innovation Index played a mediating role between HDI and GCI. In other words, investing in human development activities does not directly bring about success on global competitiveness to countries that want to increase competitiveness; they should pay attention to innovativeness of the economies. These findings indicate that in order to gain competitive advantages, countries should improve their innovative capability without compromising human capital.

Even though this study makes valuable contributions to the literature, it has several limitations. First of all, only the countries placed in these indices were included in the analysis. Secondly, the data of 2015 were examined because of their currency, but past years were not included. Finally, the PLS-SEM methodology has its own restrictions. Although these limitations are acknowledged, research findings provide a basis for future research. For instance, sub-indices of main indices can be added into the model to see the interactions between constructs. Furthermore, the model may be validated by conducting analysis of the data for each accessible year. Additionally, Hoftsede's cultural dimensions may be added to the model as a moderator.

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The Influence of the Strategic Planning Approach on the Research Agenda of R&D Organizations

Husam Arman

Abstract Strategic planning in a research and development (R&D) organization requires a different approach in analyzing and designing research programs and projects, because of the specificity of its objectives and activities. Therefore, deploying a traditional business strategic planning approach might not meet all of the organizational goals. The objective of this paper is to demonstrate how the strategic portfolio analysis using simple tools can be used to translate the strategy and influence the research agenda of an R&D organization. Kuwait Institute for Scientific Research (KISR) has developed a general and simple portfolio model that can enable organizations, in particular, R&D organizations to develop manageable research agenda that meet the strategic objectives of the organization. KISR was used as a case study enterprise to demonstrate this phenomenon and accordingly develop a practical model.

Keywords Strategic planning · Portfolio analysis · R&D planning
R&D organization

Introduction

Innovation has been an important driver for competitive success in many industries, and it has shown high impact on society if managed strategically (Schilling 2012). The rapid technological change and the resulting new innovations has compelled organizations to improve their agility to be able to adapt to and take advantage of the new opportunities and minimize any threats. Therefore, success belongs to those organizations that have the capacity not only to adapt to change, but also to thrive on it (Morris et al. 2014). For R&D organizations, it is important to rethink the way they plan and manage their research activities considering the speed of

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technological and social changes. Therefore, improving the productivity of R&D organizations is becoming a challenge. This stems from two basic reasons as follows (1) the character of the organization and (2) the type of people involved in R&D (Jain et al. 2010). In the current knowledge and creative economy, effective management of R&D is crucial.

The strategic planning specialists and consultants are under further pressure in R&D organizations to focus their efforts toward meeting strategic objectives of current and future stakeholders. Therefore, corporations that rely heavily on R&D need an innovation strategy that favor an 'incremental' approach (Ansoff's school of thought) as opposed to the common practice of 'rational' approach of Mintzberg (Tidd et al. 2013). The former approach can be more effective and consistent for a R&D organization which comfortably assumes imperfect knowledge of the environment and the future development. Hence, it is usually willing to change its strategy and even its approach to strategic planning in the light of development and changes that are frequently received and analyzed.

In R&D organizations, there is a bias toward allocation of resources to innovation activities. This sometime clashes with the business objectives of CEOs of corporates who want to acquire immediate profits, and the best way to do it. Therefore, there is a need to balance and manage innovation portfolio. According to Nagji and Tuff (2012), companies can outperform their peers if they optimize their innovation portfolio by allocating resources of about 70% to core initiatives (initiatives to make incremental changes to existing products and services), 20% to adjacent ones (initiatives that are aimed at leverage in another market something that the company does well today) and 10% to transformational ones (efforts designed to create new offers or a totally new business). This concept is very significant for independent R&D organizations and R&D functions within the corporation to keep up with the rapid pace of technological changes and to meet urgent client's needs. Therefore, they need to build their own dynamic capability that can accommodate the paradigm shifts in R&D strategies. Although it is difficult to make continuous changes to the management processes in any organization; albeit, it has been proven necessary for the long-term success.

Strategic Planning at KISR

KISR is an independent national scientific research institute that was established in 1967. KISR's initial role was dedicated to developing three fields of national importance; namely, petroleum, desert agriculture, and marine biology. Since then, KISR's role and responsibilities have greatly expanded to include the advancement of national industry and the undertaking of studies to address key challenges, such as the preservation of the environment, sustainable management of Kuwait's natural resources, responsible management of water and energy, and development of innovative methods of agriculture. Today, KISR consists of four research centers of about 580 researchers and engineers, over 100 laboratories, and three support

sectors housed at nine locations. KISR conducts scientific research and performs technological consultations for governmental and industrial clients in Kuwait.

At KISR, strategic planning has been one of the key functions that has been practiced since 1978 via formulation of a series of five-year strategic plans. Each of these five-year plans included a diversified set of goals that were oriented toward achieving KISR's goals in solving Kuwait's current and anticipated challenges. KISR completed a strategic transformation project in 2010 with the help of Arthur D. Little. The aim of this project was to transform KISR into R&D Center of Excellence focusing on innovation in support of the State of Kuwait. The project resulted in a new vision, mission, and a long-term strategy with a 2030 road map. The project also resulted in a new organizational structure and improved internal processes. Therefore, the first five-year strategy of KISR's 2030 vision was the 7th strategic plan. In this strategic plan, the research agenda included a large number of proposed research activities due to the highly positive atmosphere after the transformation project and the high expectation of hiring new researchers in addition to the anticipated improved efficiency of optimized support processes.

KISR's long-term strategy consisted of five strategic thrusts as shown in Fig. 1. These thrusts were designed to fulfill the new vision by focusing on client's needs, collaborating with leading research institutions, building research centers in application-oriented areas, commercializing technologies, and building culture of achievement and excellence.

The 7th strategic plan made reasonable progress along the five strategic thrusts, by expanding stakeholder engagement, in particular, the clients, creating key account management process, signing various MoUs with international research institutes, investing in new research facilities, establishing a division for commercialization, and revising several high impact management processes such as publication and promotion policies. However, the general quantified achievement of the 7th strategy was not as expected based on the self-assessment and the strategy evaluation conducted by the strategic planning team at KISR which has also utilized

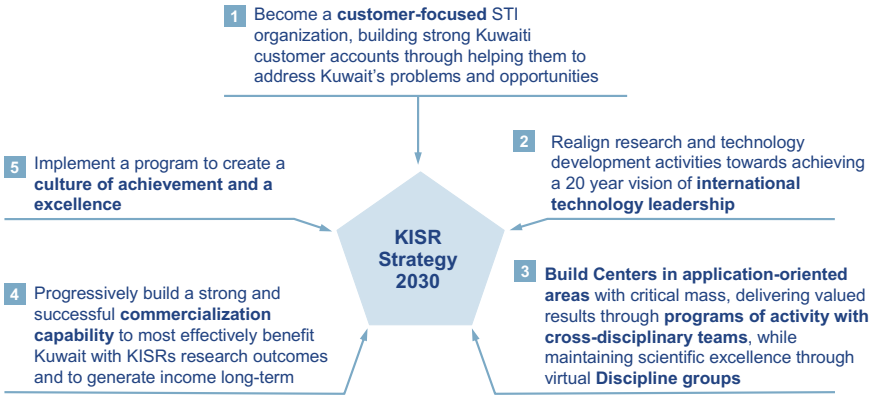

Fig. 1 KISR's five strategic thrusts for 2030

stakeholder's feedback. The justification of the aforementioned was rationally necessary and can easily be documented with direct corrective actions such as the lack of manpower (mainly researchers), inefficient support services, and bureaucratic management processes. Nevertheless, the top management and the strategic planning team reacted by questioning the strategic planning approach and decided to amend it to overcome some of the aforementioned challenges and ensure that an effective process is in place.

Methodology

The significance of this work is to highlight the challenge that strategic planning faces in R&D organizations and how, if managed with flexibility, can be useful. This paper proposes practical solutions that can be helpful to practitioners in the field of strategic planning for R&D organizations. The methodology used in this research was empirical and explorative, since there is a need to describe and document the current situation and explain factors which together cause a certain phenomenon (Yin 2003). The aim was to understand how the strategic planning approach can influence the research agenda of an R&D organization. Qualitative data were mainly used through observation, interviews, group discussions and workshops to carry out the case study at the Institute in addition to the feedback workshops after completing the strategic planning activity.

The Need for a New Strategic Planning Approach

In addition to the aforementioned identified challenges related to the 7th strategic plan, KISR followed fairly standard strategic planning approach which included revisiting the vision and mission, conducting internal and external assessment, deriving strategic objectives cascaded at various levels (Research Centers/Support sectors, divisions, and programs/departments) and projects related to these objectives.

As to KISR 8th strategic plan (2016–2020), the approach was similar, but important amendments and new tools were utilized to address various challenges. These included the gap between the plan and the implementation which was due to lack of resources such as manpower, and in particular, experienced researchers; diversion from addressing client's specific needs; spreading too thin diverse and long list of planned research activities; and the slow internal processes such as procurement and recruitment.

Considering the aforementioned challenges, several corrective actions and strategic initiatives targeting support sector processes to optimize the key internal processes were identified in the internal assessment exercise as part of the strategic planning activity. However, the strategic planning team challenged the strategic

planning approach itself and decided to revisit it with the objective of addressing proactively the aforementioned issues.

It was agreed with the top management that the 8th strategic plan includes an honest and complete assessment of how we are doing and accordingly lay out a strategy for closing any gaps, including any modifications to KISR's portfolio of research programs. The strategic planning approach was designed to steer the research centers to focus their resources toward the commitment to a high level of confidence to meet the priority elements of their strategies, which meant making conscious decisions to stop supporting less important activities, while selecting a portfolio of activities across their research programs. This is to further secure innovative solutions to key clients in addition to considering the development of innovations that will have positive impact and positioning KISR for long-term success.

Moreover, specific steps for executing the proposed strategy were required to ensure more attention to the factors that may enable or disable the strategy, particularly with respect to process improvement within the sectors and capability development in every organizational unit. This perspective of considering the strategic planning process as a problem-solving strategy was adopted as a philosophy to resolve the current issues/challenges. As Rumelt (2011) stated, good strategy results in investing time to make hard choices to gain focus and identifying obstacles and working out how to deal with them.

The terminology that was introduced during the strategic planning process was important in addressing the challenges faced, such as using the term solution areas that each program is required to deliver. The 'solution' has given the message that the research should result in a tangible output and application to the client; although, it can be addressed by more than one research project or technical service ('area'). This was a deliberate approach for this specific stage for KISR to focus on meeting key client's needs. However, the key function within the strategic planning model is the portfolio evaluation matrix (PEM). PEM was introduced to influence the research agenda to become more client-focused, address the critical few, and most importantly, produce a balanced portfolio of research activities using a tool that can communicate visually the impact of the various solutions areas within each program and at the center level. As a result, the strategic areas at the center level can be identified, and hence, the contribution of each research program.

Aligning Scarce Resources to Serve the Strategy

Aligning resources spent on R&D activities with the strategic objectives of any organization has been one of the most challenging issues, in particular to technology-based firms. The strategic planning process ideally ensures that the list of R&D projects are proposed to serve the market and product strategies. The alignment, if it happens, is usually enforced by embedding it in the evaluation criteria. This alignment criterion is useful in the evaluation process, but will not

necessarily result in a balanced portfolio that meets the strategic objectives which could lead to different directions. For instance, there are objectives regarding growth in market share and profits, focusing on the cash cows projects, and others, looking at blue sky areas.

Decision making tools and in particular, R&D portfolio analysis available in the literature are not used widely due to the perceptions held by the R&D managers that the models are unnecessarily difficult to understand and use, and do not engage practitioners in a collective creative manner, especially when dealing with models like linear programming. Cooper et al. (1997) provided various practical and simple to use bubble chart tools including risk-reward matrix which had proven to be useful and practical. Part of these sets is the Impact-Effort Matrix that has been used in many contexts, including lean and six sigma (Bunce et al. 2008). The concept of this tool is powerful that can be used as part of the strategic planning process since it can be utilized to reflect the conceptual meaning of a strategy that addresses two key questions; "Where do you want to go" (i.e., the 'Impact' you want to achieve) and "How to get there" (i.e., the 'Effort' needed to ensure the ability to execute the strategy and deliver the required results, which was the main challenge at KISR). However, these need to be translated to each organization as per their context, definitions, their mission and strategic objectives.

The generic matrix that we developed is based on the aforementioned concept, but we used the terms impact and ability. This generic framework can be used to translate any strategy to a visual and practical decision-aiding tool. The impact would reflect the expected contribution of the R&D programs and projects on the predefined strategic objectives of the organization, and these can be grouped based on the desirable portfolio shape of the organization to produce a balanced portfolio of activities.

The Portfolio Evaluation Matrix (PEM)

One of the important lessons learned from the execution of the 7th strategic plan was the number and magnitude of the projects proposed by the programs which far exceeded the organization's ability to support in terms of manpower, facilities, equipment, and administration. To correct this problem, the 8th strategic plan needed to focus on KISR's limited resources on those initiatives that will have the largest impact on meeting national challenges; client's mission critical problems; and KISR's reputation and financial commitments. Each center followed a sequential process to evaluate its existing research programs, determine which programs would be continued, added, or modified within the 8th strategic plan, and to identify the specific solution areas that would form the heart of the centers research activities over the next five years. This process is briefly described in Fig. 2 which shows the main features of the process. PEM is a critical function in the process which serves the three important objectives as follows:

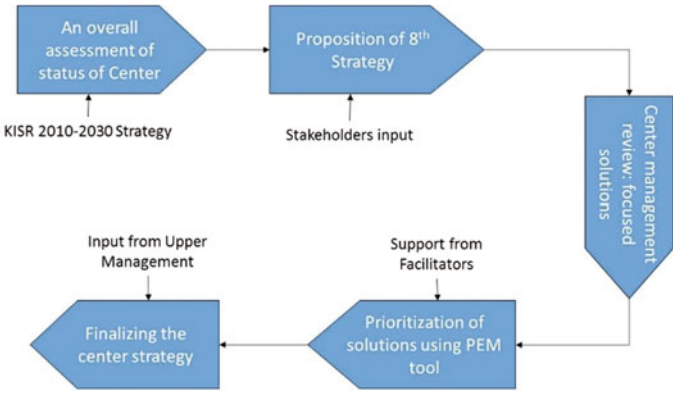

Fig. 2 Process overview for the development of the center research agenda

- To critically evaluate each of the programs and solution areas
- To help in making decisions with regard to aligning and directing programs toward the overall center strategy
- Select those program solution areas that the center will emphasize and give the highest priority.

The PEM was designed to help the center management in evaluating the solution areas that were proposed in the program strategies. The two-dimensional matrix as shown in Fig. 3 consists of two major criteria, the potential impact that the solution area may have in the next five years and the ability of the current program team to deliver what is being promised. Using this preliminary ranking as a guide, the center management can then make judgment decisions on program/solution area priorities within the center.

The codes used in the chart denote the program and solution area (e.g., P2A1 is the first solution area in research program 2) and the size of the bubble is the anticipated revenue stream from technical services/projects. The specific data about the solution areas within each program are not shown due confidentiality issue.

To calculate the potential impact of each solution area, three criteria with specific weight for each were used to evaluate each solution area. These criteria were derived from KISR's five strategic thrusts of the 2030 strategy. Each solution area is scored 1–10 scale points, as per the detailed definition of each criteria where 10 is the highest value.

- **The anticipated impact in meeting a national challenge**—Solution areas directly related to finding solutions for national challenges and expected to make high impact.
- **The anticipated revenue stream from technical services/projects and commercialization of IP**—Commercialization is broadly interpreted to include spinouts, IP income (patents, copyrights, license), and technology transfers.

- **Enhancement of KISR's regional/International reputation**—Outputs to be considered for evaluation include high impact publications, joint publications/activities with international partners, and regional STI leadership initiatives such as the Regional Persistent Organic Pollutants laboratory, patents, and attracting senior hires with an international reputation.

Likewise, to calculate the ability to deliver results, three criteria were used to evaluate each solution area using 1–10 scale point, as per the detailed definition of each criteria where 10 is the highest value.

- **Strength of the program leadership**—The talent, experience, motivation, and track record of the program manager and the identification of an adequate backup
- **Quality and depth of the program staff**—The availability of adequate professional and technician support for program execution
- **Adequate facilities**—The appropriateness of the current facilities, approved facilities and currently under construction.

The output of this process is not an overall score, i.e., a weighted average of the scores for impact and ability to implement, rather a matrix using bubble diagram function that was customized in an Excel-based program using VBA tool which shows four quadrants that can be addressed using different strategies.

- **High impact—High ability**: These are the expected winners where the anticipated impact is almost certain; hence, the center's image will rely on them and it will be a star, if expected revenues are high (e.g., P2A3, P2A1, P4A5 in Fig. 3).

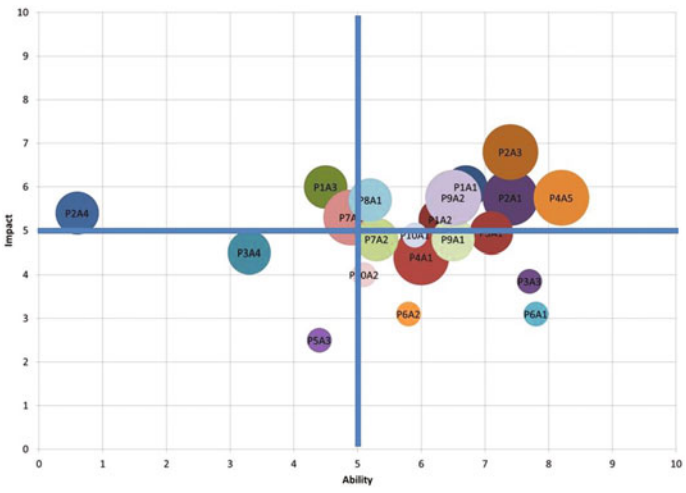

Fig. 3 Portfolio evaluation matrix (real example from one of the research center)

- **High impact—Low ability**: The solution areas here need special attention by the management and rigorous assessment to all the factors need to be addressed with urgency. These include recruitment, procurement, partnerships, consultants, etc. (e.g., P2A4 in Fig. 3).
- **Low impact—High ability**: The solution areas that fall here should be the ones that the center depends on in generating revenues, expanding its market, unless the expected revenues are not high (i.e., the size of the bubble) then a possible strategy is to divert resources to other solution areas where applicable or even use retraining strategies to enter new research area (e.g., P6A2, P6A1 in Fig. 3).
- **Low impact—Low ability**: The solution areas are not desirable here, and they should not be pursued. Therefore, it is important to revisit and reassess these solution areas and possibly abandon them at the planning stage and reallocate planned resources (e.g., P5A3 in Fig. 3).

The results of the overall ranking of the research center's solution areas are not the end of the process; further review and analysis and iterations to ensure that a balanced portfolio of research activities are maintained. This process has eventually helped the institute to focus on the critical few areas; and therefore, it has developed a much shorter list of key projects within each research program structure that satisfies the multiple goals of the institute. This has been a very useful approach from a management perspective.

However, the feedback was not received with the same motivation from the staff and research program managers, since they are usually excited and motivated to conduct a large number of research ideas based primarily on their interest, rather than on its alignment to the organization's strategy. Therefore, they found it for some time difficult to accept the portfolio result and especially if it redirects or undervalues their perspective on the program contribution when compared with other research activities. This challenge was overcome in the limited cases where the management of the involved research centers, at early stages, the research program managers, and in some occasion, the senior staff. Moreover, it is designed to make the process as transparent as possible, in addition to providing enough window for feedback and discussion.

Conclusion

This paper has demonstrated the motive to use the strategic planning approach to influence the research agenda of an R&D organization. The design of the strategic planning approach including the necessity to introduce new tools such as the PEM has helped significantly the research centers to focus their effort and energy on a manageable and balanced portfolio of research activity that meets the strategic objectives of the organization according to its long-term road map. The final research strategy addressed the identified gaps and issues of the centers resources being spread too thin and too broad to be effective in all areas. Moreover, the

strategic planning approach influenced the research agenda to include a mix of research activities that can, in totality meet the key performance indicators associated with the five strategic thrust of KISR's 2030 strategy effectively. These conclusions were documented based on the feedback that was captured from various interactive workshops with all the management of the research centers. The main lesson learned from this exercise showed that a standard and a rigid strategic planning process will not serve a research organization which evolves naturally and continuously due to the dynamic external conditions. Therefore, adopting an agile approach and introducing innovative management tools within the strategic planning approach are important to enhance the performance of the strategic planning of any research organization. Moreover, considering the workshop feedback on the 8th strategic plan approach, a further modified approach will be considered with the aim to address the important issue of producing a truly integrated institute strategy and reflecting an optimized research portfolio at the institute's level.

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Effect of Organizational Justice on Job Satisfaction

Aylin Ozel and Cahit Ali Bayraktar

Abstract The purpose of this study is to measure effect of organizational justice concept on job satisfaction of individuals. The concepts of "organizational justice" and "job satisfaction" have very important places for organizations in reaching to their objectives. Job satisfaction levels of employees are affected either positively or negatively due to their perceptions on organizational justice regarding practices in their organizations and how fairly they are treated. Employees whose job satisfaction levels are affected positively are motivated by their work and add value to their organization. The concepts of organizational justice and job satisfaction become even more important when strategic importance of human resources is taken into account in a competitive business environment. This study consists of two parts. In the theoretical part of the study, organizational justice and job satisfaction concepts are explained in detail together with their dimensions. While the concept of organizational justice was considered as the independent variable in the study, the concept of job satisfaction was considered as the dependent variable. Afterwards, the research model was formulated and implementation part of the study was introduced. This study was carried out with the participation of 165 people working in various sectors in Turkey. Throughout the study, survey technique, one of the data collection techniques, was used. Findings of the study showed that organizational justice affected job satisfaction of the individuals positively.

Keywords Human Resource Management · Organizational justice
Job satisfaction

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Introduction

The concept of organizational justice is the rules and social norms covering the management of rewards and penalties that will be given to employees. The perception of organizational justice is related to the perceptions of employees about practices in their own organizations and about how fairly they are treated. It is a phenomenon attempting to explain in what way these perceptions affect organizational outcomes such as job satisfaction and organizational commitment (Greenberg 1993). Job satisfaction means that the employee has reached to his or her job-related expectations or obtained work results in a good way. In other words, it is how an employee feels himself or herself towards the job (Demirel and Özçinar 2009: 132). A positive relationship among sense of justice and job satisfaction at workplace was reported in conducted studies (Dailey and Kirk 1992; Folger and Konovsky 1989; Martin and Bennett 1996), that is, job satisfaction increases when justice increases and job satisfaction decreases when perceptiveness of justice decreases (Cobb and Frey 1996; Fryxell and Gordon 1989; Lawson et al. 2009). Greenberg (1990), who conducted a number of researches on organizational justice, stated that employee satisfaction was a fundamental need for running of an organization.

In a globalizing world, job satisfaction of employees based on organizational justice should be provided in order to keep the organization running. Throughout the current study, positive or negative effects of organizational justice on job satisfaction will be investigated within the given framework. In addition, the relations among organizational justice and dimensions of job satisfaction will be investigated and findings will be revealed. The obtained results will be discussed and suggestions will be made in the conclusion part.

Organizational Justice

Many researchers such as Folger, Konovsky, Greenberg have conducted studies in the field of organizational justice. In these studies, organizational justice has been defined as an organizational value associated with a number of positive work outcomes (Niehoff and Moorman 1993: 531). Organizational justice is examined in three dimensions which are distributive, procedural and interactional.

Distributive Justice

According to the researchers, the first component of organizational justice is the distributive justice. Because, this dimension of justice could reach results and outputs that other dimensions could not. Distributive justice deals with a different

reality, except from an understanding of reality that varies from institution to institution and it includes equal treatment for all employees (Cropanzano et al. 2007, p. 37). Distributive justice is the sense of justice that is related to the understanding of rights regarding encountered acquisitions or gains. The scope of distributive justice covers allocating all kinds of gains such as duties, goods, services, opportunities, penalties etc. or rewards, roles, statutes, fees and promotions among the employees in an organization (Yıldırım 2010: 65).

Though it is said that all employees are equally qualified within the scope of distributive justice, this is not the case in practice. The positions, performances and benefits of employees vary. Organization evaluates its employees considering these factors. Distributive justice emerges at this point. Which employee will be given a share to what extent and what will be given to whom, are within the field of distributive justice (Abbasoğlu 2015).

Procedural Justice

Procedural justice refers to the perceived justice on formal procedures that are used for making decisions (Taskiran 2011, p. 106, as cited in Yadong Luo). The concept of procedural justice depends on the opinion of whether procedures or methods used are right from the standpoint of the individual in the process of making decisions by the management intending the individual himself or herself or other employees. Meaning of the procedural justice is, following the same procedures for everyone in the organization, employees having the opportunity of participation in the decisions and having an informative system. It also means applied procedures are appropriate for the culture formed within the organization and are away from prejudices and biased behaviours. In addition, justice perception of an employee during decision making towards the employee himself or herself or towards the others is also explained with procedural justice. Here the employee is interested in the organization as being standard. It will not escape from eyes of the employees if the organization treats some members differently in employee-concerning decisions (Yavuz 2010: 306).

Interactional Justice

Human behaviour, a different dimension of organizational justice, has come into prominence as studies on distributive and procedural justice progressed. Such issues as effects of these applications on human behaviours, manager-employee relations and justice expectancies of employees were discussed and importance of human relations in an institution was emphasized and interactional justice with communicational focus has started to become a research topic (Abbasoğlu 2015). Interactional justice is defined as in-practice treatment of an institution towards its

employees and employees' perception of justice towards the quality of this attitude (Bies and Moag 1986, pp. 43–55). According to Güçel (2013), interactional justice is the intuition of justice of the differences among interpersonal behaviours within an organization. As the sense of personal confidence increases, the power of the organization also increases. In this context, interactional justice is also affected by how and in which way the taken decisions were or will be expressed to the employees. (Kılıçlar 2011: 25). As for the result, interactional justice demands treating employees respectfully and politely, saying that is to say appropriately, explaining events and situations together with their reasons. Contributions of employees to work are directly proportional to employees' productivity and job motivation in an organization. Dealing with justice with all its dimensions and applying it in the most accurate way are necessary so that employees can use their performances in a positive way (Abbasoğlu 2015).

Job Satisfaction

People spend a large portion of their daily lives at work from a certain age onwards. In this context, a person, who gets the expected from his job, that affects not only the economical but also the psychological state, can be happier. Therefore, job satisfaction has an important role in human life in terms of both economical and psychological aspects (Bakan and Büyükbeşe 2004; 6). In the literature, job satisfaction is investigated in nine dimensions.

Pay

Studies in the literature have revealed that job satisfaction of employees is closely related to the paying. Research has shown that job satisfaction of those employees, who are pleased with their pay, is high (Bölükbaşı and Yıldırtan 2009). Regarding paying provided by an organization, employee attitude towards the job is determined by the sufficiency, being balanced and degree of meeting expectations in return for the benefits the employee believes that he provided. Again regarding paying, equality among the same level employees is more important than the degree of fulfilling the expectations (Gözen 2007, p. 39). Low paying is one of the main dissatisfaction sources for employees in businesses. However, high paying alone is not adequate to ensure job satisfaction of employees.

Promotion

Realization of promotional practices in line with justice and existence of opportunities towards promotion in an organization are closely related to job satisfaction because promotion is an indicator of a person is successful and an indicator of his or her estimated future success. Promotion also brings status and pay increase (Samadov 2006, p. 27). It is certain that dedication of work and excitement will mostly decrease of those administrators whose paths of promotion are clogged (İşcan and Sayin 2010, p. 153). While devotion to job and desire for working of those employees who get the opportunity of promotion increase, a problem of dissatisfaction among employees is experienced in organizations where a career system is not clearly defined and where a fair promotion system does not exist (Bozkurt and Bozkurt 2008: 6).

Communication

Thanks to communication, employees in organizations find a chance to learn what is expected from them, how they should do their jobs, and what their superiors or other employees think about them (Çaylı 2013). Communication is a factor that plays an important role on all morale process, and it draws attention mostly when it does not exist. Lack of communication forms one of the leading sources of dissatisfaction in organizations (Meriçöz 2015). In case of establishing adequate communication correctly and on time, the targets would be reached in a shorter time and employees would be able to get job satisfaction easier as they will get the returns of their efforts quicker (Samadov 2006, p. 33).

Fringe Benefits

Opportunities such as transportation services, lunch or health services in an organization can increase job satisfaction of the employees. Correspondingly, absence of these opportunities can cause the employees to feel dissatisfied with their job.

Supervision

Behaviour styles of the managers and their types of administrating the authority affect job satisfaction of the employees. The type of manager, who we call as reputable, democratic, or collective, provides higher job satisfaction than authoritarian and directive type of manager (Sarıkamış 2006, p. 62). The management

types, which are well-known by society, which are seen important, which value team work, which work with companies with broad service environments and which attach importance to creativity of the employees, provide their employees more satisfaction (Başaran 1982, pp. 204–205). In 2012, in a survey conducted by the Society for Human Resource Management, 71% of the employees stated that effective communication that they established with their managers played a critical role on their job satisfaction.

Operating Procedures

Policies and procedures related to work within the organization in other words, the way of doing a work, can affect the job satisfaction of the individuals.

Co-workers

It is stated that, while job satisfaction of employees is seen to be higher in small organizations with a small number of employees, this satisfaction is lower due to unmet expectations of employees in large organizations. At the same time, the reason to low level job satisfaction in large organizations may be due to the undeveloped proximity and friendship feelings among employees (Solmuş 2004, p. 189). It can be said that the reasons of employees working in small businesses have a higher job satisfaction than those working in large businesses are their better communications with their colleagues and the feeling of trust towards them.

Nature of Work

Job characteristics and job itself are the most important factors that affect employee satisfaction. In the Job Characteristics Theory (Hackman and Oldham 1980) the quality of the job being done is seen as the basic factor that affects employee satisfaction. In order to increase their motivation and job satisfaction accordingly, employees should be convinced of importance and meaningfulness of their job (Meriçöz 2015). Castillo and Cano (2004) defined quality of work as the most important motivating factor in increasing work performance based on job satisfaction.

Contingent Rewards

Performance based rewarding of employees through a fair system affects job satisfaction in a positive way. Increasing high job satisfactions of employees in an organization can be achieved by developing proper rewarding systems (Erkmen and Şencan 1994, p. 145). Rewards also consolidate the needs for trust and respect as they maintain the consciousness of being valued among employees and also the consciousness of employee benefits are considered as equal to organizational benefits (Kaynak 1990, p. 141).

Research Model and Hypothesis Formulation

The distributive justice concept refers to whether resources are distributed fairly by the organization (Andrews and Kaçmar 2001: 349; Melkonian et al. 2011: 812) and is based on evaluations regarding fairness of rewards or outcomes which individuals receive. In this content, wages, promotions, premiums and rewards can be given as examples to gains achieved by the employees (cited in Taner et al. 2015: 182).

A person at a workplace will be satisfied with his or her job if he perceives and senses fair pricing and fair opportunities of promotion (Robbins 1998: 152). Accordingly, it can be stated that distributive justice perception of people working in an organization affects job satisfaction positively.

The ways to determine the gains that staff will obtain, the elements of performance evaluation and the ways to be followed in solution of problems among employees are determinatives of perception of procedural justice (Çetinsöz and Turhan 2016). When we think of administrative-practices related satisfaction relies on fairness of these practices, it can be said that perception of procedural justice causes job satisfaction (Çetinsöz and Turhan 2016).

Interactional justice is a concept pointing to qualifications of interpersonal relations and is defined as the third separate type of justice independent of procedural and distributive justice concepts (Folger and Cropanzano 1998).

Because polite and respectful manners of managers towards their subordinates are the basic elements underlying interactional justice, it can be stated that interactional justice plays an important role in ensuring job satisfaction. Within this respect, displaying behaviours that are respectful to employees' opinions and feelings consolidates the feeling of trust towards the managers and ensures the increase of job satisfaction at the same time by reducing role ambiguity and work stress (Çetinsöz and Turhan 2016).

The research model of the study is shown in Fig. 1. The studies mentioned above have been initiators for the formulation of the following hypotheses:

H1: Organizational justice has a positive effect on job satisfaction.
H2: Interactional justice has a positive effect on organizational justice.

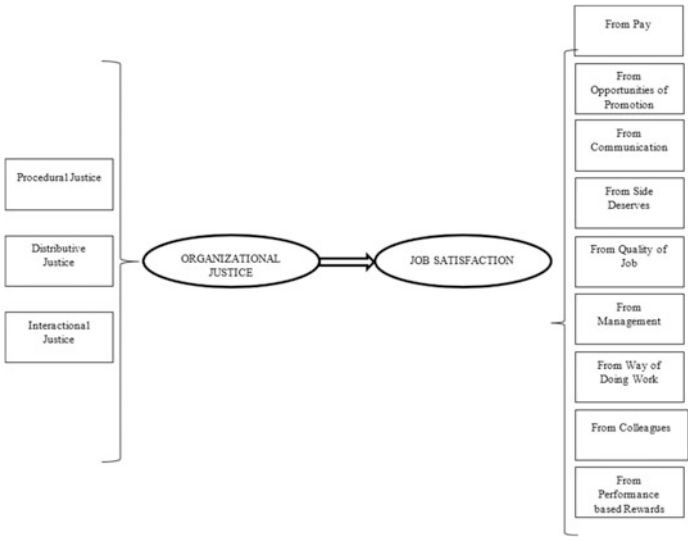

Fig. 1 Research model

H3: Procedural justice has a positive effect on organizational justice.
H4: Distributive justice has a positive effect on organizational justice.

Method

The current study was conducted with the participation of 165 people working at 20 different sectors on textile, machine manufacturing, consultancy services, finance, food, etc., in Turkey. Among the participants of the survey, 68.3% are males, 31.7% are females, 18% are younger than 25, 18% are between 25 and 34, 12.2% are between 35 and 44, 51.8% are over 45. Also 40.3% are trying to become managers, 11.5% are first-level or lower-level managers, 30.2% are mid-level managers, 18% are high-level managers, 2.2% are high school (or lower) graduates, 4.3% hold an associate degree, 59.7% hold an undergraduate degree and 33.8% hold a graduate degree.

Data Collection Tools

Job Satisfaction Survey (JSS) developed by Spector in 1985 was used in this study to measure dimensions of job satisfaction. Questions, which were used in the studies of Çavuş and Cumaliyeva (2013) to measure general job satisfaction, were benefitted.

Scale of Organizational Justice of Niehof and Moorman (1993) was used in measuring the dimensions of organizational justice. Questions prepared by Anantatmula (2007) and were benefitted in measuring general justice.

Five-point Likert-type scales with options from 1 (absolutely disagree) to 5 (absolutely agree) were used in the measurements.

Findings

When the data set used in the research is investigated, it is seen that skewness and kurtosis values for all items are within this range except for the kurtosis value of one item. That's why, this item which was not showing a normal distribution, was excluded from the analyses. For all items included in the analyses, skewness values between 1.242 and 0.733 and kurtosis values between 1.212 and 1.789 were observed.

As a result of a reliability test on organizational justice and job satisfaction, two of the dimensions specified in the research model, Cronbach's Alpha values among this dimensions were found larger than 0.5. These values were accepted as reliable since Jenkinson et al. (1994) stated that Cronbach's Alpha values larger than 0.5 were acceptable. In order to pass the reliability test, one item from colleagues' dimension and one from the way of doing works dimension were excluded from the analyses.

Since Hair and colleagues (1995) defined minimum sample size required for performing a factor analysis on a sample as 100, the sample used in the current research and consisting of 165 data is convenient for factor analysis.

15 factors were obtained after the factor analysis. All factors could be grouped under one factor except the ones of interactional justice. Items of interactional justice were grouped under a second factor (Table 1).

When the table of correlations, obtained as a result of the analysis, is investigated, positive correlations between organizational justice and job satisfaction, distributive justice, procedural justice were determined.

As a result of calculating the effect of organizational justice on job satisfaction, organizational justice was found as 23.8% effective on job satisfaction. During the analyses, Durbin–Watson value was also calculated as 1.964 which is within the ideal range. When effects of justice dimension on organizational justice, it is seen that procedural justice is 43.3% effective while interactional justice is 19.2% effective on organizational justice. According to the results of the regression analysis, the sample did not provide enough evidence for the effect of distributional justice on organizational justice. However, Bayarçelik and Fındıklı (2016) argued in their studies that interactional justice did not have an effect on job satisfaction while distributive and procedural justice had.

As the result of the regression analysis, the sample did not provide enough evidence for the H4 hypothesis while it supported H1, H2 and H3.

Table 1 Results of the factor analysis

Factor	Cronbach's alpha	KMO	% Variance
Supervision	0.792	0.772	62.11
Promotion	0.753	0.754	57.49
Pay	0.823	0.784	65.5
JS-overall	0.798	0.815	55.78
Fringe benefits	0.702	0.693	54.79
Nature of work	0.811	0.803	64.51
Communication	0.728	0.730	55.38
Contingent rewards	0.675	0.687	51.11
OJ-overall	0.836	0.838	56.14
Interactional-decisions	0.844	0.835	34.09
Interactional-fairness	0.844	0.835	24.07
Procedural	0.908	0.911	68.49
Distributive	0.84	0.829	61.208
Operating procedures	0.5	0.542	51.03
Co-workers	0.563	0.500	69.595

The analysis of variance (ANOVA) revealed differences of distributive justice perception among manufacturing and services sector employees, among employees working at the same workplace for 3–5 years and for more than 11 years and among undergraduates and graduates. Similarly, differences of procedural justice perception among these groups were also seen.

Results

In order protect their power of competition in a globalizing world, businesses should give value to their employees and employee attitudes towards their job. Attitudes of employees towards their job are closely related to the concepts of organizational justice and job satisfaction. In an organization, a case of organizational injustice will have reflections on behaviours and attitudes of the employees towards their job. As a consequence, employees will either become distant or display negative feelings towards the organization. For this reason, establishing organizational justice in an organization is of great importance.

Throughout the study, relation of organizational justice with job satisfaction was investigated considering the other studies in the literature and based on these studies, 4 hypotheses were formulated to be tested. During the process of hypothesis testing, a survey was administered on 165 employees working at organizations that are operating at 20 different sectors. The collected data was analysed using SPSS software. Three out of the four suggested hypotheses were supported but conversely, the sample did not provide enough evidence for the

remainder. As a result of the analyses, it is seen that organizational justice has a positive effect on job satisfaction of the employees. This case provides support for the research studies of Dailey and Kirk (1992), Folger and Konovsky (1989), Martin and Bennett (1996), Yürür (2008) and Çetinöz and Turhan (2016). According to the results of analyses performed, 23.8% of job satisfaction originates from the organizational justice. According to research findings, perception of organizational justice is one of the determinative factors of job satisfaction. Therefore, organizations aiming to establish job satisfaction of their employees should take effective steps for providing organizational justice. In their studies, Tekleab et al. (2005) and Simons and Roberson (2003) showed that the concept of organizational justice is effective on employee turnover rate. As per this, job satisfaction of the employees with high perception of organizational justice will increase while their intensions of leaving the organization will decrease. Conversely, employees with low satisfaction towards the job will seek other options and leave the organization.

In their study, Seyyed Javadin et al. (2008) stated dimensions of organizational justice had effects on perceptions of individuals on organizational justice and job satisfaction. While the sample in this study provided sufficient evidence supporting positive effects of procedural and interactive justice on perceptions of the individuals on organizational justice, it did not provide sufficient evidence supporting positive effects of distributive justice on organizational justice. According to the obtained findings, procedural justice explains 43.3% of organizational justice while interactional justice explains 19.2% of it.

The individuals whose perceptions of procedural and interactional justice are high will be more satisfied with their jobs. This case is contradictive with the findings given in Bayarçelik and Fındıklı's (2016) work, because these researchers argued distributive justice had effects on job satisfaction. According to the researchers, employees who obtain fair paying, fair promotions, etc., in return of their efforts will have a high job satisfaction. Though, the revealed results of the current study do not support this case.

When it is considered that 51.8% of the individuals, who are in the research sample, are 45 years and older, it can be commented that distributive justice is starting to be effective on job satisfaction with the increasing job experience. The fact that 68.3% of the surveyed employees are males which shows job satisfaction of male employees is not related to distributive justice. Besides, the fact that 59.7% of the employees have duties in various administrative positions which indicates distributive justice does not affect job satisfaction of employees in administrative positions.

The revealed results show that establishing organizational justice depends on establishing procedural and interactive justice. Procedural justice is about fairness of in-house works. In this context, perception of procedural of an employee increases if he or she believes in the fairness of the procedures and methods, that are used for taking decisions about himself or herself or about the others, and thinks himself or herself as being a part of this process. Therefore, it is suggested to make fairer the in-house decision making process, include the employees in this process, be

transparent in administrative practices, apply participatory management practices and ensure the in-house developed procedures to be in line with the organization culture. Besides, organizations should define their visions, missions, strategies and policies transparently to ensure procedural justice. The concept of interactional justice on the other hand, consists of superior-subordinate relationship resulting from positive behaviours of managers towards employees. Thus, charging skilled managers in various management positions, who show respect to employees' thoughts and feelings, who comprehend human relations in an organization and who can establish strong relations with the employees, plays an important role in establishing organizational justice. Besides, a door should be left open between managers and employees and a regular flow of thoughts and feelings should be ensured.

In addition to these, the differences of justice perception of the employees were seen among various levels of experience, levels of education and sectors of businesses. Ensuring organizational justice in a business will have reflections on job satisfaction levels of the employees and as a result, employees will be satisfied with wages, opportunities of promotion, communication, fringe benefits, the way of doing works, quality of the work, performance based rewards and colleagues. Individuals with high job satisfaction will be more motivated in their work, will feel happier at the work environment, feel healthier physically and spiritually, have more commitment to the workplace, have higher performance and efficiency and finally rates of turnover will decrease. Low job satisfaction is unhappiness for employees and is an evidence showing conditions in an organization are worsening and is an important issue that needs to be emphasized. Job satisfaction has both individual and organizational results and reaching to organizational objectives is easier with those individuals who have a high job satisfaction. And a business which can reach to its organizational objectives will exist in the sector by maintaining its power of competition.

As for the conclusion, concepts of organizational justice and job satisfaction are unarguably important concepts in our lives. In order to survive, businesses should establish organizational in-house justice, also, practices which may cause to organizational injustice should be eliminated and job satisfaction of the employees should be measured by administering questionnaires at certain intervals by the management. In this way, defective aspects of in-house organizational justice should be detected and job satisfactions of the individuals should be restored by solving problems in a short amount of time.

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Importance of Developing a Decision Support System for Diagnosis of Glaucoma

Murat Durucu

Abstract Glaucoma is a condition of irreversible blindness, but early diagnosis and appropriate interventions can enable patients to see for a longer time. This addresses the importance of developing a decision-support system for glaucoma diagnosis. Glaucoma occurs when pressure happens around the eyes, which causes damage to the optic nerves and deterioration of vision. There are different levels of glaucoma disease including blindness. Diagnosis at an early stage allows a chance for therapies that slows the progression of the disease. By using Optical Coherence Tomography (OCT) images and pattern recognition systems, it is possible to develop a support system for doctors to make decisions on glaucoma. Thus, in this recent study we develop an evaluation and support system for the use of doctors. Computer software based on a pattern recognition system would help doctors to carry out objective evaluations for their patients. It is intended that after carrying out the development and evaluation processes of the software, the system will serve for use by doctors in different hospitals.

Keywords Decision support system · Glaucoma · Image processing
Pattern recognition

Introduction

This study focuses on the need to develop an objective decision support system for evaluating the level and occurrence of glaucoma disease. Glaucoma is diagnosed by considering the patient's family history and by using clinical techniques, such as tonometry, ophthalmoscopy, perimetry, gonioscopy, and pachymetry. Glaucoma causes irreversible blindness in patients in its late stages. Diagnosis at an early stage allows for therapies that slow the progression of the disease. Also, diagnosis at an

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early stage can decrease the socio-economic wages for patients and the countries where they live (Mazhar 2013). However, problems have been experienced in the diagnosis of the disease by clinical examination, so it is necessary to develop new techniques so that diagnosis can be made at an early stage. This disease is frequently encountered, especially between the ages of 40 and 80 years, despite its dependence on genetic factors. Globally, 3.54% of the population suffers from glaucoma; also, according to data from 2013, 64.3 million people between the ages of 40 and 80 years suffer from glaucoma worldwide, and this number is expected to reach 76 million in 2020 (Quigley and Broman 2006) and 111.8 million in 2040 (Tham et al. 2014). Some studies have found that glaucoma affects 44.7 million people across the world, 2.8 million of them living in the United States, leading to 1.6 million in direct and indirect costs including 0.9 million in total. It is reported that costs of $2.5 billion are generated. The development of glaucoma is illustrated in Fig. 1. Increased blood pressure inside the pupil damages the optical nerves.

The major symptoms of glaucoma include (1) blurred vision, (2) severe pain in the eye, (3) rainbow hallows with light headache, (4) brow pain nausea, and (5) vomiting with red eye. Intraocular pressure is also identified as one of the risk factors that cause glaucomatous damage to develop, and lower pressure leads to progressive retinal degenerative change (Murthi and Madheswaran 2014).

Different levels of glaucoma are recognized in the literature. A comparison between normal vision and glaucoma eye can be seen in Fig. 2. A description of the levels of glaucoma considered by ophthalmologists can be found in Table 1.

In recent years, imaging technology such as Heidelberg retinal tomography (HRT), stereoscopic disc photography (SDP), and optical coherence tomography

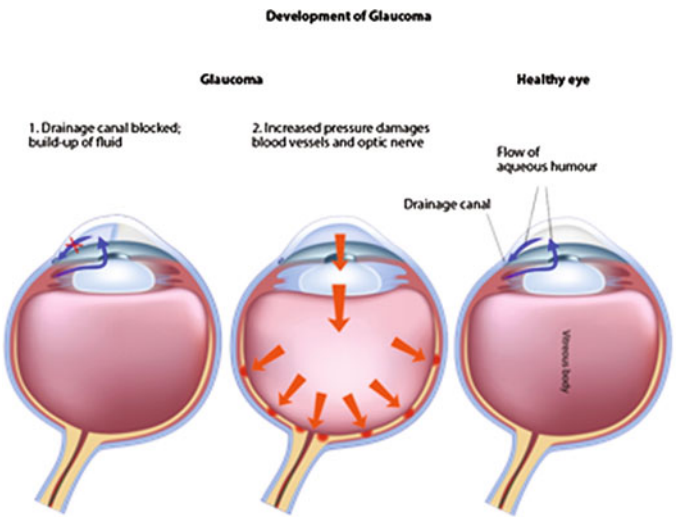

Fig. 1 Development of glaucoma

Fig. 2 Samples of different levels of patient vision

Table 1 Glaucoma levels

Light or early level glaucoma	Glaucoma is defined as optic nerve abnormalities that are similar, but there is no abnormality in the visual field in a white upon white field test
Mid-level glaucoma	Glaucoma is compatible with optic nerve abnormalities. A hemisphere is encountered and 5 is a very hard glaucoma anomaly
Extreme, last term level glaucoma	Glaucoma is consistent with glaucoma of the optic nerve, visual field abnormalities or anomalies are found in both hemispheres, and at least 5° of loss of vision occurs in one fixed hemisphere
Uncertain glaucoma	Visual fields have not yet occurred or are not suitable for patients with visual field testing or visual field tests are applicable/unreliable state

(OCT) have been used for the diagnosis of glaucoma (Mwanza and Budenz 2016). This better accuracy and faster imaging techniques in response technique of OCT has become the most common method used by experts. The retinal nerve fiber layer (RNFL), optic nerve head (ONH), and reasonable analysis are applied to detect any glaucoma damage by OCT (Bai et al. 2016). Due to all the economic factors, early diagnosis of glaucoma is very important for the patient's quality of life as economic costs. Clinically, the diagnosis of glaucoma can be done through measurement of the CDR, defined as the ratio of the vertical height of the optic cup to the vertical height of the optic disc. An increment in the cupping of the ONH corresponds to increased ganglion cell death and hence CDR can be used to measure the probability of developing the disease. A CDR value that is greater than 0.65 indicates high glaucoma risk (Li and Chutatape 2003).

Figure 3 illustrates medical imaging normal and affected eyes (Murthi and Madheswaran 2014). When there are defects in the optical nerves, irreversible blindness will begin.

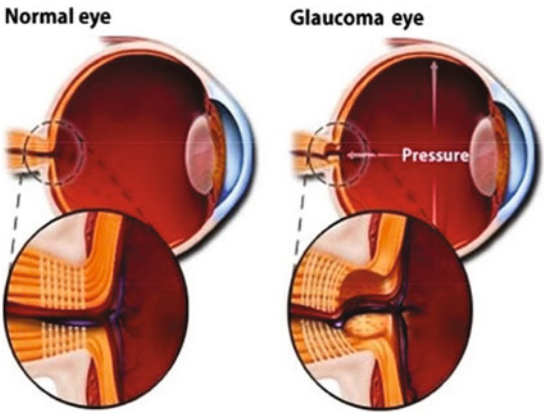

Fig. 3 Medical imaging of normal eye and affected eye (Murthi and Madheswaran 2014)

Methodology

To date, procedures that have been employed for detection of glaucomatous visual field progression may be broadly grouped into four categories: subjective clinical judgment, defect classification systems, trend analyses, and event analyses.

Clinical Judgment

Clinical judgment consists of simple subjective observation of sequential visual field test results and represents the oldest method of identification of progressive visual field defects. This approach is advantageous for a number of reasons: (1) it demands no additional computation; (2) it is highly flexible as observers with any degree of experience may apply it to the results of any instrumentation; and (3) it is easy to perform. However, the subjectivity of this approach means that it is also poorly controlled and criteria can vary considerably from one evaluator to another. A comparison of visual field series evaluated for deterioration, stability, or improvement by six expert observers illustrates the disadvantages of clinical judgment (Werner et al. 1988). When using clinical judgment to assess data, care should be taken when a patient is examined by using a variety of threshold estimation algorithms.

Defect Classification Systems

Visual field defect classification systems use predetermined criteria to grade single test results, providing a discrete score for each visual field test result. The advantages

of this approach are that test results are immediately stratified into broadly similar defect magnitudes, interpretation is relatively simple, and progression can be easily defined as worsening of the score over time. There are, however, a number of drawbacks to the use of classification systems. They do not provide information on the spatial configuration of defects and may not be scaled linearly; for example, a change from 0 to 3 may not be equal to a change from 10 to 13.

Trend Analyses

Trend analyses evaluate test parameters sequentially to determine temporal patterns that may exist within the data (Holmin and Krakau 1980, 1982). Such analyses are of value because they are capable of determining long-term characteristics with the use of information from all visual field examinations performed on a patient and therefore have the potential to discriminate subtle progressive loss from considerable degrees of test variability (Fitzke et al. 1996).

Event Analyses

Event analyses are valuable because they attempt to identify single events of significant change relative to a reference examination (Hitchings 1994). Event analyses can be relatively simple and can look for statistically significant differences between one examination and another, for example by using the DELTA program of the Octopus perimeter. This particular method employs a paired t-test to determine whether significant differences are present between one test result and another.

Conclusion

Although HRT or OCT images offer precision and quickness, especially in the early stages, difficulty and mistakes are experienced in the diagnosis of glaucoma. When the diagnosis relies on the discretion of the doctor and placement process, it is difficult to obtain objective results. It is very important to develop an objective decision-support system for diagnosis and for determining the level of glaucoma disease in patients.

In recent years, computer aided diagnosis (CAD) has played a major role in screening for glaucoma. The CAD system is simple, repetitive, not prone to inter- or intra-observer variability, and fast. Also, CAD can be used to screen many patients in a short time. There is a scarcity of ophthalmologists in many developing countries, where CAD can be very useful. The proposed decision-support system for glaucoma can differentiate normal and glaucoma classes accurately.

By using OCT images and pattern recognition systems, it is possible to develop a support system to help doctors make decisions on glaucoma. For this purpose, an evaluation and support system offered to develop to use by doctors. Computer software based on a pattern recognition system will be used to evaluate the level of glaucoma from none to severe, end-stage glaucoma. After software evaluation processes have been performed, it is intended that the system will serve for use by medical personnel in different hospitals.

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Determinants of Mobile Banking Use: An Extended TAM with Perceived Risk, Mobility Access, Compatibility, Perceived Self-efficacy and Subjective Norms

Cigdem Altin Gumussoy, Aycan Kaya and Erhan Ozlu

Abstract Due to recent technological developments in mobile applications, the use of mobile banking is becoming increasingly widespread. On the other hand, when the investment costs are taken into consideration, the desired level of utilization has not yet been achieved. This study extends Technology Acceptance Model (TAM) with the factors perceived risk, mobility access, compatibility, perceived self-efficacy and subjective norms in order to understand mobile banking use. A survey is conducted in Turkey and 225 questionnaires are collected. A stepwise multiple regression analyses are performed to reveal the determinants of behavioral intention to use, perceived usefulness and perceived ease of use. The results of the study indicate that perceived usefulness, perceived ease of use and perceived risk have significant effects on behavioral intention to use mobile banking. Furthermore, mobility access and perceived ease of use are the most significant determinants of perceived usefulness. In addition, compatibility is the most significant factor for perceived ease of use.

Introduction

Mobile banking is "the use of mobile terminals such as cell phones and personal digital assistants to access banking networks via the wireless application protocol (WAP)" (Zhou et al. 2010). With the increase in the number of smart phone users, customers gain an opportunity to do their banking activities with a device that is near. The use of mobile banking offers the users to access to the mobile application

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system at anytime from anywhere, which increases the flexibility of customers in conducting banking activities. Despite great advantages offered with the use of mobile banking, some users do not prefer to use such systems.

According to the statistics in 2015, the number of mobile contractor number in Turkey is equal to 73.2 and 41.5 million of them use smart phones (Bulamacı 2016). Furthermore, Turkey has "positioned itself as a highly attractive market for mobile banking with its 40% of population under 25 and 95% cell phone penetration" (Mendez 2016). On the other hand, the active mobile banking users is only 19.2 million at the end of 2016 (url 1: The Banks Association of Turkey 2016). This shows that there are potential customers available that are not still using that particular system. This increases the cost of banks, because the bank offers a system that aims to decrease the cost of conducting banking activities in the traditional way. Which factors are important in the decision to use mobile banking system is an issue that has to be answered.

In the current study, a research model is proposed in order to reveal the factors affecting intention to use mobile banking. Technology Acceptance Model (TAM) is a widely used and accepted model that explains human behavior. In that model, people first has an intention that motivates potential users to be one of the active users of the system. Therefore, intention to use such systems affects actual usages of mobile banking. Although TAM analyzes the effects of two important variables—perceived usefulness and perceived ease of use on intention to use an information system, additional factors should be included to the TAM for further understanding. In the current study, in addition to the TAM, additional factors such as subjective norms, perceived risk, mobility access, compatibility and perceived self-efficacy are added to the research model for further understanding.

The next section discusses the literature review on mobile banking adoption, then the developed research model is discussed with the confirmation of hypotheses from the literature. In the fourth section, the research model is tested with a data collected from the possible users of mobile banking. In the last section, the results are discussed and possible future studies are given.

Literature Review

The literature review on mobile banking have tried to understand the factors affecting actual use, intentional use (Gu et al. 2009; Lin 2011; Luarn and Lin 2005; Koenig-Lewis et al. 2010; Akturan and Tezcan 2012; Teo et al. 2012; Hanafizadeh et al. 2014) and continued intention to use mobile banking (Gumussoy 2016; Lin 2011). Gu et al. (2009) explain the intention to use mobile banking with the TAM and trust. They find that perceived usefulness is the strongest predictor, followed by the trust. Lin (2011) examines the effect of innovation attributes (perceived relative advantage, ease of use and compatibility) and knowledge-based trust (perceived competence, benevolence and integrity) on behavioral intention to use and adoption (continue to use) mobile banking with using innovation diffusion theory and knowledge based trust. The results of the study show that perceived relative

advantage, ease of use, compatibility, competence and integrity have significant effects on behavioral intention.

Luarn and Lin (2005) explain the behavioral intention to use mobile banking with TAM and theory of planned behavior (TPB) and additionally perceived credibility, perceived self-efficacy and perceived financial cost constructs. This study reveals that all constructs have significant effects on behavioral intention, and perceived credibility (security and privacy concerns of the users) is the most important factor affecting behavioral intention. Koenig-Lewis et al. (2010) examine the factors affecting behavioral intention of young consumers in England to use mobile banking using TAM and Innovation Diffusion Theory. The results indicate that compatibility, perceived usefulness and the risk are the significant constructs for adoption of mobile banking. Akturan and Tezcan (2012) investigate mobile banking adoption of young consumers in Turkey who never use mobile banking. The study indicates that perceived usefulness, perceived social risk, perceived performance risk and perceived benefit are the significant factors for attitude towards mobile banking. They find significant relationship between attitude and behavioral intention to use mobile banking. Perceived benefit is found as the most significant antecedent for attitude toward mobile banking for young consumers with no experience in mobile banking.

Teo et al. (2012) investigate the effects of demographic constructs (gender, age, education and income) and subjective norms incorporating with TAM on intention to use mobile banking in Malaysia. The results show that demographic constructs have significant effects on perceived usefulness. On the other hand, only gender and education are found as significantly related with perceived ease of use. Hanafizadeh et al. (2014) investigate the factors affecting behavioral intention to use mobile banking of Iranian bank clients using TAM and this study shows that perceived usefulness, perceived ease of use, need for interaction, perceived risk, perceived cost, compatibility, perceived credibility and trust have significant effects on behavioral intention. Compatibility and trust are found as the most important antecedents explaining the adoption of mobile banking. Gumussoy (2016) analyzes the effects of satisfaction, trust, flow, task-technology fit and service quality on continued intention to use mobile banking. According to the results, satisfaction is the significant direct predictor of continued usage intention, whereas the effect of task-technology fit is found to be insignificant.

This study differs from the studies in the literature is that a comprehensive model that explains intention to use mobile banking and it includes the variables: perceived risk, subjective norms, mobility access, compatibility and self-efficacy that are integrated with the TAM. Furthermore, this study is specific to a group of potential mobile banking users in Turkey.

Research Model and Hypotheses

The research model is shown in Fig. 1.

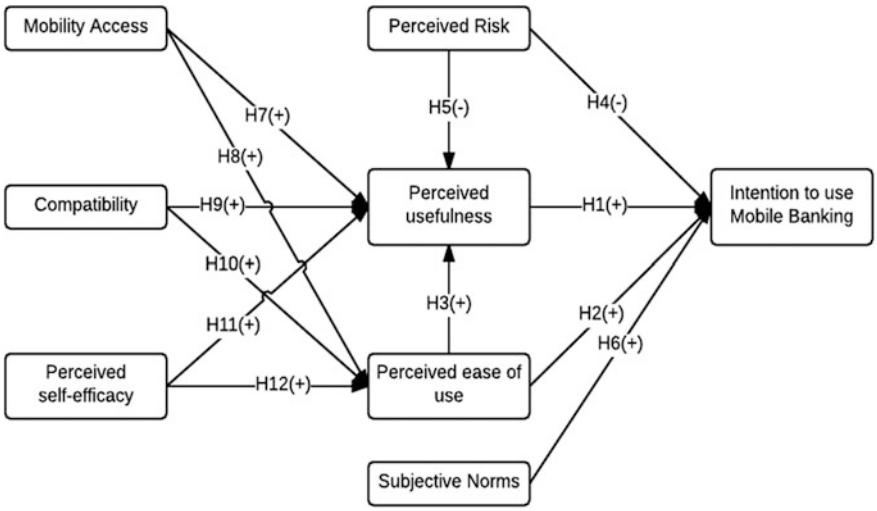

Fig. 1 Mobile banking research model

Technology Acceptance Model

In any type of behavior, people first intend to use a particular system, then actually use that system in the future. Therefore, understanding the determinants of behavioral intention to use is important in predicting actual behavior. Behavioral intention to use shows the possibility of using that system in the future (Ajzen and Fishbein 1980). TAM is one of the most used model that explain intention and actual use in a simpler but effective way. In the basic model of TAM, behavioral intention to use is predicted by two important constructs: Perceived usefulness and perceived ease of use. Perceived usefulness is defined as the "degree to which an individual believes that using a particular system would enhance his or her performance" (Davis 1989, p. 320). Another important factor is perceived ease of use, which is "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989, p. 195). As the system becomes more useful and easy to use, then people will intend to use that system more. Otherwise, they will choose any other system that satisfy the needs of the user.

Furthermore, as the people do not have to spend too much time on how to use or learning, the system is perceived to be more useful. Thereby, perceived ease of use influence perceived usefulness in a positive way.

The relationships defined in TAM are verified by several studies in the literature about mobile banking (Gu et al. 2009; Luarn and Lin 2005; Koenig-Lewis et al. 2010). Therefore, we hypothesize the followings:

H1: Perceived usefulness has a positive effect on intention to use mobile banking
H2: Perceived ease of use has a positive effect on intention to use mobile banking
H3: Perceived ease of use has a positive effect on perceived usefulness

Perceived Risk

Perceived risk has two dimensions: technology-driven risk resulting from infrastructure and relational risk resulting from behaviors of service providers (Pavlou 2003). Service provider may not behave in the way it is required in terms of reliability and they behave in an opportunistic way by taking the advantage of the uncontrollable transactions (Pavlou 2003). Moreover, there is always an inherent possibility of hacking mobile applications due to security vulnerability associated with mobile applications technology. These kind of technological and relational risks reduce the trust of the users in mobile banking, which in turn reduces the intention to use mobile banking. Furthermore, users will not find mobile banking useful when the perceived risk is high, they will prefer to use branch banking or other traditional channels. There are several studies indicating the significant relationship between perceived risk and intention to use (Hanafizadeh et al. 2014; Chitungo and Munongo 2013; Akturan and Tezcan 2012) Thus, the following hypotheses are proposed.

H4: Perceived risk has a negative effect on intention to use mobile banking
H5: Perceived risk has a negative effect on perceived usefulness

Subjective Norms

Subjective norms are defined as the "individual perception that most people who are important to him think he should or should not perform the behavior in question" (Fishbein and Ajzen 1975, p. 302). Individuals are influenced from the opinions and behaviors of other people within their social group like friends, family members or colleagues in intentional or unintentional ways. Widespread use of mobile banking within the social group will increase the intention to use of the individual. There are several studies indicating the significant relationship between subjective norms and intention to use (Teo et al. 2012; Yu 2012; Aboelmaged and Gebba 2013) Thus, the following hypothesis is proposed.

H6: Subjective norms has a positive effect on intention to use mobile banking

Mobility Access

Customers can handle their transactions faster using mobile banking than visiting bank or using phone banking. Also, using mobile banking is less time consuming than other banking options. At anytime and anywhere, users having mobile phones and internet access can easily do their banking transactions. Therefore, mobility access increase perceived usefulness of mobile banking. Thus, the following hypothesis is proposed.

H7: Mobility access has a positive effect on perceived usefulness
H8: Mobility access has a positive effect on perceived ease of use

Compatibility

Compatibility is an important aspect for adoption of new technologies. When users find new technologies familiar with their experiences and lifestyle, they can easily adopt to use this technology. If the new technology is incompatible with the user's experience and lifestyle, users have to struggle to learn how to use the technology and this learning process is time consuming and decreases the usefulness perception about the technology. Therefore, compatibility has a positive effect on perceived ease of use and perceived usefulness. Also, several studies indicate a significant relationship between compatibility and behavioral intention to use mobile banking (Koenig-Lewis et al. 2010; Lin 2011; Al-Jabri and Sohail, 2012). Thus, the following hypothesis is proposed.

H9: Compatibility has a positive effect on perceived usefulness
H10: Compatibility has a positive effect on perceived ease of use

Perceived Self-efficacy

Perceived self-efficacy refers to the belief of the respondents about their ability, skill or knowledge about conducting an activity (Luarn and Lin 2005). The relationship between perceived self-efficacy and perceived ease of use has been confirmed by several studies (Luarn and Lin 2005). Luarn and Lin (2005) find that perceived self-efficacy explain a high percentage of perceived ease of use. Therefore, the following hypotheses are proposed:

H11: Self-efficacy has a positive effect on perceived usefulness
H12: Self-efficacy has a positive effect on perceived ease of use

Methodology and the Results

A survey methodology is used in order to understand the factors affecting behavioral intention use mobile banking. The survey consists of two parts. In the first part, demographic questions about the possible users of mobile banking are asked. A total of 235 questionnaires were collected. However, 15 of them do not complete the questionnaire completely, they are deleted from the sample. Therefore, a total of 220 questionnaires are collected from the possible users of mobile banking. Among the respondents, 34.4% of them are female, the average age is the 32.11 years. Most of them have at least an undergraduate degree. The details of the demographics are given in Table 1.

In the second part, participants answer the questions related with the constructs defined in the research model. A total of 26 questions that define the constructs in the research model are asked on a five-point Likert scale (1: Completely disagree… 5: Completely agree). The items, their corresponding constructs and their references are given in Table 2.

In the analysis, to reveal the reliability of the responses the Cronbach alpha values for each construct are checked. Table 3 shows the results and according to the results all the constructs demonstrate high internal consistency ranging from 0.60 to 0.86, which are greater than the threshold value of 0.60 (Sekaran 1992).

A stepwise multiple regression analyses are performed to reveal the determinants of behavioral intention to use, perceived usefulness and perceived ease of use. IBM SPSS Statistics 23 program is used for the analyses. According to the results, shown in Table 4, intention to use mobile banking is explained by the perceived usefulness, perceived ease of use and perceived risk, whereas the effect of subjective norms is found to be insignificant. Furthermore, the regression analysis yields a regression function with a $R^2 = 0.52$.

As shown in Table 5, perceived usefulness is affected by mobility access, perceived ease of use, compatibility, perceived self-efficacy and perceived risk. These factors explain the %64 ($R^2 = 0.64$) variance of perceived usefulness.

As shown in Table 6, perceived ease of use is affected by compatibility, mobility access and perceived self-efficacy. These factors explain the %13 ($R^2 = 0.13$) variance of perceived ease of use.

Conclusion and Discussion

The use of mobile banking has become widespread in recent years. In this study, a research model is proposed in order to reveal the factors affecting intention to use mobile banking by using TAM. Eleven of the twelve hypotheses are suppwith mobile phoneorted. The results indicate that the key factors affecting behavioral intention to use are perceived usefulness ($\beta = 0.66$), perceived ease of use ($\beta = 0.31$) and perceived risk ($\beta = -0.22$). Perceived usefulness and perceived

Table 1 Demographics of respondents

Gender (%)	Female		34.4	
	Male		65.6	
Age	Max		42	
	Min		22	
	Mean		32.11	
Education level (%)	Elementary school		0	
	High school		1.4	
	Bachelor's degree		76.9	
	Master's degree		16.7	
	Doctorate degree		4.5	
Position (%)	High level manager		6.8	
	Middle level manager		11.8	
	Supervisor		24	
	Technician		22.2	
	Other		21.3	
Income %	0–1000		0.9	
	1000–2000		14.5	
	2000–3000		26.7	
	3000–4000		33.9	
	Higher than 4000		24	
Job Sectors	Automotive	2.3	Iron-steel	3.2
	Finance	3.6	Mining	1.8
	Chemical	3.6	Mac. manufact.	4.1
	Construction	5.4	Metallurgy	4.1
	Distribution	2.7	Paper products	5.2
	Electronics	3.2	Service	6.3
	Energy	6.8	Telecom.	2.3
	Food	5.9	Textile	3.2
	Glass	5	Tourism	3.6
	Health care	4.1	Transportation	4.5
	Information ser.	5.9	Other	7.7
Internet connection with mobile phone	Yes		56.1	
	No		41.2	
Average daily number of banking transactions	01-Mar		13.6	
	04-Jul		31.7	
	08-Oct		28.9	
	Higher or equal than 10		25.3	
The most used banking channel	Branch		7.2	
	Call center		7.7	
	Internet		57.9	
	ATM		21.3	
	Mobile		4.5	

ease of use are the most commonly used constructs in mobile banking studies (Shaikh and Karjaluoto 2015). When the user finds mobile banking useful, easy and performance enhancing, they prefer to use it more. Perceived usefulness is the strongest construct and has a direct effect on behavioral intention to use, and generally this is more important than perceived ease of use and perceived risk, which is compatible with several studies in the literature (Gu et al. 2009; Teo et al. 2012; Hanafizadeh et al. 2014). Furthermore, for mobile banking transactions, trust, security and risk are very important aspects affecting intention to use decision. While the users perceive mobile banking as risky and insecure, their intention to use mobile banking decreases. On the other hand, while trust increases, perceived risk for the user decreases (Pavlou 2003). This significant relationship between perceived risk and intention to use is also supported by several studies in the literature (Hanfizadeh et al. 2014; Chitungo and Munongo 2013; Akturan and Tezcan 2012). Furthermore, findings of the study show that intention to use is not affected by subjective norms ($\beta = -0.07$) or opinions of the other mobile banking users. Users do not take care of the opinions of the other users, while they find the mobile banking reliable, easy to use and useful. This result is also supported by the previous research, which shows that social influence has no effect on perceived usefulness and behavioral intention (Venkatesh et al. 2003; Gu et al. 2009). Subjective norms or social influence is important in the early stages of experience when the user has less experience and knowledge about the technology (Venkatesh et al. 2003). While the experience of the user increases in time, effect of social influence decreases (Venkatesh et al. 2003). In the current study, since most of the respondents have at least a bachelor's degree, they have knowledge about mobile banking, which may decrease the importance of others opinion.

Perceived usefulness is directly affected by mobility access ($\beta = 0.43$), perceived ease of use ($\beta = 0.41$), compatibility ($\beta = 0.34$), perceived self-efficacy ($\beta = 0.20$) and perceived risk ($\beta = -0.14$). Mobility access is the most important construct on perceived usefulness. Instead of visiting the bank or using the call center, mobile banking is more accessible and customer can use mobile banking anywhere at any time for their banking activities. This easier accessibility of mobile banking increases the perceived usefulness of the customer. Furthermore, customers find mobile banking useful while it is easy to use, easy to learn, secure and compatible with their lifestyle and past experiences. Compatibility is an important aspect for adoption of mobile banking. The significant relationship between compatibility and behavioral intention to use mobile banking is also proved by several studies (Koenig-Lewis et al. 2010; Lin 2011; Al-Jabri and Sohail 2012).

Perceived ease of use is directly affected by compatibility ($\beta = 0.25$), mobility access ($\beta = 0.22$) and perceived self-efficacy ($\beta = 0.16$). While using mobile banking is compatible with the user's lifestyle and past experiences, users find mobile banking easy to use. Accessing mobile banking from anywhere at any time increases the perceived ease of use, users find mobile banking easier than visiting bank or call center. Several studies confirm the relationship between perceived self-efficacy and perceived ease of use (Luarn and Lin 2005; Amin et al. 2007).

Table 2 Constructs of the research model, items and their references

Construct	Reference	Items
Intention to use mobile banking	Luarn and Lin (2005)	My general intention to use mobile banking is high I intend to increase my use of mobile banking in the near future
Perceived usefulness	Luarn and Lin (2005)	Using mobile banking would improve my performance in conducting banking transactions Using mobile banking would make it easier for me to conduct banking transactions I would find mobile banking useful in conducting my banking transactions
Perceived ease of use	Luarn and Lin (2005), Yu (2009)	Learning to use mobile banking is easy for me It would be easy for me to become skillful at using mobile banking I would find mobile banking easy to use Using mobile banking is often frustrating because I need remember the access code to do further banking transactions each time
Perceived risk	Luarn and Lin (2005)	I believe mobile banking providers are trustworthy I believe that my transactions with mobile baking providers are likely to be safe Using mobile banking would not divulge my personal information I would find mobile banking secure in conducting my banking transactions
Subjective norms	Hung et al. (2003)	People important to me support my use of mobile banking services People who influence my behavior want me to use mobile banking services instead of any other alternative means People whose opinions I valued preferred that I use mobile banking services
Mobility access	Yu (2009)	Using mobile banking enables me to perform banking transaction quickly Mobile banking is faster than visiting a bank or using phone banking Mobile banking is a less time consuming than other banking options Mobile banking is more accessible than other banking (e.g. visiting bank or using phone banking) Mobile banking allows me to do my banking anywhere/anytime
Compatibility	Yu (2009)	Using mobile banking fits well with the way I like to control and manage my banking transactions I use mobile banking because I am used to doing everything with my cell phone I satisfy the current banking service (e.g.: phone banking, and internet banking) at this stage because these are already a part of my daily life

(continued)

Table 2 (continued)

Construct	Reference	Items
		Mobile banking is a less time consuming than other banking options
Perceived self-efficacy	Luarn and Lin (2005)	I could conduct my banking transactions using the mobile banking systems… – if I had just the built-in help facility for assistance – if I had seen someone else using it before trying it myself – if someone showed me how to do it first

Table 3 Constructs and their corresponding Cronbach's alpha values

Construct (number of items)	Internal reliability (Cronbach's alpha)
Intention to use mobile banking (2)	0.82
Perceived usefulness (3)	0.86
Perceived ease of use (3)	0.70
Perceived risk (4)	0.77
Subjective norms (3)	0.65
Mobility access (3)	0.76
Compatibility (3)	0.61
Perceived self-efficacy (3)	0.60

Table 4 Regression on intention to use mobile banking

	Sum of squares	df	Mean square	F	Prob > F
Regression	128.459	3	42.820	81.192	0.00
Residual	114.443	217	0.527		
Total	242.902	220			
Predictors	Beta	Std error	Adjusted R^2	F	Prob > F
Intercept	0.63	0.387			
Perceived usefulness	0.66	0.076	0.45	181.793	0.00
Perceived ease of use	0.31	0.067	0.50	21.628	0.00
Perceived risk	−0.22	0.065	0.52	11.952	0.00

Managerial Implications

Mobile access is an important factor explaining usefulness. Therefore, banks should try to decrease system breakdowns to provide better mobile banking experience without interruptions and they pay attention to their information technology (IT) systems and hire qualified IT employees to provide better performance and riskless services. To decrease risk of the systems, advanced security systems like eyes, voice or fingerprint recognition can be used for mobile banking. Compatibility

Table 5 Regression on perceived usefulness

	Sum of squares	df	Mean square	F	Prob > F
Regression	85.854	5	17.171	77.980	0.00
Residual	47.342	215	0.220		
Total	133.196	220			
Predictors	Beta	Std error	Adjusted R^2	F	Prob > F
Intercept	−0.746	0.351			
Mobility access	0.43	0.066	0.36	123.045	0.00
Perceived ease of use	0.41	0.049	0.54	88.278	0.00
Compatibility	0.34	0.064	0.60	31.830	0.00
Perceived self-efficacy	0.20	0.053	0.62	12.804	0.00
Perceived risk	−0.14	0.041	0.64	11.951	0.00

Table 6 Regression on perceived ease of use

	Sum of squares	df	Mean square	F	Prob>F
Regression	15.102	3	5.034	12.011	0
Residual	90.952	217	0.419		
Total	106.054	220			
Predictors	Beta	Std error	Adjusted R^2	F	Prob > F
Intercept	1.349	0.387			
Compatibility	0.25	0.086	0.1	25.795	0
Mobility access	0.22	0.088	0.12	4.746	0.03
Perceived self-efficacy	0.16	0.073	0.13	4.546	0.03

is an important factor for perceived usefulness and perceived ease of use. Therefore, banks develop their mobile banking systems, taking into account their customers' lifestyle and personal preferences. Furthermore, advertising campaign should be done to show how easy to use mobile banking to encourage people in using mobile banking systems.

Limitations and Future Studies

Although findings of this study make contribution to understand the factors affecting intention to use mobile banking, there are several limitations. First, variables of the models explain the 52% of the variance on intention to use mobile banking, 48% of the variance remains unexplained, additional study should be conducted with including new constructs such as credibility, culture, system quality, perceived benefit, etc. Second, this study is specific to mobile banking users in Turkey and making a similar study in the other countries could provide a general

understanding the behavioral intention to use mobile banking. In the future studies, investigating the effects of demographic constructs such as age, gender, education and income on behavioral intention to use mobile banking could provide more insights about understanding adoption of mobile banking.

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Radiologists' Perspective on the Importance of Factors for MRI System Selection

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Abstract Revealing user needs, which are usually dependent on qualitative methods, is a fundamental stage for medical technology selection and purchasing. The aim of this study is to determine weights of factors affecting magnetic resonance imaging (MRI) system selection from the radiologists' perspective. In order to solve the problem, an analytic hierarchy process (AHP)-based model is used. Factors that affect the MRI system selection from radiologists' point of view include five main criteria and 19 sub-criteria that are indicated by experts. An online questionnaire containing demographic questions enables each expert to compare the relative priority of criteria with all the other criteria. According to the analysis of 39 experts (i.e., radiologists), brand- and patient comfort-related factors are the two most important factors affecting the MRI system selection. A real-world application is conducted to illustrate the utilization of the model. AHP contributes to developing an analytic and comprehensive framework of decision making. The method should be considered by practitioners involved in decisions about new medical systems.

Keywords Medical decision making · Multi-criteria decision making
Magnetic resonance imaging · Analytical hierarchy process · System selection

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Introduction

The healthcare industry is contingent on providing qualified, well-equipped and reliable medical systems in order to offer high-quality care for patients. Medical devices as a tool for diagnosis and treatment of diseases have an important role in healthcare. Therefore, there is a high volume of transactions in the market for medical equipment. Moreover, high costs are paid for providing these devices (Gray and Morin 1989; Cappellaro et al. 2011; Brasser et al. 2008). Physicians and decision-makers, who are responsible for making decisions about the development and purchasing of medical systems, are interested in factors affecting the selection of medical systems. Nevertheless, capturing user requirements for healthcare technology is not straightforward. For any medical system, there is likely to be a large number of possible users, all with different working patterns, preferences, skills and attitudes. For instance, even though clinical efficiency and safety are the main concerns in medicine, some other features such as cleaning, storage, and training needs should be considered as well (Martin et al. 2006). Moreover, information collection is complex due to a possible lack of time, and lack of knowledge of proper techniques for data collection and analysis; therefore, an effective approach is needed (Shah and Robinson 2007; Money et al. 2011).

In this study, we focus on radiologists' needs related to the use of a magnetic resonance imaging system. MRI is a non-invasive imaging technology that uses a magnetic field and radio waves to produce three-dimensional detailed anatomical images of the organs, tissues and skeletal system within the body. By producing high-resolution images, MRI is used for disease detection, diagnosis and treatment monitoring (Mayo Clinic 2016). It is usually performed to help diagnose spinal cord injuries, disorders of the eye and inner ear, tumors or other abnormalities of many organs in the body, including the liver, kidneys, pancreas, uterus, ovaries, prostate, etc. Being different to computed tomography (CT) scanning, an MRI system does not use X-rays or other radiation. Therefore, it is the best choice especially when frequent imaging is necessary for diagnosis and therapy. However, the MRI system is more expensive than CT or X-ray imaging (NIH 2016). Although MRI does not emit the damaging ionizing radiation that is found in X-ray and CT imaging, it creates a strong magnetic field around the patient, and radio waves are directed at the body. The magnetic field extends beyond the machine and exerts very powerful forces on objects of iron, some steels, and other magnetizable objects. Therefore, patients should notify their physicians of any form of medical or implant prior to an MR scan.

Radiologists are faced with different alternatives in the selection of the most appropriate MRI system. The decision-making problem is typically too complex and ill-structured to be considered through the consideration of a single criterion that will lead to the ideal decision. Indeed, such a unidimensional approach is an oversimplification of the actual nature of the problem, which may lead to improper conclusions. A more appealing approach would be the simultaneous examination of all applicable factors that are related to the problem. The selection of a medical

system is a multiple criteria decision making (MCDM) problem, and constitutes an advanced field of operations research, since it involves many conflicting criteria, goals or objectives. A variety of decision-making approaches and tools is available to support medical decision making. The intent of MCDM methods is to improve the quality of decisions about medical system selection involving multiple criteria by making choices more explicit, efficient and rational. MCDM methods have six basic functions (Hobbs and Meier 2012):

1. structuring the decision process,
2. displaying trade-offs among criteria,
3. helping decision makers to reflect upon, articulate, and apply value judgments concerning acceptable trade-offs, resulting in recommendations concerning alternatives,
4. helping people make more consistent and rational evaluations of risk and uncertainty,
5. facilitating negotiation,
6. documenting how decisions are made.

The analytic hierarchy process (AHP) is one of the most widely used MCDM tools in the last 30 years; it has been used in almost all the applications related to decision making (Saaty 1977, 1980; Saaty and Ergu 2015; Vaidya and Kumar 2006; Eldemir and Onden 2016). This approach enables the decision maker to construct problems in the system of a hierarchy: the objective, the criteria, and the alternatives. The main benefit of the AHP is its use of pairwise comparisons to measure the impact of items on one level of the hierarchy on the next higher level. Its flexibility, ease of use and wide applicability have attracted decision-makers and researchers in different fields including healthcare, education, management, manufacturing, politics, and finance. There have been numerous studies published based on AHP, which include applications of AHP in various areas such as selection, evaluation, resource allocation, decision making, etc. A bibliographic review of the MCDM tools has been provided (Steur and Na 2003). Specifically, a literature review of the applications of AHP to important problems including medical and healthcare decision making has been presented (Vaidya and Kumar 2006; Zahedi 1986; Vargas 1990; Liberatore and Nydick 2008; Schmidt et al. 2015). They point out that the largest number of articles was found in the project and technology evaluation and selection category. In addition to the applications of the stand-alone AHP, there are many studies focusing on integrated AHPs (Li and Ma 2008; Khorramshahgol 2012). A survey of the applications of integrated AHPs from 1997–2006 is available, where the tools include mathematical programming, quality function deployment, meta-heuristics, etc. According to this study, healthcare is one of the most popular application areas of integrated AHPs (Ho 2008). Here, a multi-criteria decision making methodology is proposed to determine the weights of factors affecting MRI system selection. In the proposed methodology, radiologists' opinions on the relative importance of the selection criteria are determined by the AHP procedure. Although there have been several applications

of AHP method in healthcare, to the best of our knowledge, this is the first study where a multi-criteria decision-making tool is used to examine the determinants affecting the selection of an MRI system from the perspective of radiologists.

Methodology

Identifying the Main Criteria and Sub-Criteria

Understanding consumer behavior and detecting important features of products that play a role in consumer decision-making are the cores of marketing (Stetz 1964; Paisley 1998). A common belief is that consumers buy products based on their quality (Ovretveit 2003). In a marketing mix model for consumer behavior analysis, product, price, place and promotion are taken into consideration in order to satisfy target groups (Kotler and Levy 1969). Other factors including cultural, social, personal and psychological factors that have an impact on the purchase were also determined (Armstrong et al. 2011). Promotions and advertisements, quality, price and brand are indicated as factor affecting the buyers' attitude (Ranjbarian et al. 2008). The energy of brand effect and the role of brand image in explaining consumer purchase behavior were studied (Julong 2007; Bian and Moutinho 2011). AHP was used to evaluate different criteria in medical equipment purchasing decisions where three main criteria and seven sub-criteria were considered (Uçkun et al. 2008). The determinants influencing the behavior of purchasing the capital medical equipment using the AHP were studied (Bahadori et al. 2012). The identified four determinants and 14 criteria are shown in Table 1. AHP methodology was used to elicit user needs for a new CT scanner for use in a hospital (Pecchia et al. 2013). Four categories and 12 criteria were taken into account, as shown in Table 2. 14 key default specifications were identified, including bore diameter, coils and gradient-related specifications based on the literature for selecting medical devices, and an MRI system was used as an example (Ivlev et al. 2015; Price et al. 2008). Recently, using the same 14 specifications, various methods including AHP, TOPSIS, PROMETHEE II and SAW were performed to identify the most appropriate MCDM model for medical equipment selection in the Czech Republic (Ivlev et al. 2016).

Table 1 Evaluation criteria

Quality	After-sale services	Brand	Price
Quality of output	Alternative equipment	Reputation	Credit and installment
Easy working	Accessory	Country	Low price of equipment
Standards of quality	Skill of engineers	Oldness	Low price of accessory
	Access to engineers		Discount for cash payment

Table 2 Criteria for CT scanner

Performance	Patient safety	Usability	Technical issues
Spatial resolution	Patient radiation dose	Application support	On call services
Speed run	Patient monitoring	User-friendly GUI	Maintenance
Processing software	Contrast medium control	Interoperability	Data storing

We identified and grouped evaluation criteria for MRI device selection into five main categories: performance, technical issues, patient comfort, usability and brand. Here, the main and sub-criteria in Table 3 are obtained by taking into account the pertinent scientific literature and experts' experience.

The AHP Method

The AHP is an MCDM method that is considered for decisions that necessitate the incorporation of quantitative data with less tangible, 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). The technique is an eigenvalue approach to the pair-wise

Table 3 Criteria taken into account to select the best MRI system

Main criteria	Sub-criteria
C1: Performance factors	C11: Magnetic field strength
	C12: Gradient specifications
	C13: Coils
	C14: Software applications
	C15: Oldness of device
C2: Technical issues	C21: Cost of device
	C22: Accessibility of technical support
	C23: Installation
	C24: Maintenance cost
	C25: Training of technical staff
	C26: Data storage capacity
C3: Patient comfort	C31: MRI accessories
	C32: Bore diameter
	C33: Patient monitoring
C4: Usability	C41: Software support
	C42: User-friendly independent workstation
C5: Brand	C51: Significant design features
	C52: Reputation
	C53: Country of manufacture

comparisons, and has been applied to many areas including healthcare and medical decision making. An AHP method involves the following key and basic steps:

- state the problem,
- identify the goal of the problem,
- identify the criteria, sub-criteria and alternatives under consideration,
- construct the problem in a hierarchy of different levels: goal, criteria, sub-criteria and alternatives,
- conduct a series of comparisons among each element in the corresponding level, and calibrate them on the numerical scale,
- calculate the maximum eigenvalue, consistency ratio (CR), and normalized values for each criteria/alternative,
- determine the relative ranking or the best alternative.

The selection hierarchy for the best MRI system is illustrated in Fig. 1.

Questionnaire

Our study is a descriptive cross-sectional study for the purpose of assessing and identifying the importance of the aforementioned criteria affecting MRI system selection from radiologists' perspective. A questionnaire, containing demographic questions, enables each expert to compare the relative priority of criteria with all other criteria within the same category. Before conducting the survey, a pilot test was conducted with a few radiologists in the radiology department of the university hospital. Based on the input received, the questionnaire was modified. The resulting questionnaire was e-mailed to the respondents. We conducted a survey involving 39 radiologists with the following demographic characteristics of experts provided in Table 4. The average age of the radiologists is 36.8, of which 66.7% are male 33.3% are female. The average working experience as a medical doctor and radiologist is 18.4 and 14 years, respectively. 61.6% work in a university hospital, and

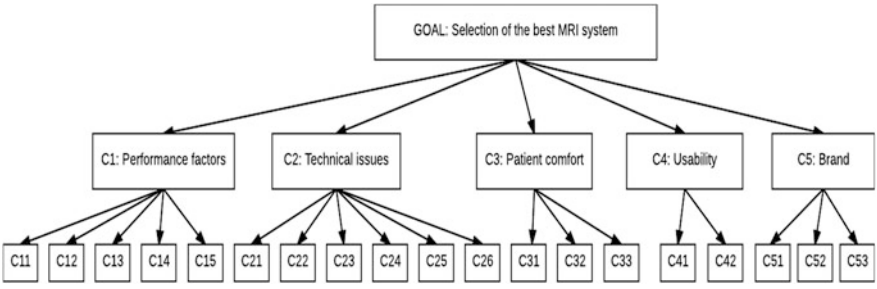

Fig. 1 A hierarchy for selection of the most appropriate MRI system

Table 4 Demographic characteristics of the experts

Gender			
Female: 33.3	Male: 66.7		
Age (*year*)			
Max: 57	Min: 25	Avg: 36.8	
Workplace (%)			
Private hospital: 5.1	University hospital: 61.6	Training and research hospital: 23.1	Public hospital: 10.2
Work experience as an MD (*year*)			
Max: 33	Min: 8	Avg: 18.4	
Work experience as a radiologist (*year*)			
Max: 30	Min: 3	Avg: 14.3	
MRI system experience (*year*)			
Max: 25	Min: 1	Avg: 9.2	
Computer experience (*year*)			
Max: 30	Min: 9	Avg: 17.7	
Level of participation in MRI selection and procurement (%)			
Not at all: 43.5	Low: 23.1	Moderate: 23.1	High: 10.3

a total of 56.5% are somehow involved in the MRI system selection and procurement process.

In order to detect the relevant criteria, we apply Saaty's pairwise comparison (Saaty 1980). For each pair of criteria, the experts were asked the following question: "in the selection of an MRI system, considering merely 'performance', how important is each element on the left compared with each element on the right?" The respondents were asked to rate each factor using the nine-point scale shown in Table 5.

Results

Factors that affect the MRI system selection from a radiologist point of view include five main criteria and 19 sub-criteria. In the questionnaire completed by 39 radiologists, the responses concerning the prioritization of the criteria were calculated using the Super Decisions software, and the consistency ratios of the paired comparisons were analyzed. The priority weights of the main criteria influencing the selection of MRI system are provided in Table 6. Among the five main criteria, "brand" is the most important criteria with the highest weight; and "performance" is the least important, with the lowest weight value. All responders achieved the threshold for coherence (CR $\leq$ 0.1).

According to the analysis, "brand" and "patient comfort" are the two most important main criteria affecting magnetic resonance imaging (MRI) system

Table 5 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 6 Priority of criteria at level 1 of AHP

Criteria	Priority weight
Performance factors	0.08
Technical issues	0.10
Patient comfort	0.30
Usability	0.15
Brand	0.36

Consistency ratio (CR): 0.02 (values of 0.1 or below represent 90% or higher confidence level)

selection from radiologists' perspective. Specifically, it may be worthwhile to examine the weights of the sub-criteria for brand- and patient comfort-related factors, which are summarized in Table 7.

According to Table 7, "performance" includes five sub-criteria where "oldness of device" is the most influential sub-criteria with the priority weight of 0.34, and "magnetic field strength" is the least important, with a weight of 0.15. "Technical issues" includes six sub-criteria; "installation" has the highest importance with the priority weight of 0.33. On the other hand, "accessibility of technical support" has the lowest importance with the priority weight of 0.09. "Patient comfort" has three sub-criteria, "MRI accessories" has the most priority with the weight of 0.36, and "bore diameter" has the lowest impact with the weight 0.30. "Usability" includes two sub-criteria; "user-friendly independent workstation" has greater priority than "software support". Finally, "brand" includes three sub-criteria of which "country of manufacture" is the most influential with the priority weight of 0.53, and "significant design features" is the least important, with a weight of 0.19.

Discussion and Conclusion

This study was conducted for the purpose of examining and prioritizing the factors affecting the MRI system selection from radiologists' point-of-view. We present the results of a study on the application of an AHP methodology. The three-level hierarchy composed of five main criteria and 19 sub-criteria is given in Fig. 1. Thirty-nine radiologists evaluated the considered criteria to determine the relative

Table 7 Priority of sub-criteria at level 2 AHP

Criteria	Priority weight	Global priority	CR
Sub-criteria for performance factors			
Magnetic field strength	0.16	0.01	0.007
Gradient specifications	0.16	0.01	
Coils	0.18	0.02	
Software applications	0.16	0.01	
Oldness of device	0.33	0.03	
Sub-criteria for technical issues			
Cost of device	0.16	0.02	0.004
Accessibility of technical support	0.10	0.01	
Installation	0.33	0.04	
Maintenance cost	0.16	0.02	
Training of technical staff	0.11	0.01	
Data storage capacity	0.14	0.01	
Sub-criteria for patient comfort			
MRI accessories	0.37	0.11	0.004
Bore diameter	0.31	0.09	
Patient monitoring	0.32	0.10	
Sub-criteria for usability			
Software support	0.38	0.06	Not applicable
User-friendly independent workstation	0.62	0.09	
Sub-criteria for brand			
Significant design features	0.20	0.07	0.05
Reputation	0.28	0.10	
Country of manufacture	0.52	0.18	

CR values of 0.1 or below represent 90% or higher confidence level

weights. Each criterion of the hierarchy is evaluated by the experts under the defined criteria. Each expert provides a decision about her/his judgment as a precise numerical value, range of numerical values, or a linguistic term.

Table 6 provides the weights of the criteria for MRI system selection from radiologists' perspective. The results of this study imply that among the main criteria effective in the selection of an MRI system including performance, technical issues, patient comfort, usability, and brand, the brand has the highest priority and the technical issues the lowest priority from radiologists' perspective. Moreover, patient comfort has the next highest importance after the brand, showing that health service organizations pay attention to the quality of the MRI systems. Discussion of the results with the experts confirms that their views are the same: first brand, then patient comfort, usability, technical issues and performance. In order to provide high-quality care for patients, healthcare providers aim to provide well-equipped and reliable medical systems, which are the tool for diagnosis and treatment of diseases.

Concerning priority weights within the category of "performance", the oldness of the device is considered the most important criterion. This implies that, according to the radiologists, the performance of the MRI system is affected by how old the device is. Moreover, since an MRI system is a developing technology, which should be followed by the users and radiologists, the newer the MRI system, the better screening features and diagnosis environment radiologists have. Regarding the priority weights of "technical issues", the installation sub-criterion has the highest importance. This result reveals that, due to the large physical configuration of the MRI system, which re-quires a great deal of space to install, the fitting and setting up of the system play an important role according to the experts. Regarding the priority weights of "patient comfort", the sub-criteria are close to each other, considered al-most equally important. However, MRI accessories have slightly greater importance due to the fact that the general specifications of all MRI systems are almost same; however, new accessories of a system make a difference com-pared to the other available systems in the market, which add more features to use. Regarding the priority weights of "usability", where the highest variation in weights is detected, the user-friendly independent workstation has the highest priority. This result reflects the fact that radiologists look for an accessible, intelligible and easy-to-use workspace during screening and diagnosis. Finally, considering the weights of "brand", the radiologists first check in which country the MRI system was manufactured, which is also related to the reputation of the company. Healthcare providers would like to have the best MRI system available subject to their budget, as they are dependent on providing qualified, well-equipped and reliable medical systems in order to offer high-quality care for patients. Since MRI systems are evolving technologies, there is a huge potential market. In addition to well-known brands and companies, there are many new firms joining the market, and selling with at-tractive prices to gain market share. In order to reduce their total costs, companies prefer to carry out their manufacturing operations in various fields and countries, which sometimes leads to a decrease in quality. Therefore, the brand, the country of manufacture and the reputation of the company play important roles in selecting the MRI system.

These results are consistent with the study that demonstrates that brand, after-sale services, price, software and hardware should be considered as determinants when purchasing medical equipment (Zucker and Chua 2010). Price, quality, brand, and after-sale services were shown to be the factors effective in ultrasound device purchase (Abdolahian and Mehrani 2009). Similarly, it has been also shown that brand affects customers' preferences in selection of the products (Ranjbarian, Jamshidian et al. 2008). Patient monitoring and a user-friendly GUI are the two important criteria eliciting user needs for a new computed tomography scanner for use in a public hospital (Saaty and Ergu 2015). 29 In this study, "performance," one of the main criteria affecting the MRI system selection, is ranked as the least priority, implying that no matter what the magnetic field strength or gradient specifications are, it will be next in priority order. Based on our results, the brand, patient comfort, usability, technical issues and performance as factors affecting MRI system selection should be taken into ac-count by the radiologists.

Medical systems play a leading role in diagnosis and treatment and are the crucial reason for increasing healthcare costs. The selection of medical systems is becoming a more complex problem due to a number of factors and variable conditions. Here, we have concentrated on radiologists' perspectives on magnetic resonance imaging system selection. The proposed multi-criteria decision-making methodology, AHP, enables experts to be flexible and to practice a large evaluation pool containing precise numerical values, ranges of numerical values, and linguistic terms. Therefore, the proposed methodology has the capability of taking care of all kinds of evaluations from experts; in our case, radiologists. Our results provide a guideline for decision makers when selecting an MRI system based on several criteria. For further research, other multi-criteria decision-making approaches such as TOPSIS, PROMETHEE II and VIKOR can be used and compared to the results of this study.

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Part III
Healthcare Systems Engineering and Management

Relation of Grip Style to the Onset of Elbow Pain in Tennis Players

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Abstract The gradual onset of pain over the region of the lateral epicondyle can result in the Tennis Elbow condition that affects a significant number of people whose activities involve repetitive wrist movements. This study is the first effort so far to propose an experimental design based research to investigate the effects of different backhand grips of tennis players regarding the onset of elbow pain. A sample population of tennis players is selected for implementing various tests using the same test measurements and evaluation conditions. Non-parametric variance analysis techniques fulfil the hypothesis test and derive inferential statistics of the research. The clear and significant differences among the evaluated grips prove that using a two-handed backhand style for backhand strokes is safer than other common grip styles.

Keywords Lateral epicondyle · Grip style · Statistical analysis
Experimental design

Introduction

Tennis Elbow affects hundreds of thousands of tennis players, typically manifesting with a gradual onset of pain, without a chronic trauma, over the region of the lateral epicondyle of the humerus (Roetert et al. 1995). The elbow is a three-joint group composed of the humerus, radius, and ulna. One aetiology of lateral epicondylitis

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(LE) is thought to be over-exertion of the extensor carpi radialis brevis (ECRB) muscle, resulting in microtrauma (Morris et al. 1989). It supports flexion and expansion of the joint and flexion, extension, pronation, and supination of the wrist. There is a risk of damage to bodies performing monotonous wrist movements in recreational, sports and occupational activities. It appears that tennis players, in particular, are at risk of developing LE and often complain of pain when delivering a backhand stroke. Lateral epicondylitis occurs in up to 50% of recreational tennis players (Morris et al. 1989).

Blackwell and Cole (1995) suggested raised grip pressure as an expert-novice distinction that may contribute to over-exertion of the ECRB muscle, and concluded that the analyses on participants revealed no differences when performing a backhand tennis stroke. Ingelman (1991), Blackwell and Cole (1995) investigated EMG profiles of expert and novice tennis players performing backhand strokes and noted a sharp differentiation between the two groups. The wrist joint angle patterns perceived in players of the novice group might designate shapes that increase wrist extensor injury through unusual contraction of the ECRB. Riek et al. (1999) performed a computer simulation of the behavior of the extensor carpi radialis brevis during backhand tennis strokes by beginners and expert players to investigate a latent mechanism of injury. They set kinematic data in conjunction with a computer model to give a time-varying representation of changes of muscle force and length.

Kumar et al. (2016) stated that grip strength is often considered as a predictor of cognitive functioning and has been found to be associated with a cognitive act with personal differences in some special cross-sectional investigations. Nurul et al. (2015) attempted to discover the correlation between anthropometric measures and handgrip strength in elderly Malaysians. The results revealed that there was a substantial correlation among stature, sitting hip breadth, wrist circumference, hand circumference and heel ankle circumference and handgrip strength. Works such as (Abaraogu et al. 2017; Bertrand et al. 2015; Branson et al. 2016; Daphnee et al. 2017; Ekşioğlu 2016; García-Esquinas and Rodríguez-Artalejo 2017; Gubelmann et al. 2017; Karaduman et al. 2016; Kaux et al. 2016; Larson and Ye 2017; Mat Jaiset al. 2017; Moreno-Pérez et al. 2016; Nofuji et al. 2016; Nurul Shahida et al. 2015; Omar et al. 2017; Petitdant 2017; Wachter et al. 2017) considered the importance and measurement of grip strength in different studies.

In addition, Lee and Sechachalam (2016) examines the effect of wrist position, in the flexion-extension plane, on grip endurance and grip strength and applied a procedure in which grip strength and grip endurance were quantified bilaterally at 6 different wrist positions (unrestrained, 45°, 30°, and 15° extensions, 0° and 30° flexion) in 38 healthy right-handed individuals. The research showed that wrist orthosis significantly decreased grip strength beyond all positions and the highest grip strength in the position with an orthosis occurred at 15° and 30° extensions for the dominant hand and 15°, 30°, and 45° extensions for the non-dominant hand. Hand dominance and gender did not significantly affect grip endurance. Using a wrist orthosis did not significantly reduce grip endurance at 45° and 30° extensions.

Christensen et al. (2016) advanced a method to investigate the consequences of grip size and grip firmness on the kinematic contribution of angular velocity

Fig. 1 Three different backhand grips (The Guardian 2009)

(KCAV) to the generation of racket head speed during a forehand swing. This feasibility research led for the first time to quantifying the KCAV while producing a topspin forehand, with changing of the grip size and grip pressure in an advanced male tennis player. Despite speculation about the roles of different grip styles (Fig. 1 depicts the three most common backhand stroke styles) in sustaining lateral epicondylitis injuries, there have not yet been sufficient studies to assess this theory. This research, therefore, proposes for the first time a research design to examine the effects of different grip styles of players regarding the onset of pain in the elbow, which is an initialization for Tennis Elbow. The proposed method may indeed provide a potential and pilot investigation for further and comprehensive studies considering all possible effective factors in the onset of elbow pain in people (not only tennis players) with repetitive wrist movements.

This paper is organised as follows. In Section "Methods", we propose the research method and its components, such as the definition of the research question, research strategy to be followed, and data analysis approach. In Section "Results", we apply statistical techniques to infer results from the specified data set. In Section "Discussion", we develop a discussion on the results obtained. The conclusion of the study and some future works are summarized in Section "Conclusion".

Methods

Considering the literature mentioned above and the specified deficiency of studies on the significant role of various styles of gripping a tennis racket in the onset of elbow pain in players, a comprehensive research design and data collection strategy were applied. For this, an individual structural process starts with a research question that is a testable prediction designating the relationship between two or more variables. Next, details in relation to defining the variables are described.

Classifying a population and selecting samples, collecting information from and/or about these samples by using special research instruments, are the next steps of the method. Data analysis, interpreting the data and drawing conclusions that may be considered as a starting point for new hypotheses are further steps of the methodology.

Research Question

"The majority of tennis elbow results from chronic overloading and under-recovery due to poor biomechanics caused by grip style and size, and related movement pattern dysfunction", according to Mark Verstegen, president and founder of Athletes' Performance (Brown 2009). To avoid getting an injury, one should cease hitting balls as soon as feeling inflammation of the tendon, the outer part of the elbow, which is a sign of starting to get Tennis Elbow. Despite much research, analyzing players suffering from lateral Tennis Elbow based on the backhand stroke, such as (Alizadehkhaiyat and Frostick 2015; Bauer and Murray 1999; John and Blackwell 1994; Kentel et al. 2008; Kevin and Chung 2017; King et al. 2012; King et al. 2010; Pitzer et al. 2014; Philip Buttaravoli 2012; Riek et al. 1999; Wang et al. 2010), most tennis players and professionals believe that elbow injuries are directly related to the grip style of the backhand stroke. Based on these speculations, our proposed explanation for this phenomenon (hypothesis) can be expressed, as "grip style is effective in the onset of elbow pain in tennis players".

Research Strategy

In order to test the hypothesis mentioned above, we describe a concept to design experimental research before progressing to the operational phase. For this, a target population should be identified, and a sample population of tennis players is selected for implementing different tests under identical test measurements and evaluation conditions. After fulfilling the systematic steps of the tests, information is gathered using precise, valid and reliable research instruments. Table 1 illustrates the targeted sample population to be analyzed, which is a group of 25 individuals of different genders and ages. Regarding their playing techniques, three different grip styles for the backhand stroke have been observed. These are the eastern backhand grip, the double-handed backhand grip and the semi-western backhand grip. Each player is requested to deliver backhand strokes to balls launched from an automatic ball machine. The balls are shot to the backhand position of the players at a speed of 45 mph and at 3-second intervals. Between each backhand stroke, the player has to control the pain inflammation in his/her elbow by opening and closing the fingers of the dominant hand. It is worth mentioning that the tennis rackets and balls used, as well as the speeds and directions of the launched balls are identical for all players

Table 1 Test sample with dependent and independent variables

Subject	Gender	Age	Backhand style	Backhand stroke
1	Female	23	1; The eastern backhand grip	160
2	Male	28	1; The eastern backhand grip	168
3	Male	21	1; The eastern backhand grip	121
4	Male	32	1; The eastern backhand grip	174
5	Female	34	1; The eastern backhand grip	181
6	Female	25	1; The eastern backhand grip	162
7	Male	21	2; The double-handed backhand grip	186
8	Female	18	2; The double-handed backhand grip	221
9	Female	28	2; The double-handed backhand grip	214
10	Male	22	2; The double-handed backhand grip	245
11	Male	18	2; The double-handed backhand grip	165
12	Female	31	2; The double-handed backhand grip	232
13	Male	26	2; The double-handed backhand grip	189
14	Female	17	2; The double-handed backhand grip	220
15	Female	26	2; The double-handed backhand grip	185
16	Female	24	3; The semi-western backhand grip	170
17	Female	29	3; The semi-western backhand grip	139
18	Male	26	3; The semi-western backhand grip	137
19	Male	28	3; The semi-western backhand grip	198
20	Female	19	3; The semi-western backhand grip	156
21	Female	24	3; The semi-western backhand grip	152
22	Female	31	3; The semi-western backhand grip	178
23	Female	22	3; The semi-western backhand grip	180
24	Male	45	3; The semi-western backhand grip	125
25	Female	26	3; The semi-western backhand grip	176

throughout the tests. The backhand strokes are counted until the exact moment that the player reports the starting of pain in his elbow. At this time, the ball machine is stopped, and the number of backhand strokes is recorded (Table 1).

Analysis Approach

Two principal statistical techniques are used in the data interpretation: descriptive statistics, which compile data from a sample using criteria such as the mean or standard deviation, and inferential statistics, which yield results from data that are subject to random variation (e.g., observational errors, sampling variation). Descriptive statistics often involve two sets of features of distribution (sample or population): the central tendency (or location) attempts to portray the central or typical value of the distribution, while scattering (or variability) characterizes the

range within which segments of the distribution diverge from its centre and each other. Deductions on statistics are made under the structure of probability assumption, which deals with the examination of random phenomena.

A conventional statistical method includes testing the link between two statistical data sets, or a data set and artificial data drawn from the idealised shape. A hypothesis is stated for the statistical relationship among the two data sets, and this is compared as an alternative to an idealized null hypothesis of no correlation between data sets. Rejecting or disproving the null hypothesis is done by applying analytical tests that quantify the sense in which the null can be demonstrated to be false, given the data that are handled in the test. To analyze the captured data, we need a method for testing whether samples originate from the same distribution. For this, analysis of variance has to be applied to gage the differences among group means and their associated procedures, as well as testing the developed hypotheses.

Regarding the population size; where the backhand stroke is nominated as the dependent variable, and the backhand style is the independent variable, a non-parametric method is used for testing or comparing two or more independent samples of equal or different sizes. For testing the hypothesis, the Kruskal–Wallis test by ranks (one-way ANOVA on ranks), which enlarges the Mann–Whitney U test when there are more than two groups, has been employed. A significant Kruskal–Wallis test designates that a minimum of one sample dominates another sample stochastically. The test does not recognize where this stochastic dominance occurs or for how many pairs of groups the stochastic dominance scores. As it is a non-parametric method, the Kruskal–Wallis test does not consider a normal distribution of the residuals, contrary to the analogous one-way analysis of variance. If the researcher can make the less powerful hypotheses of an identically formed and sized distribution for all groups, except for any deviation in medians, then the null hypothesis is that the medians of all groups are alike, and the alternative hypothesis is that at least one population median of one group is distinct from the population median of at least one other group.

Results

The analyses have been performed using IBM SPSS v.23. Table 2 illustrates the descriptive statistics for the backhand strokes factor to summarise the given data set, which is a representation of the entire population. The descriptive statistics are broken down into measures of the central tendency (mean), measures of variability (standard deviation, the minimum and maximum variables), and percentiles. Thus, the mean value of backhand shots by the 25 players is 177.360 with a standard deviation of 31.8223, where the maximum number of received shots is 245.

Table 2 The descriptive statistics presentation of the data set

	N	Mean	Std. deviation	Minimum	Maximum	Percentiles		
						25th	50th (median)	75th
Backhand	25	177.360	31.8223	121.0	245.0	158.000	176.000	193.500

Table 3 Ranks

	Backhand style	N	Mean rank
Backhand	1	6	9.00
	2	9	19.78
	3	10	9.30
	Total	25	

Kruskal–Wallis Analysis Results

In this section, to test whether there are statistically significant differences among backhand styles, a Kruskal–Wallis rank test was applied at the significance level of 0.05. Table 3 depicts the number of subjects for each backhand style. Regarding the test statistics for grouping of the backhand style variable, Table 4 shows the results.

Considering mean ranks, it looks at least superficially as if there is probably going to be a difference between backhand style 2 and the other two styles. When we look at our Kruskal–Wallis result, which is an omnibus statistic, it is looking for at least one difference somewhere, and we can see that the Chi-square is 11.933 with a p-value of 0.003. As the asymptotic significance result is 0.003 (< 0.05), we can reject the null hypothesis of no differences between the mean ranks for the backhand factor, which means that there is a significant difference among backhand styles considering the dependent variable when the minimum expected cell frequency is 2.0.

Mann–Whitney U Test Analysis Results

After determining the existence of differences between grip styles considering the onset of pain in tennis players' elbows, we need to follow up the Kruskal–Wallis test results with a post hoc test or accurate comparison testing because we do not know which backhand grip is statistically different from the others. Thus we will have specified the safest grip style for the backhand stroke. Consequently, the Mann–Whitney U test for analyzing within groups has been used to test the hypotheses. Paired comparisons between backhand styles have been conducted, and the results of the analyses are illustrated in Tables 5 and 6.

Regarding Table 6, there is no significant difference between backhand styles 1 and 3. Besides, due to the derived asymptotic significance results between

Table 4 Test statistics[a, b]

	Backhand
Chi-square	11.933
df	2
Asymp. sig.	0.003

[a]Kruskal Wallis test
[b]Grouping variable: backhand style

Table 5 Ranks for backhand styles

	Backhand style	N	Mean rank	Sum of ranks
Backhand	1	6	4	24
	2	9	10.67	96
	Total	15		
	1	6	8.5	51
	3	10	8.5	85
	Total	16		
	2	9	14.11	127
	3	10	6.3	63
	Total	19		

Table 6 Test statistics[a] for backhand styles using Mann–Whitney U test analysis

		Backhand
Backhand styles 1 and 2	Mann-Whitney U	3
	Wilcoxon W	24
	Z	−2.828
	Asymp. Sig. (2-tailed)	0.005
	Exact Sig. [2 * (1-tailed Sig.)]	0.003[b]
Backhand styles 1 and 3	Mann-Whitney U	30
	Wilcoxon W	85
	Z	0
	Asymp. Sig. (2-tailed)	1
	Exact Sig. [2 * (1-tailed Sig.)]	1.000[b]
Backhand styles 2 and 3	Mann-Whitney U	8
	Wilcoxon W	63
	Z	−3.021
	Asymp. Sig. (2-tailed)	0.003
	Exact Sig. [2 * (1-tailed Sig.)]	0.001[b]

[a]Grouping variable: backhand style
[b]Not corrected for ties

backhand styles 1 and 2 (p-value; $0.005 < \alpha$-value; 0.05) as well as between backhand styles 2 and 3 (p-value; $0.003 < \alpha$-value; 0.05), it is clearly observable that the backhand style 2 is very different from the other styles.

Discussion

Although Tennis Elbow is a very complicated issue with a vast range of factors, such as physical status, racket weights, grip-head balance and wet balls, these cause the elbow to become sore and tender at the extensor carpi radialis brevis muscle. Besides, lateral epicondylitis is not exclusive to the sport of tennis, and it can also occur in golf players and casual workers who make repetitive monotonous wrist movements. However, this paper has advanced research on a pilot sample that may suggest an avenue for further investigation. Thus, the study of the role of grip style in the onset of elbow pain in tennis players was the primary challenge. On this point, an experimental design was adopted to analyze three different grip styles during backhand strokes. Because of the sample size, two non-parametric testing methods were used to interpret the data gathered on the tennis players. Kruskal–Wallis analysis showed the existence of statistically significant differences among backhand styles. The Mann–Witney U test was used to conduct paired comparisons among backhand techniques, and it was concluded that the second grip style (two-handed backhand style) was significantly different. Players using two-handed backhand grip style while swinging the racket to deliver backhand strokes reported the number of strokes before the onset of pain in their elbows. From another point of view, however, using the two-handed backhand style is safer than other common grip styles.

Finally, but importantly, it has been proven statistically through this work that the double-handed grip style is the proper technique to limit injuries of the elbow by minimizing wrist flexion and ulnar deviation while delivering a backhand stroke. The potential limitation of this study is the number of independent variables as factors influencing the onset of pain in tennis players. Resolving this shortcoming will depend on more design and testing of hypotheses based on the speculations and related literature.

Conclusion

The developed hypothesis has been tested via statistical analysis techniques in the designed experimental research. The inferences drawn from the results of the analyses are consistent with the research question. What is more, the results confirm the present concerns and speculations about the role of grip style in the onset of pain in tennis players. The proposed experimental design based on the onset of pain and preparing a background for further and comprehensive studies are considered

as the present work's main contribution. Hence it is recommended to more fully include all the possible active influencing factors for investigation in future work. Besides reviewing the accuracy levels of the parametric analyses of variances, studying larger samples could promote the superiority of future studies.

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Application of Lean Principles in Hospitals: A Process Design in an Emergency Department

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Abstract This study aims to apply lean thinking to the Emergency Department of Kocaeli University Education and Research Hospital. From analyzing to designing the improved system, lean techniques are adopted in order to reduce waste compared to the current system and to make the process continuous. Although lean defines wastes in the process, it does not indicate which wastes should be eliminated primarily. At this point, Arena simulation software program is used. To compare the current and simulated systems, the length of stay of patients in the Emergency Department is selected as the main quality measurement. According to Arena outcomes, the main bottlenecks are identified and then suggested improvements are implemented in the newly designed system with lean approaches. To determine the effects of the improvement, Arena is run again to see whether or not there is a significant difference. Taking into account these considerations, the Arena simulation program helped the application of lean tools in redesigning the Emergency Department process.

Keywords Lean · Hospital · ED · Arena · Simulation

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Introduction

In today's healthcare sector, patients consider not only obtaining a service from hospitals but also the quality level of the medical care throughout their journey. Providing high-quality healthcare has become a widespread issue around the world as well as in Turkey. In order to increase the quality level of hospitals, total quality management applications started to be used in hospitals in the 1990s. After 2010, lean initiatives, a tool for total quality management, started to be adopted in the healthcare sector in Turkey (Çavuş and Gemici 2013). Long waiting times, delayed test results, increased medical errors, and departures from hospitals without seeing a doctor in the Emergency Department (ED) result in patient dissatisfaction, while lean defines them as activities that patients do not want to pay for. According to the main purpose of lean, any kind of non-value added activity should be eliminated from the patient's path by focusing on process flow. Therefore, lean techniques make it possible to find a better way to provide a good-quality service to patients by decreasing the level of dissatisfaction due to the defined problems. More specifically, the need to improve the service quality and satisfaction of patients and medical staff in emergencies can be met through the benefits of lean. The aim of this paper is to decrease the total length of stay of patients as well as the waiting times, which are the main problems in the ED of Kocaeli University Training and Research Hospital, in the light of lean thinking. In addition, in order to eliminate waste, this paper focuses on the process throughout the ED by using the lean approach with a streamlined and smooth flow.

Literature Review

Lean can be seen as a rescuer for organizations by serving products at the desired level to customers in a short time without any further cost to them. Fillingham (2007) corrected a misunderstanding of the lean perspective by stating that instead of producing more products by forcing workers to study more, lean is about eliminating the seven types of wastes (motion, waiting, over-processing, transport, defects, over-production, and inventory), which are the main parts of the obstructions from the efficient production by workers. The results of the application of lean affect and stimulate further results as a chain effect. Carrying out production by responding to the customer's requirements leads to decreased stock levels, which in turn leads to the elimination of waste and affects the financial situation of the organization positively.

The principles of lean are not only used in manufacturing areas but have also started to be used widely in the service sector. According to Dibia et al. (2014), lean is applied in the ceramics, aerospace, finance, building, and electronics industries as well as in the healthcare industry.

Lean in Healthcare

The critical role of healthcare in people's lives and enhanced quality of sanitation, which are increased competency between healthcare organizations, have led to significant improvements in the healthcare sector. The evolution of healthcare quality in Turkey started with the application of "Total Quality Management (TQM)" in 1990 and continued with the taking of the ISO 9001 certificate in 2003 and the setting of "Health Quality Standards" by the Ministry of Health. In 2010, the first lean applications and adoptions in hospitals were seen (Çavuş and Gemici 2013). It can be said that there was a major step forward in 2003 with the "Healthcare Conversion Program" regulation, whose main objective is to provide qualified, sustainable, effective, and efficient healthcare services for everyone (Lamba et al. 2014).

Despite these initiatives, various problems such as medical errors and waiting times can result in failure in the healthcare process. Lean philosophy has started to be applied in hospitals to address these wastes. Lean can be applied well in healthcare systems because it is not hard for doctors, nurses, and other medical personnel to learn and adopt lean techniques (Curatolo et al. 2014).

Virginia Mason Medical Center achieved the following improvements by applying lean for three years: a 53% decrease in stocks, a 36% increase in efficiency, a 41% reduction in space requirements, a 65% decrease in lead times, a 44% reduction in walking distances, a 72% decrease in the movement of materials, and an 82% reduction in setup times (Womack et al. 2005). It can be stated that the application of lean can result in reduction of seven types of wastes in healthcare.

Lean in Emergency Departments

Seven types of wastes, which are defined as non-valued activities, can also be defined for EDs in healthcare. Dickson et al. (2009) highlighted this issue by giving long waiting times for tests, doctors, and long walking distances as examples. Patients do not want to encounter these types of delays during their ED journeys.

Problems including the waiting time at each stage in the ED affect the process in a negative way. Mazzocato et al. (2012) stated that the problems of congestion and waiting are mainly derived from the breakdown of the process. It can be inferred that to decrease these problems, the process flow should be considered. Lean focuses on the flow and process to help ameliorate these problems. Mazzocato et al. (2014) indicated that the value defined by the customers at the ED is taking the service on time. Lean succeeds in this respect by presenting a continuous process for the patients to link the valued activities by eliminating wastes. This enduring process can be obtained by establishing the wastes during the process of the patients in the emergency services and regulating the process by small improvements to eliminate the unnecessary tasks. Chan et al. (2014) observed that with lean work in the ED, the consultation waiting time decreased from 13.68 to 11.65 min and the final waiting time also decreased from 16.86 to 14.28 min.

Simulation is one of the lean tools that is helpful for seeing the bottlenecks of the current situation and the effects of the implementation on the system statistically. Wang et al. (2015) mentioned that the program Rockwell Arena 13.51 provides a preview of the waiting time and service level when changing the condition only in the program. Discrete event simulation is beneficial for simulating the hospital environment since it reflects instantaneous changes in the program. In addition, it is very difficult to see the bottlenecks and the effects of the improvements in such a complex system without using a simulation. Arena simulation software is helpful at that point to make it possible to see the waiting time, queues, and length of the service and also to allow different improvement scenarios to be compared with the current process. Robinson et al. (2012) highlighted that simulation and lean should be used together in the healthcare sector because they have the same motivations. By using discrete event simulation with lean, the process will be better designed than if lean is used only as a tool.

Methodology

The objective of this paper is to increase the satisfaction level of the adult patients and medical staff by decreasing waiting times and the time spent in the ED of Kocaeli University Education and Research Hospital. In order to achieve this aim, the process journey of the patients was taken with a flowchart by applying lean methodologies and tools. Lean was preferred in the study because one of the main principles of lean thinking is the achievement of a smooth flow. For that reason, the non-valued steps and wastes during the process were established by observing and taking approval of nurses and doctors in a focus group. The data were collected from the Information Technology department and the HUY system and all were confirmed by observations and a focus group. The current flow with the collected data was transferred to the Arena software program to simulate and trace the real patient flow and specify the bottlenecks. Multiple small improvements were offered to enhance the process by looking at the designated wastes and bottlenecks by using the lean approach. The ED process at Kocaeli University Education and Research Hospital was redesigned with a flowchart to offer a better quality service to patients by conducting a focus group and the simulation was rerun to track the improvements.

Application and Results

Current Process Flow

The journey of adult patients in the ED of Kocaeli University Education and Research Hospital was observed for 12 weeks and traced in terms of each step of the patients to draw up the current flowchart.

After a patient arrives at the ED, triage or a paramedic classifies the patient as green, yellow, or red according to severity. These different kinds of patients are directed to the green area or the yellow/red area. These areas have their own bed capacities and their own medical staff in terms of doctors, nurses, and interns. Patients classified as red are the critical ones and should be examined and cured immediately. Patients classified as yellow also have serious problems but these health problems are not life threatening and can wait. Patients classified as green have minor health problems and are at low risk so they can wait for longer compared to yellow patients. Triage needs to stand up and go to the closed bed areas to check bed availabilities for each incoming patient. After a suitable bed has been found, the patient's journey continues with examination by a doctor, tests (blood, X-ray, tomography, urine), consulted doctor examination, treatment, and finally discharge from hospital. The HUY system is used in the hospital to track these stages.

Observed Problems in the Emergency Department

While observing each step of the ED patients and drawing the flowchart of the patients, some problems were observed. It was also seen that these observed problems are parallel to those of the EDs examined in the literature, which were described in the literature review section. While identifying the problems in the ED of Kocaeli University Education and Research Hospital, the patients were also interviewed and a focus group was conducted with medical personnel working in the emergency service (Table 1).

Application of Arena Simulation Program

Data regarding the duration of each stage of the flowchart were collected from the HUY system and by observation and were translated into the Arena Input Analyzer to find their distributions. To simulate the current process of Kocaeli University Education and Research Hospital ED and to see the bottlenecks, the Rockwell Arena simulation program was used within the context of discrete event simulation. This program was used just to see the obstacles in the process in terms of delays and waiting times to be minimized, as lean suggests.

The main indicator for the hospital is the length of stay (LOS) of the patient in the ED. The LOS of the patient was measured in the simulation model by using the record module. The difference between the arrival and discharge times gives the length of stay of a patient in the model. After the current drawn process flow had been modeled in Arena with reflected data from Input Analyzer, it was run with a replication length of 30 days and 100 iterations to obtain accurate results. The comparison of the simulated and LOS data is used to check the validity of the

Table 1 Seven types of wastes at the ED of Kocaeli University Hospital

The seven wastes in healthcare	Wastes at Kocaeli University Hospital Emergency Department
Motion	Triage goes into the green bed area to check bed availability Triage goes into the yellow bed area to check bed availability Non-emergency department patients crowd the emergency service Patients walk around the ED due to the long waiting times
Waiting	The average waiting time for green patients to be seen by a doctor is 10 min The average waiting time for yellow patients to be seen by a doctor is 29 min The average waiting time for consultation is 121 min
Over-processing	For the consultation, the doctor is also telephoned after an order is entered in the HUY system The triage and registration secretary are used by non-ED patients to obtain directions about other hospital departments Consultation requests are assigned without knowing whether the consultant doctor is available or present at the hospital
Transport	Wheelchairs left in the corridors are transported to patients who need them at the entrance
Defects	There are defects in urine and blood tests because patient IDs are written incorrectly on blood tubes and beakers by hand
Over-production	Urine and blood are reanalyzed due to defects on them
Inventory	There are queues in front of the triage ward

created model. According to these statistics, it can be said that it is valid while the current length of stay of patients at the hospital is 198,110 min while the simulation model gives a patient LOS of 197,412 min.

Scenarios and Suggested Improvements

Scenario 1: Suggested Improvement for Bed Capacities

After seeing the long waiting times before being directed to the bed area and the length of stay, first of all it was thought that the bed capacity was insufficient. In order to minimize this waiting waste, the number of the beds was increased in the resource spreadsheet in Arena to see the effect. After changing the bed capacity, the simulation program was run 100 times to decrease the variance. The length of stay was decreased by increasing the bed capacities. This mean of this scenario was compared with the mean of the current situation using a two-sample t-test. The two-sample t-test was used because at each iteration, the Arena simulation program selects random entities according to the distributions that are entered. For this test, the hypotheses were as follows:

H0: The means of the bed scenario and the current situation are equal.
H1: The means of the bed scenario and the current situation are not equal.

The result showed that there is no significant difference compared to current situation. This may originate from the lack of medical staff when the bed capacity is increased. For this reason, this scenario is not suggested as an improvement.

Scenario 2: Suggested Improvement for Triage Bed Availability Checking

After patients arrive at the ED, triage does not know the bed availability and goes there to check it. Since triage has other regular jobs and may be busy, he or she cannot go there and check it every time. This leads to a waiting delay. It is suggested that this waste should be minimized by adopting a screen in the ED that shows bed availabilities automatically; in other words, triage will not need to go to the bed area to check the status of the beds.

In order to see the results of this improvement, the Hold module, which presents the waiting area of the patients, was rearranged in Arena. After making the new arrangement, the Arena simulation program was run for 100 iterations to see the effects. The result showed that the length of stay decreased from 197,421 to 174,059 min, while the waiting time of the green patients decreased from 10,073 to 0 min and that of the yellow patients decreased from 29,238 to 24,462 min. This suggested improvement was also transferred to the Output Analyzer of the Arena simulation program in order to compare the mean of the scenario with the mean of the current situation.

H0: The means of the suggested triage bed-checking improvement and the current situation are equal.
H1: The means of the suggested triage bed-checking improvement and the current situation are not equal.

The results of the two-sample t-test indicated that the length of stay and the waiting times of the green and yellow patients show significant differences compared to the current situation. So, this suggested improvement can be beneficial for decreasing the motion of the triage checking the bed availability, the waiting waste of the patients, and the motion of the patients due to waiting.

Scenario 3: Suggested Improvement for Asking Triage and Registration Secretary for Directions

In this scenario, it is suggested that the process of asking the triage and secretary for directions to and locations of other departments in the hospital be minimized, since

this is a motion waste according to lean. To see the effect of this improvement, this process was eliminated from Arena and simulated for 100 iterations.

The length of stay of patients decreased from 197,421 to 194,736 min. However, when these two statistics were compared in the Arena Output Analyzer with the two-sample t-test, the result showed that there was no significant difference between the two means. Even though this improvement did not affect the length of stay or waiting times significantly, due to quality assurance, this motion waste should be eliminated.

At this point, it is important to highlight that decreased waiting time is not the only indicator of increased service quality according to lean. This study targets the minimization of wastes in the process, so to achieve this aim, the suggested improvement will be established by placing signs that show the locations of other departments around the ED in order to help the non-ED patients to find directions. Also, these signs are associated with the visualization tool of lean.

Scenario 4: Suggested Improvement for Consultation Waiting Time

This scenario deals with reducing the waiting time for consultation, a waiting type of waste. When the emergency doctor cannot diagnose the patient's disease and needs a specialist's opinion, a consultation order is made by a nurse via HUY. The problem in this process is that the nurse does not know whether that consultant is available at that moment, so the patient may wait for a long time. The suggested improvement is the addition of a feature in the HUY system that will show only the available doctors who have recently logged into the system with their passwords so that the consultation request will not be sent to busy doctors.

According to the hospital medical staff, the average waiting time for consultation can be decreased from 112 to 40 min by implementing this new feature in the HUY system. To see the effect of this scenario, the duration of the Consultation Module is changed from 112 to 40 min by taking into account their distribution in Arena, and the improved model is run for 100 replications. As a result, the average length of stay of patients decreased from 197,421 to 190,765 min.

A two-sample t-test is conducted with Arena Output Analyzer and the null hypothesis is that the means are equal. With a 95% confidence interval, the null hypothesis is rejected, meaning that there is a significant difference between the current model and improved model with regard to the consultation. In this scenario, the suggested improvement helped to decrease waiting waste, a non-valued activity, in the healthcare process in the Kocaeli ED.

Scenario 5: All the Suggested Improvement Scenarios Together

In addition to scenarios that affect the length of stay directly, it was also decided to suggest small lean improvements with regard to the defined and observed problems associated with the seven types of wastes previously to increase the quality level. They do not affect the duration of the stages significantly, but they are required to increase patient satisfaction. Currently, patient IDs are written on tubes and beakers by hand and sometimes nurses write them incorrectly. To minimize this defect waste, it is suggested that a barcode be stuck on the tubes. Also, wheelchairs are left in the ED corridors and members of the medical staff transport them unnecessarily when a new patient arrives. It is suggested that the lean tool 5S should be applied; in other words, a specific place should be assigned for wheelchairs at the entrance. In addition, students use ED corridors as a shortcut to the canteen. To prevent crowd and motion waste, it is suggested that a password feature be installed in the door so that it can be used for urgent situations only. In this scenario, the aim is to see the effects of all improvements. That is why, in addition to these small improvements, scenarios 2, 3, and 4 were simulated together. The improved simulation model was rerun for 100 replications to decrease the variance.

The new arrangement decreased the length of stay from 197,412 to 153,603 min, decreased the yellow patients' bed-waiting queue from 29,238 to 13,047 min, and eliminated the green patients' bed-waiting queue totally. From these decreased times, it can be stated that implementing all the suggested improvements in the model succeeded in minimizing waste in the process. The Arena outputs show that applying all the suggested improvements in the current Kocaeli University Education and Research Hospital ED would result in a more continuous flow in the process as parallel to lean intention.

The Arena Output Analyzer was used to conduct a two-sample t-test with a 95% confidence level.

H0: The means of the improved model and current model are equal.
H1: The means of the improved model and current model are not equal.

According to the results of the Arena Output Analyzer, H0 is rejected for all indicators. This means that applying all the improvements to the simulation model together decreased the waiting time queues and length of stay of patients significantly.

Improved Flowchart and Simulation

In order to increase patient satisfaction and service quality level and also to provide continuous flow, the suggestions for improvement explained above were reflected to the flowchart. Some of those suggestions do not affect the flow of the process but

do affect the layout. In order to better compare the current patient journey in the ED and the new improved process flow, the implemented processes are shown in yellow color. Appendix 1 presents the improved flowchart for the analyzed ED and Appendix 2 shows the improved Arena simulation.

Conclusion

The main objective of this study was to focus on the wastes that do not add any value for customers throughout the process. The service sector has started to adopt lean in order to increase quality. One of the quality tools, lean, defines the non-valued activities and classifies them as seven wastes that should be minimized to increase the quality. Lean deals with the elimination of these wastes as they disturb the process of the patients in the ED in order to achieve a smooth flow.

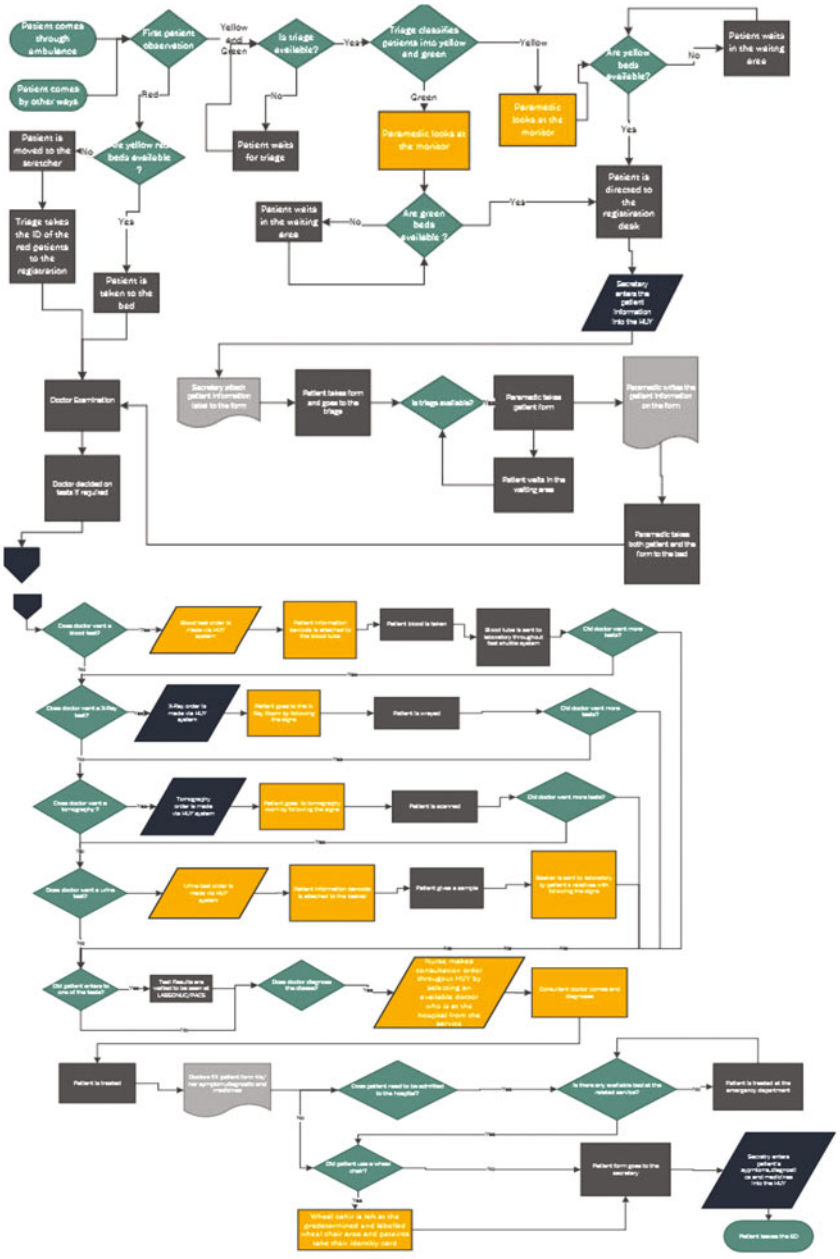
After carrying out observations and a focus group with the medical staff of the ED, the discussed wastes were associated with the seven wastes after the process flow was drawn up. The aim was to minimize these wastes. In addition, to track the current situation and the suggested improvements, the Arena simulation program was used as a lean tool. After data had been collected from the information technology of the hospital and confirmed with a focus group and observations, the distributions of the data were obtained using the Arena Input Analyzer. After translating the data into the simulation program, it was iterated 100 times, the results were obtained, and different scenarios were tested with Arena to see the effects of each improvement. As the main quality indicators are the length of stay and the waiting time of the patients, the effects of the scenarios on these indicators were considered.

As the lean approach states, small improvements to the current situation were suggested. With regard to the triage going and checking bed availabilities, it is suggested that a monitor should be purchased to eliminate the waiting waste of the patients and the motion waste of the triage. With regard to the delayed consultation stage in the process, it is advised that a new feature should be added to the HUY system to prevent the medical staff from selecting a doctor who is not available or present at the hospital. With regard to the defect waste stemming from writing patient information on tubes and beakers by hand, it is suggested that a barcode containing information should be stuck on these items to increase the quality. To address the transportation waste originating from wheelchairs being left in corridors, it is suggested that a wheelchair area should be designated at the entrance within the scope of one of the lean tools, 5S. In order to minimize the motion waste of the medical faculty's students, it is advised that a password or card pass feature should be installed in the door of the ED open to the faculty. To deal with the unnecessary motion waste due to patients being unable to find different departments and occupying the registration and triage unnecessarily, it is recommended that colored signs indicating the way to the most frequently requested departments be placed on the floor to guide the patients.

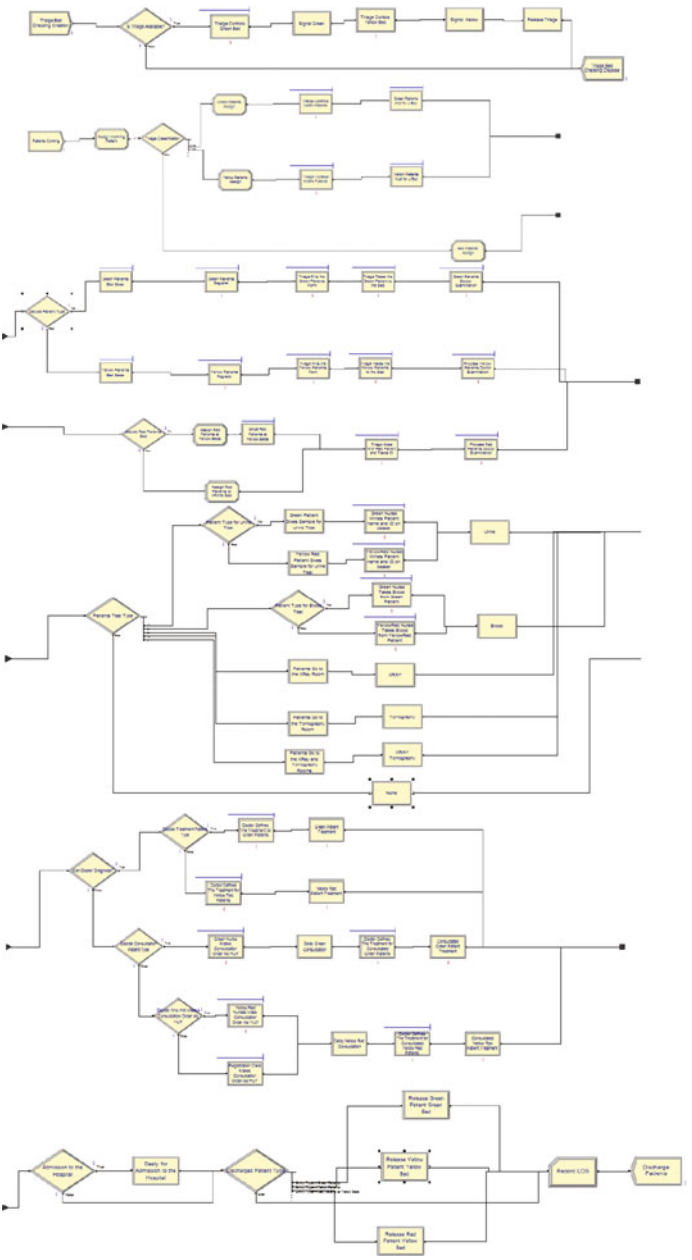
These improvements were added to the newly designed flowchart to present the improvements to the process in yellow color. In addition, when the improvements were defined in the Arena simulation program, it was found that the total length of stay decreased, on average, from 197.412 to 153.603 min, the waiting time of the green patients decreased from 10.073 to 0 min, and the waiting time of the yellow patients decreased, on average, from 29.238 to 13.047 min. The two-sample t-tests showed that the simulation results were significantly different from those for the current situation. With these improvements, the non-valued wastes can be minimized, the quality of the service that the patients receive will increase, and patients will be satisfied due to the continuous process.

With regard to further studies, these improvements should be maintained at the ED of Kocaeli University Education and Research Hospital as lean culture focuses on continuous improvement. The adoption of lean by the ED should not be limited to the recommendations of this study but should be continued.

Appendix 1: Improved Flow Chart for ED



Appendix 2: Improved Arena Simulation



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