Lecture Notes in Management and Industrial Engineering

Fethi Calisir
Orhan Korhan *Editors*

Industrial Engineering in the Digital Disruption Era

Selected papers from the Global Joint Conference on Industrial Engineering and Its Application Areas, GJCIE 2019, September 2–3, 2019, Gazimagusa, North Cyprus, Turkey

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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) 2019, held in Famagusta. 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 Digital Disruption Era." Digital disruption is a transformation that is triggered by emerging digital technologies and business models. Digital disruption is expanding beyond the technology sector to engulf a diverse set of industries, including construction, energy, finance, health care, IT services, manufacturing, and transportation, that represent a large portion of the global economy. The escalating digital disruption in these industries will put unprecedented pressure on managers to formulate effective strategies to change organizational structures, and eliminate barriers that are keeping them from taking full advantage of the contemporary digital technologies. For this to be achieved, companies will need to improve and/or reengineer most of their processes before they are partially or fully automated. This means that industrial engineering skills will be the cornerstone for achieving maximum value from investments in automation. This book will shed new light on the role of industrial engineering in this endeavor. Contributions have been arranged in three parts:

- Industrial engineering;
- Engineering and technology management;
- Healthcare systems engineering and management.

We would like to express our gratitude to all the contributors, reviewers, and international scientific committee members who have aided in the publication of this book. We would also like to express our gratitude to Springer for their full

support during the publishing process. Last but not least, we gratefully acknowledge the sponsors (Elginkan Foundation, Gulaylar Group, Yapi Turk, alBaraka, ias, and Necat & Zorlu) of GJCIE 2019.

September 2019

Fethi Calisir
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Industrial Engineering

3-D Printing: a Non-disrupting Technology for Sales, Distribution, and Logistics

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Abstract. Experts forecast that 3D printing was a disruptive technology for conventional supply chains based on mass production, economies of scale, global transportation, and local inventories. However, 3D printing has many limitations in customers supply: Long operational times cause high manufacturing cost. 3D printing is not precise enough for functional surfaces and many parts and products have to be coated, assembled, or post-processed before they can be sold to customers. Spare parts could be ideal applications, but they must have the same abilities as original parts, and spare part business is too important to give away design data for 3D printing. So 3D printing is and will be limited to small volume production with new design options like the bionic design or lightweight design and for customer-configured products.

Keywords: 3-D printing · Generative manufacturing · Bionic design · Customized product · Low volume production

1 Technology of 3D-Printing

3D-Printing is the popular name of generative manufacturing, also called additive manufacturing. Unlike many other manufacturing technologies, a part is not generated by removing material from a blank (machining), by squeezing material in a die (forming) or by pouring a formless material like a melt into a die (casting). Generative manufacturing technologies generate a part layer by layer (Fig. 1). To generate a part in such a way, there must be a digital model of the solid part in the computer first. This 3D-model is then sliced into virtual layers so that for every layer a 2D contour exists. These layers are stacked, and the stack of layers can form the solid part again.

Slicing and calculating the contour of each layer is done in a computer, the 3D printer does the stacking of material. Therefore, the printing machine literally generates 3D parts of almost any geometry. Materials to be 3D printed are:

- Plastic materials (e.g., thermoplastic materials, UV-curing materials, thermal hardening resin),
- metals,
- molding sand

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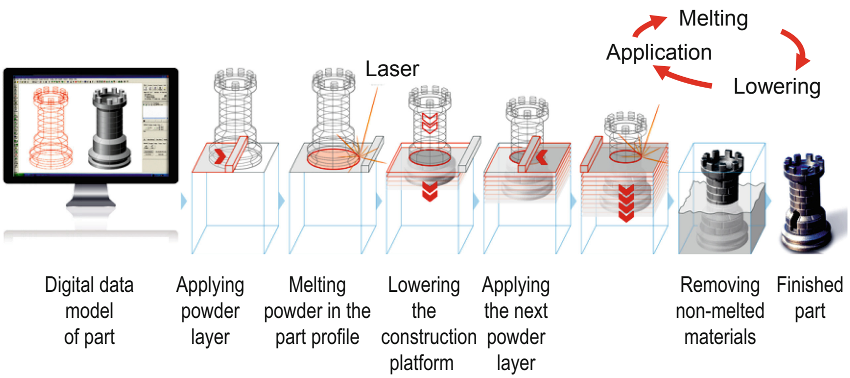

Fig. 1. Process of 3D printing with Selective Laser Sintering (source: EOS)

Industrial printing technologies are a field of continuous innovation. The most popular technologies are (Black and Kohser 2019; Groover 2017; Koether and Sauer 2017):

- Fused deposition modeling (FDM),
- PolyJet 3D printing,
- Stereolithography,
- Selective laser sintering.

In FDM a thermoplastic strand is molten in a moving jet. The jet moves at the operational level along a contour line. The hot plasticized strand connects to the level below before it cools and solidifies. After completing the contour in the specific layer, the part is lowered by one level, and the process starts again in the next layer. If the printer has more jets in the moving arm, the part can be printed out of different materials, e.g., different colors or different abilities, e.g. elastic and rigid sections.

A PolyJet 3D printing process is similar to printing in an office inkjet printer. The printer heads are mounted on a beam, which moves in the plane. Unlike the office printer, the beam also carries a UV lamp. For generating the contour in the plane, small drops of a temperable UV polymer are shot on the part, hardened immediately by UV radiation and form the next layer of material. The object is lowered by one level, and the next level can be printed. For Polyjet 3D printing, a wide range of materials is available, and different materials can be printed simultaneously.

In stereolithography, a laser beam hardens the contour of a layer. The material is a liquid synthetic resin. By hardening one layer, the hardened contour is connected to the existing semi-finished object adding another solid layer to the object. The object is lowered by the thickness of one layer so that the object is submerged in the liquid resin and the process starts again.

The process of Selective Laser Sintering is similar to stereolithography, but the material is not a liquid but a powder. The powder can be a thermoplastic material, it can be a metal powder, or it can be molding sand impregnated with plastic for sand casting. A layer of powder is placed on top of the semi-finished object. A laser beam melts the powder corns partially and connects the droplets to the layer below. The contour of the molten material forms the solid layer of the object. After the laser melting, the object is lowered by the thickness of one layer, and the process starts again.

FDM is a low-cost process, with Polyjet demonstration parts and parts of different materials can be generated. Stereolithography is used for precision parts. Selective Laser Sintering offers a wide variety of industrial applications: Metal parts of high rigidity can be printed as well as sand molds for low volume sand casting parts. Plastic parts of similar abilities like injection molded parts can be 3D printed too.

Advantages of 3D-printing processes are:

- Almost any desired geometry can be printed. Superior geometries for low weight design by complex hollow forms or bionic forms can be printed.
- Short throughput time in spite of long processing time, because parts are manufactured in one step only without part-specific setup.
- No cost for tooling and fixtures.
- Low personnel costs thanks to unattended operation.
- Low material cost, no material waste, unneeded materials can be reused.

But 3D printing technologies share disadvantages too:

- Long processing times (up to 2 days per job), but in one job many different parts can be made; the limitation is the space in the printing machine,
- high material costs per kg; unused material can be reused, but the kg-price of powder or plastic material is high,
- raw surfaces need additional machining of functional surfaces (fitting, sealing, friction…)

2 New Opportunities by 3D Printing

2.1 New Engineering Opportunities

With 3D printing, geometries can be manufactured that no other technology would make possible like:

- Complex geometries in a small volume.
- Dies for molding with improved cooling by conformal cooling.
- Lightweight design by bionic, load-capable design.
- Single piece manufacturing with the same manufacturing costs like series manufacturing, e.g. for tooling.

Unlimited freedom of design is the dream of many designers. 3D-printing places solid material almost freely in space. Other manufacturing technologies could be found which allow similar structures, but not as easy to manufacture like 3D-printing. Examples are shown in Fig. 2.

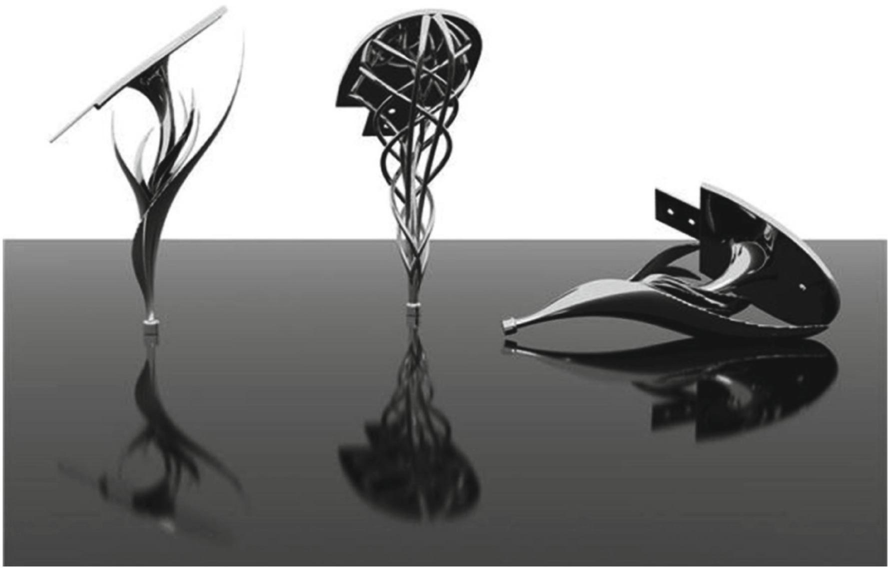

Fig. 2. 3D printing simplifies the production of bizarre geometries like these design models of heels (photograph: EOS)

With injection molding, plastic parts are manufactured. The liquid plastic material is injected in the die and solidifies there. After solidification, the part is ejected from the die. The cycle time and productivity (parts per minute) are triggered by the time for freezing the plastic material. With a conformal cooling, freezing can be accelerated, cycle time reduced, and productivity improved. The cooling channels in the die must follow the outer surface of the die as closely as possible. The complex geometry of the die with the integrated conformal cooling is selective laser sintered (example in Fig. 3).

Nature teaches designers to place material only at positions where the material enhances stiffness and strength of a structure. Bionic design asks for round geometries with the varying thickness or grid structures. In conventional manufacturing technologies, these geometries are hard to make, especially when the volume is low like in the aerospace industry. Manufacturing cost in 3D-printing is same for straight structures like for bionic structures. Therefore, a hydraulic block for an Airbus A 380 designed for 3D-printing could save 35% of weight compared to a conventionally milled and drilled hydraulic block (Thum 2017) (Fig. 4).

As 3D-printing does not generate cost advantages for series or mass production, in 3D-printing single piece can be produced for the same cost like large quantities. Customized products can, therefore, be 3D-printed. Dental prosthesis, crowns, inlays, which have to be fitted to the patients' teeth, are examples of customized products. They are also examples for the competition of technologies as these parts can also be made by conventional technologies like vacuum casting in reasonable throughput time of a few days.

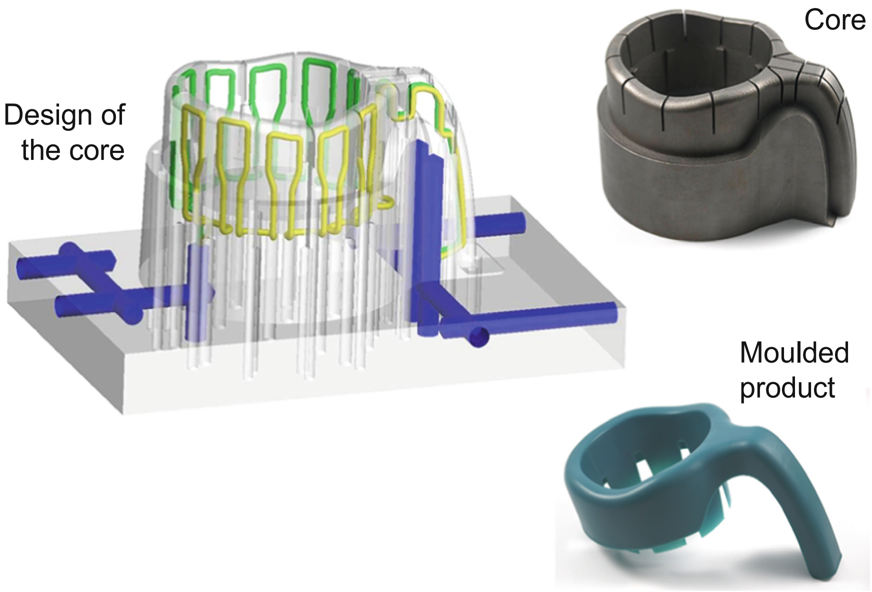

Fig. 3. Conformal cooling channels in a plastic injection molding die (die construction: Innomia, core and end product: EOS)

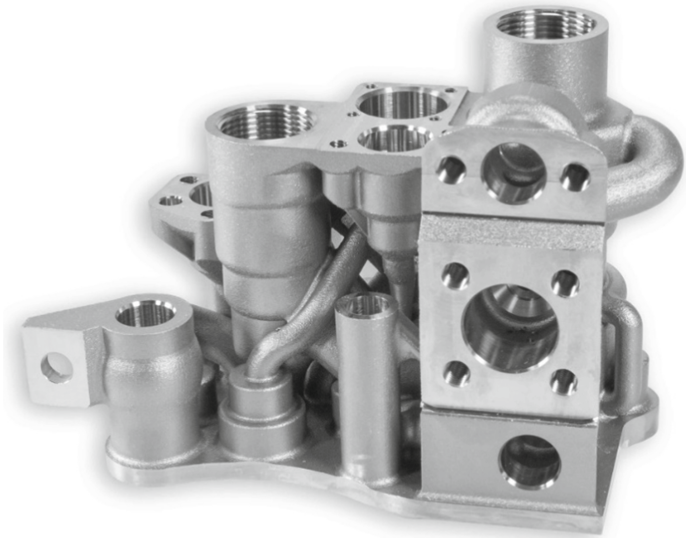

Fig. 4. 3D printed hydraulic block for an Airbus A380 (photograph: EOS)

2.2 New Opportunities in Marketing, Sales and Outbound Logistics

For a long time, it is the rule of economies of scale that specializing in a product, and accumulating volume allows a reduction of manufacturing costs per unit. The fixed costs of manufacturing, e.g. for engineering the manufacturing technology, for fixtures, for tooling and machines can be distributed to a larger quantity, thus reducing the fixed cost per unit. The economies of scale drive the globalization: Products become uniform on the globe, like a computer, a smartphone, or even a pair of jeans that is the same in Europe, Asia, or America. Central production facilities accumulate volume and produce products with minimum costs.

The products are shipped around the world and are stored in warehouses in the specific markets to fulfill customers' orders in an acceptable time. Transportation and warehousing partly compensate for the cost savings in manufacturing. Also, this way of supply causes overproduction because an unexpected rise in demand cannot be fulfilled in a short time. So sale's forecasts tend to be optimistic. If the forecasted volume is not met, obsolete inventory has to be scraped or sold with discounts, adding more sales costs to the supply (Koether 2018).

With 3D-printing there are no economies of scale so that the conventional supply chain can be disrupted: Instead of storing the physical product, the data for 3D printing are stored and used to print a part when and where it is needed. Printing centers next to the customers can print overnight the needed product and service the customer at the same time or quicker than before, but

- without long-distance transportation,
- without warehousing and inventory,
- without forecast and forecast errors of sales volume,
- without an obsolete inventory that has to be scrapped.

Also, the decentralized manufacturing of a configured product allows the response to customers' local preferences. Many local, regional, or national markets have preferences for certain products. History, national rules, laws, or culture are the backgrounds of these preferences. The market-driven product variants reduce batch sizes and counterbalance the economies of scale in conventional manufacturing. With 3D printed parts the optimal batch size is one anyway, so market specific or customized manufacturing is free.

An example of a customer specific, 3D printed product is an Adidas running shoe, which's sole is 3-D printed (Adidas 2015a; Adidas 2015b). A running shoe consists of a knit top and a plastic sole. The upper of the configured running shoe is still mass produced in different colors and different sizes. The sole and their support and damping properties are customized, depending on the customer‘s

- foot position and
- weight.

For the customized running shoe, the customer's feet are gauged to fit the optimal sole for him or her. Then this pair of specific soles, whose left and right sole can be different too, is manufactured in a 3-D printer (Fig. 5). Subsequently, the sole is connected to the upper part and handed over to the customer.

Fig. 5. The Space framework design allows the sole of a running shoe to be individually attached to the runner's need. The sole is made in 3-D printing (photograph: Carbon)

3 Limitations in 3D Printing and 3D Printed Products

3D printing will not replace conventional manufacturing and supply chains for technical and for business reasons. 3D printing technologies offer new opportunities but do not replace conventional manufacturing technologies.

3D printed products are not as precise and do not offer the same surface quality (roughness) as machined parts. The hydraulic block shown in Fig. 4, for example, has to be machined at fittings and seals. Also, many parts are coated or painted for a better look or corrosion protection before they are sold. Coating and painting cannot be integrated into a 3D printing process. Very few products for sale consist of a single part. Most products are assembled, tested, and packed before they are sold to the customer. Even in pure printing jobs, additional operations are needed: Support structures have to be removed. Powder with very small corn size can be harmful and has to be removed after printing under health and safety conditions for workers.

Therefore, in general, a 3D printer is not a simple box in which material is fed, the button pressed, and the finished part is removed. Moreover, in many cases, a 3D printer cannot manufacture a ready to use or ready to assemble part or even ready to sell a product.

Spare parts have to be supplied in a wide variety for the present and the previous product generations. The volume of a single part number is small, and very often the demand is urgent because the spare part is needed to repair a broken down product. So spare parts supply could be an ideal application for 3D printing. However, a spare part must replace the original part and has to guarantee the same properties as the original part. If the original part is mass produced, e.g., in a forging, forming or molding process, if it was precision machined it will be hard to produce a spare part with an alternative process to the original one. In these cases, 3D printing cannot be used except the original part was 3D printed too.

Spare parts are a logistic challenge, but they are also highly profitable business, as prices and margins are high. Furthermore, the supply of spare parts is crucial for customer satisfaction. In many industries business experience shows that the first product is sold by sales, the second and the following products are sold by service. Therefore, a producer will keep control over is service and spare parts business. Therefore, it is very unlikely that a third party printing center will have access to the design files of a specific part. There would be a high risk, that these parts could only be copied without authorization and in questionable quality. If spare parts can be 3D printed at all, it will be done by carefully chosen service partners or own service organization. Prices will then still not only be justified by manufacturing cost.

3D printing is slow with process times in the range of one or two digit hours. As an industrial printer is an investment like an average machine tool, cost for machine hours account for high manufacturing cost, which is not competitive to conventional series or mass production.

So a decentralized 3D printing center in the market, next to the customer

- needs noteworthy additional operations, equipment, and qualification,
- needs a supply network and a supply chain management if these additional operations are sourced out,
- needs noteworthy investment with high utilization, which hinders flexible response time on customer orders.

In the new world of 3D printing centers next to the customers would print parts on demand like copy shops print and copy documents today. This is especially attractive for parts designed by the customer and for spare parts.

It is questionable if customers are gifted designers. In many cases, do-it-your-self-products are of inferior quality than products designed and made by qualified engineers and craftsmen.

4 Conclusion: Business Opportunities for 3D Printing

For small volume production, 3D printing offers new opportunities (Ebeling 2017):

- Tool design and tool making profits from new technical opportunities of 3D printing like conformal cooling (Fig. 3)
- Lightweight design (Fig. 4) gains new opportunities by bionic design and hollow structures
- Configured products develop new markets for individual products with defined quality (Fig. 5)
- Small volume products like for race cars (Fig. 6) or luxury cars can be manufactured with low fixed cost and without tooling.
- Samples, prototypes, sample tooling, and prototype tooling are produced in short lead time to accelerate time to market in a product development business process.
- Simple parts (one component, no coating, no assembly, no precision) can be copied and printed with or without permission of the original manufacturer or designer.

Fig. 6. Water pump wheel for a race car, 3D printed (source: BMW)

Because of the technical, legal, and economic limitations, 3D printing will not disrupt the well-known manufacturing, sales, and supply system of industrial products:

- Manufacturing costs of 3D printing are too expensive for mass products because costs for machine hours are similar, like conventional tool machines, but operation times are much longer.
- Functional parts or functional sections of a part are not precise enough to be 3D printed (Fig. 4)
- Products for sale have to be machined, coated, and/or assembled. So pure printing is not enough
- Spare parts must have the same abilities as the original part, so it has to be produced in the same process as the original part.
- Furthermore, spare part business is too important for a producer to give up control over the spare part supply and sales.

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A Comparative Study of Multiple Objectives for Disaster Relief Logistics

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Abstract. Disaster relief logistics is a critical part of humanitarian emergency operations. In this study, we develop integer programming models with a focus on the pre-disaster location selection for depots in which relief items would be stored and the post-disaster distribution of relief items to demand locations. The goal is to determine the optimal depot locations and depot-demand node allocations by minimizing the total transportation cost of delivering relief items. We incorporate performance measures that represent the efficiency, efficacy, and equity of the decisions in our models in terms of total transportation cost, total waiting time, and percent of unmet demand, respectively. We consider the uncertainties that would affect the decisions made in terms of demand and transportation times in our case study by analyzing the results under various scenarios. We provide observations regarding the performance of different objectives under different scenarios for demand and transportation network conditions.

Keywords: Disaster management · Humanitarian relief logistics · Location selection · Integer programming · Multi-objective programming · Demand and distance uncertainty

1 Introduction

One of the most important challenges that humanity faces are dealing with disasters. According to the International Federation of Red Cross and Red Crescent Societies (IFRC), a disaster is "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources" (IFRC 2019). Disasters can have natural or human-made causes. Natural disasters include floods, hurricanes, earthquakes, and cyclones, whereas human-made disasters include wars, famines, and epidemics, all of which are relevant threats for the world population today. It is extremely important to be prepared for disasters to alleviate the problems during disaster relief operations. As one of the most frequently observed natural disasters, earthquakes are experienced in various locations that cause significant damage and a great number of casualties. For example, more than 165,000 people died as a result of the Indian Ocean earthquake that triggered tsunamis and hit Indonesia in 2004 and more than 222,000 people died in the 2010 earthquake in Haiti, which is considered the worst

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earthquake encountered by the United Nations (UN) (de la Torre et al. 2012). Even with the advanced seismic technology, it is extremely difficult to determine where and when the earthquake will attack early enough to take precautions.

In Turkey, Istanbul, being a densely populated mega-city with a population of 15+ million, is facing a great risk as it is in the highly active North Anatolian Fault Zone (NAFZ). It has been reported by geoscientists that an earthquake of magnitude 7 or greater is expected to originate in the eastern Marmara Sea, twenty kilometers south of Istanbul, where there has not been an earthquake since 1776 (Weston 2017). Such an earthquake could devastate the region, and many people would need shelter, food, water, and medical care. To prevent further damage to people in the aftermath of such an earthquake, required relief items must be delivered timely to the affected population, and the success of these logistics operations relies on the level of preparedness. In this study, we focus on the pre-disaster location selection for depots in which relief items would be stored and the post-disaster distribution of relief items to demand locations.

Disaster operations management (DOM) deals with activities before, during, and after the disasters aiming mainly to minimize casualties and costs. DOM is commonly described in four phases in the literature: mitigation, preparedness, response, and recovery (Altay and Green 2006). Mitigation and preparedness are pre-disaster phases in which the goal is to reduce the possible impacts of a disaster and prepare a community to respond effectively when a disaster occurs. Response and recovery are post-disaster phases in which the affected people are helped by the government and non-governmental organizations (NGOs) immediately using the available resources and the stabilization efforts continue to support the community until returning to a state of normalcy. This study aims to determine the best depot locations in the preparedness phase and the best possible depot assignments to demand locations in the response and recovery phase of a disaster.

Research in disaster relief logistics deals with decisions regarding the numbers, capacities, and locations of depots to store emergency relief items and shelters to protect the affected population as well as the transportation of items to those in need. The challenges in disaster relief operations are mainly due to destabilized infrastructure, limited time and capacity to distribute relief materials, and uncertain demand (de la Torre et al. 2012). As the frequency and scale of disasters increase, efficient and accountable use of scarce resources has become crucial in relief operations and the quality of decisions made in disaster relief logistics can be measured in terms of efficiency, efficacy, and equity (Beamon and Balcik 2008; Huang et al. 2012). In this study, we incorporate performance measures that represent the efficiency, efficacy, and equity of the decisions in our model in terms of total transportation cost, total waiting time, and percent of unmet demand, respectively.

As disasters occur at uncertain times and locations, the post-disaster demand and transportation conditions are also uncertain. In modeling systems with such uncertainties involved, one must take into account a range of possible scenarios to provide more applicable solutions. Therefore, we consider the uncertainties that would affect the decisions made in terms of demand and transportation times in our case study by analyzing the results under various scenarios.

2 Literature Review

The increase in the number and impact of disasters in the recent decades necessitated the smart use of scarce resources, which, in essence, is a common goal in operations research and management sciences (OR/MS). Therefore, the OR/MS community has been increasingly studying disaster management issues and developing quantitative methods to support humanitarian operations. Altay and Green (2006) review the OR/MS studies in DOM from 1980 to 2004 and report that, of the 109 papers, 44% address mitigation, 21.1% address preparedness, 23.9% address response, and 11% address recovery in the disaster lifecycle. Galindo and Batta (2013) also review the OR/MS literature in DOM from 2005 to 2010 and show that, of the 155 papers, 23.9% are in mitigation, 28.4% are in preparedness, 33.5% are in response, only 3.2% are in recovery, and 11% are in multiple stages, similar to this study where we deal with both pre-disaster and post-disaster decisions. This shows that more research needs to focus on, especially recovery operations, including relief distribution.

A review of 83 papers in relief distribution networks with an OR component from 1990 to 2013 by Anaya-Arenas et al. (2012) shows that only 8 of these papers study both location and transportation problems. Our study deals with both depot location selection and transportation problems, contributing to this less studied area of research. This review article also points out the need to design more sophisticated but realistic models that are capable of supporting crisis managers.

One realistic assumption regarding disaster management, in general, is that there are multiple perspectives (of NGOs, government organizations, or affected population); hence, multiple objective functions. Boonmee et al. (2017) review the optimization models for facility location problems in humanitarian logistics, specifically the models in four categories: deterministic, dynamic, stochastic, and robust. Minimizing response time, risk, cost (in terms of distance, time, facility fixed costs, or operating costs), unsatisfied demand are found to be the main objectives in the emergency humanitarian logistics literature. To support integrated disaster stage management, developing new objective functions by integrating the facility location problem with other problems such as routing, evacuation, inventory, resource allocation, and relief distribution problems is suggested.

Several humanitarian logistics studies adopt multiple objective functions. Gutjahr and Nolz (2016) provide a review on multi-criteria optimization in humanitarian OR and classify criteria in three categories: efficiency (cost), effectiveness (time, coverage, travel distance, reliability, and security), and equity (fairness). As an example in relief logistics, Tzeng et al. (2007) propose a multi-objective relief distribution model with three objectives: minimizing the total cost and the total travel time for efficiency and maximizing the minimal satisfaction for fairness. In another study, Huang et al. (2015) assume three objective functions of lifesaving utility, delay cost, and fairness with a rolling horizon approach to update information in their convex quadratic network flow problem. Zhan et al. (2014) propose a multi-objective, multi-supplier, multi-affected area, multi-relief, and multi-vehicle relief allocation problem based on disaster scenario information updates to coordinate efficiency and equity. Gralla et al. (2014) study the trade-offs among multiple objectives in an immediate humanitarian aid delivery after an earthquake scenario by surveying 18 expert humanitarian logisticians. They identify the amount of cargo delivered to be the most important and the cost to be the least important objective, compared to the prioritization of aid by commodity type, the prioritization of aid by delivery location, and the delivery speed. Ransikarbum and Mason (2016) develop a multi-objective network optimization model that integrates supply distribution and network restoration decisions. This model maximizes the minimum percent of satisfying demand, minimizes the total unsatisfied demand, and minimizes the total network restoration and transportation costs as a weighted objective function subject to capacity, resource, and budget constraints. Ferrer et al. (2018) develop a compromise programming model for multi-criteria optimization in humanitarian last mile distribution for a single commodity using a convoy of vehicles with the criteria of time, cost, equity, priority, security, and reliability. This model is illustrated using a case based on the 2010 Pakistan floods, and a detailed vehicle schedule is produced. To ensure equity in humanitarian relief distribution, Gutjahr and Fischer (2018) propose extending the deprivation cost objective, that quantifies human suffering due to the lack of resources or services, by a term proportional to the Gini inequity index. The frequency of deliveries of a single commodity with recurring demand is decided. The model is illustrated using the 2015 Nepal earthquake, and it is argued that a high level of equity can be obtained at the expense of a slight increase in deprivation cost.

There are also studies using two-stage stochastic models in humanitarian operations such as emergency relief distribution (Barbarosoglu and Arda 2004, Rawls and Turnquist 2010) and facility location (Mete and Zabinsky 2010). Gonçalves et al. (2013) also propose a two-stage linear stochastic optimization model for humanitarian aid supply operations of the World Food Program (WFP) in Ethiopia. The first stage of this model includes supply and prepositioning stock decisions, and the second stage includes distribution flows from an origin to a destination. They show that incorporating uncertainty in model parameters such as demand, transportation cost, and accessibility improve the cost-effectiveness of the food aid distribution operations. Noyan et al. (2015) develop a two-stage stochastic programming model to design the last mile relief network. The model determines the locations and capacities of distribution points, assigns demand locations to distribution points, and allocates supplies with a hybrid allocation policy and criteria of accessibility and equity. The model also considers the uncertain demand and transportation network conditions.

According to the aforementioned classifications in the disaster relief logistics literature, our study proposes a deterministic model for both the pre- and post-disaster stages where demand and transportation time uncertainties are included by considering various scenarios.

3 Methodology

The disaster relief logistics models proposed in this study are integer programming models with the objectives of minimizing costs (in terms of total distance and transportation cost), total waiting time, and maximum percent of unmet demand. The assumptions of the proposed model are as follows:

1. There is enough storage capacity at the depots to meet the total demand.
2. Only a specific number of locations can be chosen out of the total number of available depot locations.

3. Each depot can send relief aid to a specific number of demand nodes based on the number of available vehicles for that depot.
4. The unit transportation cost is a constant that does not depend on the depot-demand node pair.
5. Loading time and unloading time for a truck are assumed to be equal.
6. There is enough number of trucks available at time zero, such that all demand can be loaded starting at the same time and delivered immediately.

The notation used in the model is defined as follows.

Sets:

$\boldsymbol{S}$: a set of alternative depot nodes, $i = 1, 2, \ldots, S$
$\boldsymbol{D}$: a set of demand nodes, $j = 1, 2, \ldots, D$
$\boldsymbol{K_i}$: set of available vehicles (trucks) at depot i, $k = 1, 2, \ldots, Nv_i$

Parameters:

cap_i: The capacity of depot i in number of pallets
dem_j: Demand of node j in number of pallets
d_{ij}: Distance between depot i and demand node j in kilometers
t_{ij}: Total transportation cost per pallet from depot i to demand node j in dollars (the per pallet cost based on the sum of fuel cost, f_{ij}, distribution cost, $Dist_{ij}$, and worker cost, Wr_i)
$Accu_{ij}$: Accumulated waiting time in minutes (the sum of loading time, unloading time, and the time needed to reach demand nodes)
MD: Maximum number of depots that can be opened
Nv_i: Number of vehicles available at each depot at time zero
$vcap$: Capacity of a truck in a number of pallets

Decision variables:

x_{ij}: Number of pallets delivered from depot i to demand node j

$$w_{ij} = \begin{cases} 1, & depot\ i\ serves\ node\ j \\ 0, & otherwise \end{cases}$$

$$y_i = \begin{cases} 1, & if\ depot\ location\ i\ is\ selected \\ 0, & otherwise \end{cases}$$

The mathematical models for the depot location selection problem with two different objective functions are called Model 1 and Model 2 and are formulated as follows.

Models 1 and 2:

$$\text{Minimize } Z_1 = \sum\nolimits_{i \in \mathrm{S}} \sum\nolimits_{j \in \mathrm{D}} \left(x_{ij} d_{ij} \right) \tag{1}$$

$$\text{Minimize } Z_2 = \sum\nolimits_{i \in \mathrm{S}} \sum\nolimits_{j \in \mathrm{D}} \left(x_{ij} t_{ij} \right) \tag{2}$$

Subject to:

$$\sum\nolimits_{j\in \mathrm{D}} x_{ij} \le Cap_i \times y_i \qquad \forall i \in S \tag{3}$$

$$\sum\nolimits_{i\in \mathrm{S}} x_{ij} \ge dem_j \qquad \forall j \in D \tag{4}$$

$$\sum\nolimits_{i\in \mathrm{S}} y_i \le MD \tag{5}$$

$$x_{ij} \ge 0, \text{integer} \qquad \forall i \in S, \forall j \in D \tag{6}$$

$$y_i \in \{0, 1\} \qquad \forall i \in S \tag{7}$$

The objective function Z_1 in (1) minimizes the total distance between the demand nodes and the depot locations selected. The objective function Z_2 in (2) minimizes the total transportation cost that consists of fuel cost, distribution cost, and worker cost. Constraint (3) ensures that the storage capacity of depots is not exceeded while (4) ensures the amount of relief materials will satisfy the demand for each node. Constraint (5) controls the number of selected depot locations with the maximum number required. Constraint (6) and (7) are the non-negativity and binary constraints for the x_{ij} and y_i variables, respectively.

The mathematical models for the response stage problems in which depots are allocated to demand nodes are given as Models 3 and 4 below.

Model 3:

$$\text{Minimize } Z_3 = \sum\nolimits_{i\in \mathrm{S}} \sum\nolimits_{j\in \mathrm{D}} \left(x_{ij} Accu_{ij}\right) \tag{8}$$

Subject to: (3)–(7)

$$\sum\nolimits_{j\in \mathrm{D}} x_{ij} \le vcap \times Nv_i \qquad \forall i \in S \tag{9}$$

$$x_{ij} \le vcap \times w_{ij} \qquad \forall i \in S, \forall j \in D \tag{10}$$

$$\sum\nolimits_{j\in \mathrm{D}} w_{ij} \le Nv_i \times y_i \qquad \forall i \in S \tag{11}$$

$$w_{ij} \in \{0, 1\} \qquad \forall i \in S, \forall j \in D \tag{12}$$

The objective function Z_3 in (8) minimizes the total accumulated waiting time for the demand nodes to receive relief items. In addition to constraints (3)–(7), constraint (9) limits delivered pallets with the number of vehicles. Constraint (10) ensures the number of delivered pallets is at most as much as the capacity of vehicles for each trip. Constraint (11) limits the number of demand nodes that can be served by a depot with the number of available vehicles at that depot. Constraint (12) defines the binary w_{ij} variables.

Model 4:

$$\text{Minimize} \quad Z_4 \tag{13}$$

Subject to: (3), (5)–(7), (9)–(12)

$$Z_4 \geq \frac{dem_j - \sum_{i \in S} x_{ij}}{dem_j} \qquad \forall j \in D \tag{14}$$

$$\sum_{i \in S} x_{ij} \leq dem_j \qquad \forall j \in D \tag{15}$$

The objective function Z_4 in (13) minimizes the maximum percent of unmet demand defined by constraint (14). To allow for unmet demand, constraint (4) is modified as constraint (15).

The disaster relief logistics optimization models defined above are related to decision making in the preparedness stage and the response stage. These decisions are based on different performance metrics, which requires a multi-objective decision-making approach.

3.1 Multi-objective Optimization

In multi-objective optimization problems, there is usually a trade-off between various objectives. Different studies have offered many approaches to model the trade-off between multiple objective functions from the decision maker's perspective. According to Chiandussi et al. (2012), *a priori* preference articulation assume that the decision maker can pre-order the objectives before searching for the solution. The Global Criterion Method (GCM) is one of the *a priori* preference articulation methods. The target of GCM is to know how close the model is to the ideal solution (or the vector of optimal solutions for every objective function separately, while achieving all of the objective functions at the same point). We apply the GCM to determine the best set of objective function weights using the following equation.

$$L(x) = \sum_{f=1}^{F} c_f \left(\frac{Z_f(x) - Z_f^*}{Z_f^*} \right) \tag{16}$$

Where F is the number of objectives, c_f is the weight of objective function f, $Z_f(x)$ is the function value at solution x, Z_f^* is the ideal function value, and $L(x)$ is the closeness percentage. This approach is also called compromise programming. A second methodology, linear combination of weights or the weighted sum method, is an *a posteriori* preference articulation according to Chiandussi et al. (2012). We determine the objective function weights that provide the minimum closeness measure based on the GCM and use those weights when minimizing the weighted sum of objectives as min $\sum_{f=1}^{F} c_f Z_f(x)$.

4 Case Study and Computational Results

This case study is based on a sample network shown in Fig. 1 below. In this network, there are 12 demand nodes (blue nodes) and 7 alternative depot locations (orange triangular nodes), and 2 collection points (black squares). The collection points will be used when the direct access from depots to demand nodes is limited because of the disaster impact. In those scenarios, the relief items will be sent from depots to the available collection point and then sent to the demand nodes, which is reflected in the models as increased distances to be traveled. At most 4 depot locations can be selected out of 7 to open depots at ($MD = 4$). The capacity of each depot is 600 pallets ($cap_i = 600, \forall i \in S$).

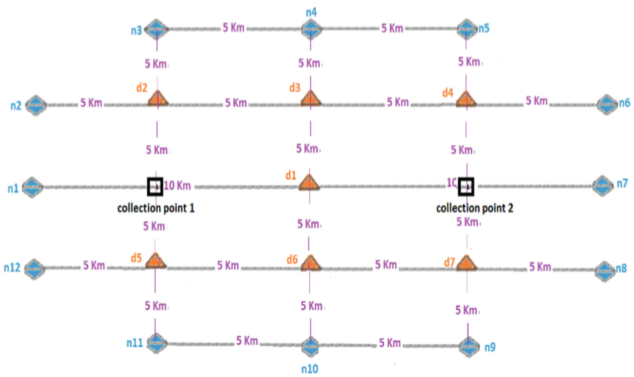

Fig. 1. The sample disaster relief logistics network

The vehicles used for transportation are trucks with a capacity of 160 pallets ($vcap = 160$). Average truck speed is assumed to be 45 km/hr. The total loading and unloading time is assumed to be 40 min. It is assumed that 5 workers and 5 vehicles are available at each depot ($Nv_i = 5$). Since the number of vehicles available at each depot is 5, and we assume that each vehicle is sent to one demand node, each depot can serve at most 5 distinct demand nodes.

Fuel cost, f_{ij}, is the product of distances and the unit transportation cost of \$2.5 per km. Distribution cost, $Dist_{ij}$, is related to shipping taxes, truck driver cost, and maintenance cost, that depend on distances traveled. We assume that there are three levels of distribution costs (low, medium, and high) depending on the location of depots, as shown in Table 1. Worker cost Wr_i is equal to the product of the number of workers at a depot and the wage of each worker for that depot, which also depends on the type of depot classified as Grade A, B, or C.

The relief items are stored on pallets at depots. As an international collaborative project of NGOs, the Sphere Handbook provides universal minimum humanitarian standards, such as 2100 calories and 2.5–3 L of water per person per day (The Sphere Project 2018). The assumptions regarding the demand for relief items are made based on these standards. The types of items that should be stored on a pallet are determined based on Tzeng et al. (2007), and the quantities of items per pallet are determined to provide relief aid for four people. The value or cost of items on a pallet is estimated by an online

Table 1. Distribution and worker costs for depots

	Depots (i)	Distribution Cost ($Dist_{ij}$) ($)		Depots (i)	Worker Cost (Wr_{2i}) ($)
Low	1	120	Grade A	4, 7	40
Medium	2, 3, 4	140	Grade B	2, 5	30
High	5, 6, 7	160	Grade C	1, 3, 6	20

search for these types of relief aid items. The number of items of each type and their costs are shown in Table 2.

Table 2. Pallet contents

Relief Materials	Amount	Volume (cm^3)	Volume (unit)	Price ($)
Sleeping bag	4	12375	1	7.5
Tent	1	27300	2.21	50
Box of mineral water	1	28080	2.27	18
Rice (5 kg)	2	5225	0.42	10
Box of instant noodles	1	21199	1.71	12
Box of dry food	2	18468	1.49	15
Box of canned food	2	3532	0.29	36

In this study, we consider the demand and distances to be random parameters. We use a set of scenarios, Ω, to represent uncertainty regarding demand and distance in the model. The probability of each scenario is $P^s, s \in \Omega$, where $P^s \in [0, 1]$ and $\sum_{s\in\Omega} P^s = 1$. As shown in Table 3, we define three demand scenarios: high demand scenario with 30% probability, medium demand scenario with 45% probability, and low demand scenario with 25% probability. A set of demand values are generated from the Uniform distribution between 100 and 150 pallets for the medium demand case. Then, 125% of the medium demand is taken as the high demand case, and 75% of the medium demand is taken as the low demand case. The total random demand values for each demand scenario are shown in Table 3.

The other random factor is the condition of the transportation network. We define three distance scenarios as shown in Table 3: normal transportation conditions scenario with 40% probability, limited accessibility of demand nodes with 35% probability (direct transportation is not possible, collection point 1 must be used), and highly affected transportation network scenario with 25% probability (direct transportation or using collection point 1 is not possible, collection point 2 must be used). Therefore, S1 is the

Table 3. Scenario probabilities

		Demand		
		Low (25%)	Medium (45%)	High (30%)
	Total demand (pallets)	987	1312	1647
Distances	Direct transportation (40%)	10% S1	18% S2	12% S3
	Limited accessibility (collection point 1) (35%)	8.75% S4	15.75% S5	10.5% S6
	Highly affected network (collection point 2) (25%)	6.25% S7	11.25% S8	7.5% S9

best-case scenario in terms of low demand and short distances to be traveled, whereas S9 is the worst-case scenario with high demand and long distances to be travelled.

The case study problem is solved for Model 1–4 under scenarios S1–S9. First, Model 1–4 are individually solved for each scenario and Z_f^* are obtained. The weights of objective functions are determined to be $c_2 = 0.1$ and $c_1 = c_3 = c_4 = 0.3$ having the lowest closeness percentage according to the GCM from Eq. (16) and these are used in the linear combination of weights to find $Z_{weighted}^*$. The results are obtained using GAMS 24.6.1 software with CPLEX 12.6.3 solver on a computer with 1.50 GHz CPU AMD processor and 4 GB RAM. We provide the optimal objective function values in Table 4 and optimal depot locations in Table 5.

Table 4. Optimal objective values for each demand-distance scenario

Scenario	Z_1^*	Z_2^*	Z_3^*	Z_4^* (%)	σ_{Z_4} (%)	$Z_{weighted}^*$
S1	**5,599**	**249,220**	**47,385**	6.7	0.372	**44,135**
S2	7,442	335,830	62,987	6.2	0.202	57,728
S3	9,347	427,823	79,077	24.8	11.862	72,571
S4	16,139	267,410	61,305	**3.5**	0.458	53,624
S5	21,462	362,660	81,503	5.7	2.136	68,078
S6	26,937	465,210	102,308	24.8	11.929	86,678
S7	16,108	267,330	61,259	**3.5**	0.458	50,429
S8	21,405	362,520	81,421	5.7	1.548	68,024
S9	26,872	465,040	102,210	24.8	12.340	86,615

Our observations based on these results are as follows:

1. Given a certain distance scenario, Z_1^*, Z_2^*, and Z_3^* values decrease as the demand decreases. These objective function values are at their lowest level (best value) for

Table 5. Optimal depot locations for each demand-distance scenario

Scenario	Model 1	Model 2	Model 3	Model 4
S1	2, 4, 5, 7	1, 3	2, 4, 5, 7	1, 3, 6
S2	2, 4, 5, 7	1, 3, 6	2, 4, 5, 7	1, 2, 3, 6
S3	2, 4, 5, 7	1, 3, 6	2, 4, 5, 7	1, 3, 4, 6
S4	2, 5	1, 3	1, 2, 5	1, 3, 6
S5	1, 2, 5	1, 3, 6	1, 2, 5	1, 3, 5, 6
S6	1, 2, 5	1, 3, 6	1, 2, 5	1, 2, 3, 6
S7	4, 7	1, 3	1, 4, 7	1, 3, 6
S8	1, 4, 7	1, 3, 6	1, 4, 7	1, 3, 4, 6
S9	1, 4, 7	1, 3, 6	1, 4, 7	1, 3, 4, 6

the low demand scenarios (S1, S4, S7) and their highest level (worst value) for the medium demand scenarios (S2, S5, S8). They have slightly lower values for the high demand scenarios (S3, S6, S9) than for the medium demand scenarios.

2. The Z_4^* values are the same in S3, S6, S9, where the demand is high. So, no matter what the distance scenario is, the best possible maximum percent of unmet demand is 24.8% for this case study. The Z_4^* values for S4 and S7 are equal, the Z_4^* values of S5 and S8 are equal, as well.
3. We can also see from the results of Model 4 that the equity of percent of unmet demand gets worse as the demand gets higher. The standard deviations of percent of unmet demand among demand nodes, σ_{Z_4}, (provided in Table 4) are significantly higher in S3, S6, and S9 than other scenarios.
4. It is clear from the results that the first model can also present the optimal values not just for Z_1^* also, it gives the optimal values for Z_3^*.
5. The $Z_{weighted}^*$ value increases as the demand gets higher, given any distance scenario. It also increases in the second and third distance scenarios compared to the normal traffic conditions scenario.
6. In all the models, depot location decisions do not change significantly depending on the level of demand. There are exceptions only in the form of selecting a subset of the depots when the demand is lower, such as in S4 and S7 for Model 1 and S1, S4, and S7 in Model 2.
7. Depot location decisions in Model 1, Model 3, and Model 4 change as the matrices of distance, total transportation cost, and total accumulated waiting time are changed, i.e., as the distances change. We can see this behavior for Model 1: In S4 and S7, two depot locations are selected as opposed to four locations in S1. Also, in S5 (or S6) and S8 (or S9), three depot locations are selected as opposed to four locations in S2 (or S3). Model 3 results also show a similar pattern. However, Model 2 depot location decisions are not affected by the changing distances, and this is because the objective function cost coefficients are proportionally increasing as the distances increase. Therefore, the optimal solutions for S4 and S7 are the same for Model 2, and the optimal solution for S1 is slightly different in terms of only a few x_{ij}^* values.

8. Considering the limitation that at most 4 depot locations can be chosen, Model 1 and Model 3 choose 4 depots only in the direct transportation scenarios, but Model 4 chooses 4 depots in all but the low demand scenarios to ensure equity in terms of percent of unmet demand.

5 Discussion and Conclusion

In this comparative study of multiple objectives for disaster relief logistics, we develop models to determine depot locations and plan the distribution of relief items to demand nodes in a region affected by a disaster such as an earthquake. We consider multiple scenarios for uncertain demand and uncertain transportation network conditions. Based on the comparison of results for different objective functions and different scenarios, we identify the characteristics of the decisions made in each case. We observe that given a certain distance scenario, total distance (Z_1^*), total transportation cost (Z_2^*), and accumulated waiting time (Z_3^*) values decrease with demand. Depot location decisions in Model 1, Model 3, and Model 4 change as the distances change; however, they are not affected in Model 2 since cost coefficients are proportionally increasing with the distances. Also, the equity of percent of unmet demand (Z_4^*) gets worse as demand rises.

As a future research direction, the assumption that there are enough vehicles to deliver relief aid can be modified such that not all the demanded pallets can be loaded starting at time zero. In this case, either additional vehicles must wait, or the initial vehicles must be waited to return from the demand nodes after delivery, which would make Model 3 (minimizing the accumulated waiting time) more realistic. Considering the uncertainties in time-related parameters at the time of a disaster, this humanitarian aid distribution problem can be studied using stochastic modeling to improve the applicability of solutions. Another future research direction would be the application of the proposed models based on real data for a central region of a city such as Istanbul where the population that can be affected by a disaster is dense.

Uncertainty in demand and transportation network conditions necessitates consideration of different scenarios for disaster relief logistics. This scenario-based comparative study of multiple objectives provides valuable information regarding the performance of relief distribution decisions in various cases, and such studies can provide decision makers different perspectives and options to improve disaster relief operations and help reduce the losses due to disasters.

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An Integrated Employability Aptitude Survey-Cognitive Test Model for Assessing Students' Skills Retention Threshold

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Abstract. An integrated employability aptitude survey-cognitive test is proposed to assess the retention threshold of students with the view of appraising the capabilities of engineering students in readiness for engineering positions. Numerical ability, space visualization, numerical reasoning, and symbolic reasoning responses are adapted into the model. One hundred six undergraduate students of the Department of Industrial Engineering at Eastern Mediterranean University selected across freshman, sophomore, junior and senior in the 2016–2017 academic years assessed their aptitudes through the proposed EAS cognitive tests. Analysis of variance is employed to analyze the model, and the results indicate a significant difference between students' abilities in terms of raw scores and respective academic levels. Academic years and CGPA groups are found to have significant effects on the student's percentile. Additionally, strong correlations between CGPA and the student's percentile are found. However, space visualization ability is not affected by academic progression.

Keywords: Aptitude · EAS-cognitive tests · Student's percentile · Skills retention threshold · Battery score

1 Introduction

The new economy characterized by technology and globalization has led to the creation of a high-wage; highly skilled and high-changing jobs that are demanding new skill sets from graduates. This continually brews various concerns for graduate employability. Psychological discoveries have specifically revealed that for engineering skills gained during studies to be retained, knowledge garnered have to be embedded functionally, engraved in professional behavior, applied tactfully and in realistic contexts, and must be demonstrated through achievable and practical skills and values. Quite often, rate of retention and its threshold have been examined and determined through some widely reported concepts such as general cognitive ability (GCA), cognitive ability tests (CAT), general mental ability (GMA), just to mention a few. Schmidt (2002) has shown that there

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is a link between GCA and job performance. More often, experience have shown that the level of job performance is a function of the retainability (amount of knowledge learned that could be readily recollected and leveraged to satisfy the job skill requirements) and its threshold (the amount of skills and knowledge retained that could serve appreciably and adequately as basis for meeting the minimum skill requirements). Similar to GCA, many researchers concluded that CAT also correlates highly with job performance (Bobko *et al.* 1999 and Schmidt et *al.* 1997).

Cognitive or mental ability is the prime determining factor of job performance that dictates the dynamics of employability. Over time the impact of cognitive ability on performance is expected to continue to rise (Schmidt et *al.* 1981). Tests such as the GMA and CAT have been employed in the past decades to assess the mental and cognitive ability of employee during the selection process (2002). CAT tends to produce significant racial variances; similarly, Hunter and Hunter (1984), Schmidt and Hunter (1999) and Sackett et al. (2001) through various studies confirmed the efficiency of GMA as a valid means of evaluating employee empirically. The performance and effectiveness of employees have been evaluated by the newly introduced general aptitude test battery (GATB) (Bobko et al. 1999). This cognitive ability is calculated as the raw score (RS), which is the combination of general, verbal, and numerical (G, V, N) aptitude scales of the GATB. The EAS, a kind of GMA test, has been developed to assess the psychomotor, perceptual, and cognitive capabilities, mainly for the selection of employees, career guidance, development, and advancement. Retention acts as the fulcrum on which students' ability to re-create and apply skills gained are pivoted (Hodges *et al.* 2013).

The main aim of this article is to emphasize the essence of cognitive skills for employment-driven skills development during academic learning. Furthermore, the significance of EAS in promoting skills retention and threshold toward a successful job engagement is of utmost interest of this study. EAS consists of different ten (10) tests that can be employed separately, and the choice of any test is guided by the user's assessment of the job requirements (Ruch 1994). This study assesses the array of abilities through four of the Employee Aptitude Survey EAS tests to develop battery and percentile models for monitoring students' progression and efficiency. This provides a new frontier for assessing the retention rate of students right from freshman to senior year. Thus the readiness and propensity of graduates for employability are easily evaluated.

2 Methodology

2.1 Instrumentation: Employee Aptitude Survey (EAS)

EAS was used for assessing the capabilities of engineering students as required by the junior engineering positions. Four EAS tests were selected out of ten as the requirements to determine the students' battery and percentile for appraising their progression between different academic years. These tests are numerical ability (EAS-2), space visualization (EAS-5), numerical reasoning (EAS-6), and symbolic reasoning (EAS-10).

2.2 Procedures for Data Gathering

Approval was secured from the Ethics committee to administer the tests to the students. Permissions were also taken from the instructors to apply the EAS tests on the students during lecture hours. At least 40 min is required to complete the four tests; each test takes 5 min. The numerical ability test (EAS-2) is in three parts, and it requires ten minutes to complete. A 3–5-min break was allowed in-between the two tests. Instructions on how to complete the tests are written clearly on the front page of the sheet. Additionally, some personal information about the students such as age, CGPA, and Cumulative Credit Hours (Cum. CH) relevant to this study were extracted from the student registration database.

2.3 Participants

One hundred six undergraduate students of the Department of Industrial Engineering at Eastern Mediterranean University between the age of 17 and 30 years old across all academic levels (Freshman, Sophomore, Junior and Senior) took part in this study conducted during both fall and spring semesters of the 2016–2017 academic session. The students were examined during the following lectures; Introduction to IE (IENG112), Modeling and Optimization (IENG212), Operations Research-I (IENG313), Fundamentals of Work Study and Ergonomics (IENG301), Production Planning-II (IENG431), Systems Modeling and Simulation (IENG461). These lecture sessions were chosen because they are available for experimentation and comprises of students from all academic levels. The following research questions were addressed:

(i) Do academic advancements have significant effects on engineering students' abilities?
(ii) Which of the students' abilities (numerical ability, space imagining, numerical reasoning, and symbolic reasoning) is affected by these academic levels?
(iii) Does the age of the students have any significant effect on the students' percentile?
(iv) Is there any correlation between CGPA and percentile?

Analysis of variance (ANOVA) was employed to analyze responses from these questions.

2.4 Calculation of the Raw Scores, Battery and Percentile

The raw score is defined as the number of questions responded to by the participants without considering the number of questions on the test or each question point. The total number of answers marked wrong and right were recorded. It should be noted that each test has different RS formulas. The battery score is determined through the following formula:

$$\text{Battery Score} = 0.5 * (\text{EAS } 2) + 0.5 * (\text{EAS } 5) + \text{EAS } 6 + \text{EAS}10 \quad (1)$$

The percentile for each student was determined from the norm table of junior engineer (Ruch 1994). For the statistical analysis, variables were defined as independent and dependent. The dependent variable is the students' percentile, while the independent variables are academic years, CGPA groups, and age groups. To protect the students' privacy, codes A to D were assigned to all students instead of their student numbers. Normality assumptions were examined using the normal test, frequency histograms, and normal plot of residuals. Minitab 17 statistical package was employed for the analysis.

3 Results

The results show that normality assumptions are not violated, and thus confirming the data are normally distributed. Consequently, ANOVA with ($\alpha = 5\%$) is a suitable test to be used for the data analysis. The mean, standard deviation, maximum, and minimum values of students' percentile are listed in Table 1.

Table 1. Descriptive statistics of students' percentile

Source	Variables	Count	% students	Mean	St.Dev	Min	Max
Gender	F	30.00	28.30	37.90	22.31	2.00	80.00
	M	76.00	71.70	28.39	19.97	1.00	80.00
Age groups	<=22	45.00	42.45	29.80	19.87	1.00	60.00
	23–25	52.00	49.06	33.21	22.91	1.00	80.00
	26–28	7.00	6.60	26.43	11.44	15.00	40.00
	>=29	2.00	1.89	21.0	26.9	2.00	40.00
Academic year	Freshman	13.00	12.26	13.69	11.52	1.00	40.00
	Sophomore	29.00	27.35	18.86	16.12	1.00	50.00
	Junior	37.00	34.90	34.19	18.20	5.00	70.00
	Senior	27.00	25.47	48.33	18.45	10.00	80.00
CGPA groups	<=1.99	29.00	27.36	11.62	10.82	1.00	40.00
	2–2.49	24.00	22.64	27.50	14.89	5.00	60.00
	2.5–2.99	17.00	16.04	36.76	16.48	15.00	70.00
	3–3.49	16.00	15.09	48.75	12.04	30.00	80.00
	>=3.5	15.00	14.15	56.00	13.52	30.00	80.00
	Newstudent	5.00	4.72	10.60	12.18	1.00	30.00

Students who got the highest total cumulative credit hours and CGPA greater than 3 recorded the maximum value of the percentile of 80. From the raw score, the results of numerical ability with academic level show a significant effect (*p-value* = *0.000*). Additionally, the Tukey test reveals the numerical ability of the senior students is significantly different from other academic levels. These results connote that students' numerical ability differs and it is a function of academic years. The rank is from the senior level with the largest value of raw score of 42.50 to freshman level with the smallest value of mean raw score = 27.52. Therefore, the higher the academic level, the better the numerical tendency of students.

For space visualization ability EAS-5 test, there is no significant difference (*p-value* = 0.074) between different academic levels. However, there is a significant difference between academic years and numerical reasoning EAS-6 test at (*p-value* = 0.008) based on the students' raw scores. Similarly, the Tukey test shows that senior-level students have the highest numerical reasoning score. For symbolic reasoning, EAS-10 test, a significant difference (*p-value* = 0.000) between academic years is observed. This test entails how students can easily decipher mathematical symbols and expressions. The multiple comparison tests reveal higher symbolic reasoning ability as the academic year progresses. The result shows that there is a significant effect between students' academic years and students' percentile (p-value = 0.00). However, students' age does not have any significant effect on student' percentile (p-value = 0.07). This implies that age would not influence the estimation of the response (percentile) given in Table 2.

Table 2. General linear model: percentile versus academic years and age

Factor	Type	Levels	Values			
Academic year	fixed	4	Freshman, Junior, Sophomore, Senior			
Age	fixed	4	<=22, 23-25, 26-28, >=29			
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Academic year	3	16654.3	18023.7	6007.9	21.54	0.000
Age	3	2034.0	2034.0	678.0	2.43	0.070
Error	99	27611.9	27611.9	278.9		
Total	105	46300.2				

A general linear model is used to examine the interrelationships between student's percentile, academic levels, and CGPA. However, the freshman level is ignored. This is because most of the new students (freshman) do not have CGPA. The ANOVA shows that there are significant effects (*p-value* = 0.000) of students' academic years on the percentile scores. It can be well said that these scores significantly vary with the CGPA groups at (*p-value* = 0.000). However, the interaction between CGPA groups and academic levels does not have any significant effect on the percentile scores of students (*p-value* = 0.69), as shown in Table 3.

Furthermore, correlation analysis conducted among the percentile scores and students CGPA illustrates a large correlation between students CGPA grades and percentile scores (r = 0.752). According to Cohen (1988) and Kim (2018), a correlation value greater than 0.5 is described as large; 0.5 to 0.3 as moderate, 0.3 to 0.1 as small; and anything smaller than 0.1 is described as being trivial; variables of such trivial relationships have no noticeable relationships.

Table 3. General linear model: percentile versus academic year and CGPA

Factor	Type	Levels	Values			
Academic year	fixed	3	Junior, Sophomore, Senior			
CGPA group	fixed	5	<=1.99, 2-2.49, 2.5-2.99, 3-3.49, >=3.5			
Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Academic year	2	12172.1	3547.2	1773.6	11.79	0.000
CGPA groups	4	15483.4	12963.1	3240.8	21.54	0.000
Academic year*CGPA	8	833.6	833.6	104.2	0.69	0.697
Error	78	11736.1	11736.1	150.5		
Total	92	40225.2				

4 Discussion and Conclusion

This study investigated the skills retainability of IE students as they progress academically through the years of studies relative to their ages and CGPA. The findings show that the ability of students improves as the students advance in their academic studies. This is in agreement with the finding of Brockman and Russel (2012), where a positive relationship between academic level and the abilities of the students was reported. As the student progresses in their academic endeavors, they are better equipped with all the necessary knowledge and skills; thus, senior students have superior abilities than junior and freshman students. Therefore, retention of skills increases proportionally with an academic level even as the abilities of students improves as the academic studies advances.

Additionally, aligning with another study of Cassidy (2007), the academic level is of the essence in determining students' retainability. Especially for freshman, attrition is because of a lack of the ability to understand how their personal dimension for learning could influence the capacity for proper adaptation into the university study. This explains how the perception of their external world could translate into knowledge or belief (Jama et al. 2008).

The study also reveals no relationship between academic years and space visualization. This result is similar to what was reported by Kozhevnikov and Thornton (2006) that students' levels of spatial visualization ability are based on physics training within the confinement of the microcomputer-based laboratory (MBL). The space visualization prediction of students' performances is not significantly affected by the level of the instructions given to the students. This accounts for the poor disposition of educators toward emphasizing this skill in the curriculum. For numerical reasoning, senior students have the highest scores. The results obtained in this study is akin to the results obtained elsewhere (James 2015) where literacy (mathematics, writing quality and comprehension) was used as an indicator for success in the skills for Tertiary Education Preparatory Studies (STEPS) program.

The EAS tests reveal students' percentile is not significantly affected by students' age. Ebenuwa-Okoh (2010) also reported that age, gender, and financial status do not seem to cause any significant difference in academic performance. Therefore, counseling should be provided for students of all ages, financial status, and gender. Similarly, the results of this study are in-line with that of Hodges et al. (2013) where age was reported to have an insignificant effect on student's academic capabilities. This has cast doubts on the functionality of age as a variable that can effectively influence the academic capabilities of a student. This also inferred beyond doubt that there is no significant relationship between students' age and academic ability. Therefore based on the EAS tests, relationships exist between CGPA groups and percentile, and between percentile and academic levels. Hence, as students advance academically year-on-year, they acquire more skills and can score higher percentile on the EAS tests. Consequent on this, it could infer that retainability increases as the academic level progresses. This is also in tandem with some previous studies on students' attrition (see Gabb et al. 2006; Jones 2008 and Rose-Adam and Lindsay 2012; Winne and Nesbit 2010) where various ways of improving retention have been reported.

The average percentile of students that studied in the fourth year is larger than those that studied in the previous academic years. This research has explored the effects of academic years and CGPA. This is discovered to have some significant effects on student abilities. Here, we have concentrated on the importance of academic progression in improving students' abilities. Skills such as numerical ability, numerical reasoning, and symbolic reasoning have been identified. Thus, it demonstrates that graduate students from the industrial engineering department of Eastern Mediterranean University have higher retainability of skills, and thus possesses greater propensity and readiness to take on the responsibility of the workplace. The outcome of space visualization test indicates student's ability does not improve as the academic level progresses; thereby; all students irrespective of their academic level possess this ability close to each other.

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Optimal Order Quantity for the Mean-Variance Newsvendor Problem with Stockout

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Abstract. This paper extends the formula that derives the optimal order quantity for the risk-neutral newsvendor under stockout. Its objective is to maximize the mean-variance risk-averse profit utility function under the general demand probability distribution. The obtained formula is applied for the cases of the Uniform, Normal, and Exponential distributions. The obtained results confirmed earlier findings that the optimal order quantity for the risk-averse newsvendor problem with stockout using the mean-variance utility can either be less than or greater than the optimal quantity of the risk-neutral case.

Keywords: Supply chain · Newsvendor problem · Mean-variance utility · Risk-averse

1 Introduction

Over the last few decades, the problem of the newsvendor single period order quantity to fulfill random demand was the focus of several research papers and through different extensions. The problem proved its fascinating realization in situations that are very common in supply chain management. Originally, the problem was considered for the objective of maximizing the expected profit when an order quantity is decided, given its purchase cost per unit and its selling price per unit, and where the operation is subject to overstock that is sold at a salvage price per unit. Later on, the problem was extended to include the risk of understocking that may result in a penalty cost per unit due to shortages. The maximization of the expected profit as such merely reflects the neutral behavior of the vendor who does not consider such risk.

To incorporate risk consideration into the decision-making process of the vendor utility-based analysis such as the one introduced in financial portfolio design problems has to be used. Several models were devised in the literature of utility theory of decision making. That included mean-variance (MV), down-side mean-variance, value-at-risk, conditional value-at-risk, piecewise-linear loss-aversion utility, exponential utility, etc. This paper only considers the MV model in order to develop a decision formula that provides the optimal order quantity and the objective is to maximize a single-period profit utility for the newsvendor subject to random demand that may lead to the outcome of either overstock with associated salvage value, or understock that result into a stockout penalty cost.

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The MV analysis was first introduced by Markowitz (1959) in financial portfolio designs and was primarily approached for the newsvendor problem by Berman and Schnabel (1986), then followed by other works such as Choi et al. (2008), and Wu et al. (2009). All of those works considered risk-averse vendors with various extensions concerning the condition of the problem and stockout was the most recently studied situation under MV utility. In most of those works without stockout, the optimal order quantity was less than or equal to its risk-neutral optimal counterpart. In the case of existence of stockout with penalty cost associated with it, Wu et al. (2009) proved that the optimal order quantity for a risk-averse newsvendor profit utility might be larger than that for a newsvendor who is risk-neutral. Their works were based on power-distributed demand random variable. However, they concluded their paper short of providing a general solution for the optimal order quantity that maximizes the newsvendor MV utility in the general case of a demand probability distribution.

More recently, Choi and Chiu (2012) proved that the optimal order quantity for the mean-variance and the mean-downside-risk utility that only considers the negative impact of risks are the same. Tekin and Özekici (2015) discussed financial hedging of demand and supply risks and illustrated the effects of such hedging on reducing the risk for the newsvendor problem. On their part, Herrero et al. (2015) discussed the pricing decisions for the newsvendor for both risk-averse and risk-seeking cases and compared their results with previous research.

The main contribution of this paper is to derive the equation that leads to the general solution of the optimal order quantity for the MV newsvendor problem subject to stockout for the general case of a demand probability distribution. It completes the previous works, especially Wu et al. (2009), and applies its results on the common distributions of Uniform, Normal, and Exponential density functions.

The organization of this paper is as follows. The next section develops the mathematical model for the MV utility of the risk-averse newsvendor problem with stockout and derives the formula that provides the optimal order quantity that maximizes this utility. It is followed by a section that applies its results to the Uniform, Normal, and Exponential distribution and provides numerical examples. The optimal order quantities that were obtained in those examples happen to be either larger or smaller than the risk-neutral optimal order quantity. It is then concluded with a summary of the results.

2 The Newsvendor Mean-Variance Model with Stockout and Its Solution

The aim in this section is to derive the optimal order quantity Q for the newsvendor who deals with random demand D that is subject to a probability distribution with density function f defined in a finite range $[\alpha, \beta]$. Let F be the cumulative distribution function which is assumed to be continuous positive and strictly increasing in its range. Let μ and σ be the mean and the standard deviation of D, respectively.

Let c be the unit cost of purchase, r its selling price, and consider at the end of the selling period a salvage value s for each unsold unit, or a penalty cost p per unit in the case of stockout. Assume that $r > c > s > 0$ and that $p > 0$, all of which are naturally justified in real situations.

Given the order quantity Q at the beginning of the selling period, with a realized demand D, the net profit function as a function of the decision variable Q is determined by the equation

$$\pi(Q) = -cQ + r\ \min(Q, D) + s\ \max(Q - D, 0) - p\ \max(D - Q, 0) \tag{1}$$

One can write $\min(Q, D) = Q - \max(Q - D, 0)$, so Eq. 1 can be rewritten as

$$\pi(Q) = (r - c)Q + (s - r)\ \max(Q - D, 0) - p\max(D - Q, 0). \tag{2}$$

A risk neutral vendor would simply maximize his expected profit. In this case,

$$E[\pi(Q)] = (r - c)Q + (s - r)\int_{\alpha}^{Q}(Q - x)f(x)dx - p\int_{Q}^{\beta}(x - Q)f(x)dx. \tag{3}$$

Define $A_1(Q) = \int_{\alpha}^{Q}(Q - x)f(x)dx$ and $B_1(Q) = \int_{Q}^{\beta}(x - Q)f(x)dx$ So Eq. 3 can be re-written as

$$E[\pi(Q)] = (r - c)Q + (s - r)A_1(Q) - pB_1(Q). \tag{4}$$

Taking the derivative of the expected profit in Eq. 4 and setting it equal to zero will provide the optimal order quantity Q^* for a risk-neutral newsvendor and the solution found is identical to the results in Wu et al. (2008), that is

$$F\left(Q^*\right) = \frac{r + p - c}{r + p - s}. \tag{5}$$

The existence for such a solution is guaranteed considering the assumptions on r, c, s, and p as above.

However, newsvendors are more likely to be risk-averse, and that they would rather maximize their mean-variance utility function of the profit instead. Hence, the mean-variance utility function is

$$U(Q) = E[\pi(Q)] - \lambda Var[\pi(Q)]. \tag{6}$$

Here λ is a positive number that measures the risk sensitivity of the vendor. If it is equal to zero, then the vendor becomes risk neutral, and as it gets larger, the vendor becomes more risk-sensitive because of the higher impact of the profit variance on the vendor's utility function. The derivation for $Var[\pi(Q)]$ proceeds as follows.

$$Var[\pi(Q)] = E[\pi^2(Q)] - (E[\pi(Q)])^2. \tag{7}$$

Here,

$$\begin{aligned} E[\pi(Q)]^2 &= (r - c)^2Q^2 + (s - r)^2A_2(Q) + p^2B_2(Q) \\ &\quad + 2(r - c)(s - r)QA_1(Q) - 2(r - c)pQB_1(Q), \end{aligned} \tag{8}$$

where $A_2(Q) = \int_{\alpha}^{Q}(Q - x)^2f(x)dx$ and $B_2(Q) = \int_{Q}^{\beta}(x - Q)^2f(x)dx$.

On the other hand,

$$\begin{aligned}(E[\pi(Q)])^2 &= (r-c)^2Q^2 + (s-r)^2A_1^2(Q) + p^2B_1^2(Q) \\ &\quad + 2(r-c)(s-r)QA_1(Q) - 2(r-c)pQB_1(Q) \\ &\quad - 2(s-r)pA_1(Q)B_1(Q). \end{aligned} \tag{9}$$

The substitution of Eqs. 8–9 into Eq. 7 leads to

$$Var[\pi(Q)] = (s-r)^2A_2(Q) + p^2B_2(Q) - [(s-r)A_1(Q) - pB_1(Q)]^2. \tag{10}$$

Therefore,

$$\begin{aligned}U(Q) &= (r-c)Q + (s-r)A_1(Q) - pB_1(Q) \\ &\quad - \lambda\Big\{(s-r)^2A_2(Q) + p^2B_2(Q) - [(s-r)A_1(Q) - pB_1(Q)]^2\Big\}. \end{aligned} \tag{11}$$

The objective is to find the optimal order quantity that maximizes the above utility function. It is obtained by taking the derivative of $U(Q)$ concerning Q which yields to

$$\begin{aligned}\frac{dU}{dQ} &= (r-c) + (s-r)F(Q) + p(1-F(Q)) \\ &\quad - 2\lambda(s-r-p)[(s-r)(1-F(Q))A_1(Q) + pF(Q)B_1(Q)]. \end{aligned} \tag{12}$$

Finding the solution for $\frac{dU}{dQ} = 0$ is cumbersome, but instead, one can argue that this solution exists as follows.

If $Q = \alpha$, then $F(\alpha) = 0$, $A_1(\alpha) = 0$, and $B_1(\alpha) = \mu - \alpha$. It follows that $\frac{dU}{dQ}(\alpha) = r - c + p > 0$.

On the other hand, if $Q = \beta$, then $F(\beta) = 1$, $A_1(\beta) = \beta - \mu$, $B_1(\beta) = 0$ for which $\frac{dU}{dQ}(\beta) = s - c < 0$.

It is therefore clear that the derivative $\frac{dU}{dQ}$ decreases from a positive value to a negative one over the whole range of D. Hence, a unique zero solution exists for $\frac{dU}{dQ} = 0$, which lead to an extreme value for U. Also, as this derivative is decreasing over the whole range of D, one can deduce that the second derivative of the utility function is negative, which makes the utility function concave and for that the optimal quantity is a maximum.

The following equation provides the formula that can be solved numerically and find the optimal order quantity Q^*

$$F\big(Q^*\big) = \frac{(r+p-c) + 2\lambda(r+p-s)(r-s)A_1(Q^*)}{(r+p-s)[1 + 2\lambda((r-s)A_1(Q^*) + pB_1(Q^*))]}. \tag{13}$$

That optimal quantity obtained is a maximum. One may immediately observe that when $\lambda = 0$, that optimal order quantity is identical to the solution for a risk-neutral vendor as provided in Eq. 5.

3 Numerical Examples

In this section, three examples of demand probability distributions are considered for which optimal order quantities are numerically computed.

3.1 The Case of Uniform Distribution

Consider the uniform distribution for the random demand in the range $[\alpha, \beta]$. Here, $F(Q) = \frac{Q-\alpha}{\beta-\alpha}$, $1 - F(Q) = \frac{\beta-Q}{\beta-\alpha}$, $A_1(Q) = \frac{(Q-\alpha)^2}{2(\beta-\alpha)}$, and $B_1(Q) = \frac{(\beta-Q)^2}{2(\beta-\alpha)}$.

For a numerical example, let $\alpha = 0$, and $\beta = 10$. In this case, $F(Q) = \frac{Q}{5}$, and $1 - F(Q) = \frac{10-Q}{5}$, $A_1(Q) = \frac{Q^2}{10}$, and $B_1(Q) = \frac{(10-Q)^2}{10}$. Also assume that the unit cost $c = 5$, the selling price per unit $r = 10$, the salvage value per unit $s = 2$, and the stockout penalty per unit $p = 4$. Consider as well $\lambda = 1$.

The solution for Eq. 13 within the range of demand [0, 10] is obtained numerically using EXCEL™ Solver® to be $Q^* = 3.17$.

For a risk-neutral vendor based on the same financial parameters as above, the quantity that maximizes his expected profit is obtained equal to 7.5.

3.2 The Case of Normal Distribution

Consider a project duration with Normal distribution that has a mean μ and standard deviation σ. The derivation for $A_1(Q)$ and $B_1(Q)$ can be proven to be

$$A_1(Q) = (Q - \mu)\Phi\left(\frac{Q-\mu}{\sigma}\right) + \sigma\varphi\left(\frac{Q-\mu}{\sigma}\right).$$

and

$$B_1(Q) = (\mu - Q)\left[1 - \Phi\left(\frac{Q-\mu}{\sigma}\right)\right] + \sigma\varphi\left(\frac{Q-\mu}{\sigma}\right).$$

Here $\varphi(\cdot)$ and $\Phi(\cdot)$ are the standard Normal density and cumulative distribution functions for the random demand D, respectively.

Now assume that demand mean $\mu = 5$ and the standard deviation $\sigma = 1.67$. Also assume that the unit cost $c = 5$, the selling price per unit $r = 10$, the salvage value per unit $s = 2$, and the stockout penalty per unit $p = 4$. Consider as well $\lambda = 1$. Using EXCEL™ Solver® to numerically solve Eq. 13 for a solution. In this case, the optimal order quantity for the risk-averse vendor is $Q^* = 4.52$.

For a risk-neutral vendor, the quantity that maximizes his expected profit is obtained equal to 6.35.

3.3 The Case of Exponential Distribution

$$F(Q) = 1 - e^{-\theta Q}, 1 - F(Q) = e^{-\theta Q},$$

$$A_1(Q) = Q - \frac{1}{\theta} + \frac{e^{-\theta Q}}{\theta}, \text{ and } B_1(Q) = \frac{e^{-\theta Q}}{\theta}.$$

Consider a random demand that has an exponential distribution with a mean of 5. Also assume that the unit cost $c = 5$, the selling price per unit $r = 10$, the salvage value per unit $s = 2$, and the stockout penalty per unit $p = 4$. Consider as well $\lambda = 1$. Using EXCEL™ Solver®, Eq. 13 is numerically solved to obtain the optimal order quantity for the risk-averse vendor as $Q^* = 3.67$.

For a risk-neutral vendor, the quantity that maximizes his expected profit is obtained equal to 1.44.

4 Conclusion

In this paper, the derivation of the optimal order quantity for the risk-averse newsvendor problem was derived for the general case of demand distribution where the objective was to maximize the mean-variance profit utility criterion. This result was applied for the three cases of Uniform, Normal, and Exponential distributions and numerical examples were provided. The obtained results conform with the findings in previous research works that the optimal order quantity in the case of the risk-averse profit utility function with stockout can either be less than or greater than the optimal order quantity for the risk-neutral case. Further work shall inspect the main result closer in order to understand the impact of the problem parameters on the optimal order quantity and their managerial implications.

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Sexual Harassment in Higher Education: Students' Perceptions and Attitudes

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Abstract. The study examines university students' attitudes toward sexual harassment and their perceptions of sexual harassment behaviors in a culturally diverse university in North Cyprus. Data is collected from 460 university students. The findings suggest that university students' perceptions about what constitutes sexual harassment behavior were similar, regardless of their gender. However, women were more likely than men to perceive a wider range of verbal and non-verbal behaviors as sexual harassment. Furthermore, different perceptions of sexual harassment behavior were identified based on culture and age. When attitudes toward sexual harassment were compared, it was found that female students had lower tolerance levels and that age had an effect on attitudes toward sexual harassment.

Keywords: Sexual harassment · Attitudes · Perceptions · University students

1 Introduction

Sexual harassment is a universal phenomenon. According to the survey of the European Union Agency for Fundamental Rights, 45%–55% of women in the workforce in the European Union have experienced at least one form of sexual harassment (Latcheva 2017). Despite a high number of occurrences in the workplace, there is no consensus on a universally accepted definition of sexual harassment. MacKinnon (1979) underlined the absence of a "… generalized, shared, and social definition of [sexual harassment]" (p. 27). The absence of a universal definition poses a problem when targets of sexual harassment try to identify it and when strategies for preventing or dealing with sexual harassment are proposed (Uggen and Blackstone 2004). It is generally stated that an agreed upon more generalized and operational definition of sexual harassment would be helpful to develop mechanisms to prevent such behavior (Fitzgerald 1990). Barr (1993) argued that when individuals have different definitions and perceptions about sexual harassment, it becomes difficult to determine whether to file a complaint, which results in under-reporting of such incidents in the workplace. In the 1970s, sexual harassment received socio-legal recognition, which somewhat alleviated the problem from going unnoticed in North America (MacKinnon 1979).

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In Europe, sexual harassment and its prevention attracted attention in the 1980s. However, sexual harassment incidences are generally under-reported. One reason for the under-reporting of sexual harassment may be the lack of a shared understanding of what constitutes sexual harassment.

It might be very challenging to establish a universal definition of sexual harassment given the cross-cultural differences in the behavioral standards of different countries (Barak 1997). Therefore, trying to establish a universal definition may not be feasible given the differences in cultural values related to behaviors constituting sexual harassment. Despite these difficulties, a widely used definition was offered by MacKinnon (1979) who states that sexual harassment is any "unwanted imposition of sexual requirements in the context of a relationship of unequal power" (MacKinnon 1979, p. 1). However, it should be stated that, from a practical perspective, this broad definition may be ineffective when trying to identify cases of sexual harassment. Recently, Latcheva (2017) indicated that sexual harassment is discrimination on the grounds of gender and argues that it violates equal treatment for both genders principle.

From a more practical standpoint, the Equality Act of 2010 defined sexual harassment as "unwanted conduct of a sexual nature which has the purpose or effect of violating someone's dignity, or creating an intimidating, hostile, degrading, humiliating or offensive environment for them" (Williams 2017). This definition has a broader approach covering indecent or suggestive remarks, unwanted touching, requests or demands for sex and the dissemination of pornography.

Fitzgerald (1990) grouped definitions of sexual harassment into two, "those that are *a priori* (theoretical) in nature, and [secondly] those that have been developed empirically, particularly through investigation of what various groups of people perceive sexual harassment to be under different circumstances and in different contexts" (*see* Fitzgerald 1990 for a detailed overview). Definitions of sexual harassment that are behaviorally focused may be more effective for identifying incidences of sexual harassment and developing effective strategies for preventing sexual harassment. Behaviorally oriented definitions of sexual harassment may be most effective when developed by taking into consideration the sociocultural values of the people within a particular organization. Establishing a list of behavioral statements that offer guidance as to what constitutes sexual harassment, while taking into consideration the sociocultural values of the people within the setting, grants organizations, such as universities, plays a critical role in the identification of sexual harassment incidences.

Eastern Mediterranean University (EMU) in North Cyprus is a multicultural institution with close to 19000 students from 106 different countries (www.emu.edu.tr). More than forty percent of the students are coming from Turkey, less than 20 percent of the students are locals, and about forty percent of the students are international. The international students of EMU are from West African, Middle Eastern, and Central Asian countries. Not only the University but also the country is increasingly attracting more international students from across the globe (Gunsen 2014). The rise in the number of students from different cultures increases the need for a cross-culturally accepted understanding of sexual harassment. However, the absence of a clear definition of sexual harassment does exist at EMU.

Therefore, it is the aim of this study to analyze the relationship between gender, age and nationality, and EMU students' (i) perceptions of sexual harassment behavior and (ii) attitudes toward sexual harassment.

2 Background

Rotundo et al. (2001), in their meta-analytic review of gender differences in perceptions of sexual harassment, found that women perceived a wider range of behaviors as sexual harassment compared to men across seven behavioral categories of sexual harassment. These categories included derogatory attitudes of a personal and impersonal nature, unwanted dating pressure, sexual propositions, physical sexual contact, nonsexual physical contact, and sexual coercion. The authors provide descriptions and behavioral examples for these seven categories of sexual harassment (Rotundo et al. 2001). The definitions are more abstract compared to the behavioral examples. For practical purposes, the behavioral examples may be more useful for identifying an incidence of sexual harassment. Studies in higher education presented different findings. In the United States, Bursik and Gefter (2011) explored undergraduate university students' perceptions of sexual harassment in 1990 and 2000, with two different student samples. The authors found that students' perceptions of what constitutes sexual harassment were diverse but appear to have remained stable at the two-time points. More importantly, the authors conclude that differences in personal perceptions of sexual harassment and legal definitions may be damaging to victims and academic institutions (Bursik and Gefter 2011). The authors suggest that further research is needed with more diverse groups, as there were significant differences in perceptions of sexual harassment between Caucasian and non-Caucasian participants in 2000. In her study, Barr (1993) found no differences between genders in perceptions of sexual harassment behavior. In another study of university students, Corr and Jackson (2001) found differences in sexual harassment perceptions of male and female students.

In a cross-cultural study, Sigal and colleagues (2005) investigated perceptions of sexual harassment among university students in the United States, Canada, Germany, Netherlands, Ecuador, Pakistan, the Philippines, Taiwan, and Turkey. Participants were given a scenario containing sexual harassment and were asked to rate the severity of the sexual harassment behavior, to determine whether the perpetrator was guilty and if so, to choose a type of punishment ranging from mild to severe. The authors found that participants in individualistic countries (Unites States, Canada, Germany, and the Netherlands) reported the perpetrator guilty of sexual harassment more often than participants from collectivist countries (Ecuador, Pakistan, the Philippines, Taiwan, and Turkey). These findings demonstrate differences due to cultural factors among people's perceptions of what constitutes sexual harassment.

As the current literature suggests, there may be differences in people's perceptions of what constitutes sexual harassment and their attitudes toward sexual harassment. Therefore, this study aims to answer the following research questions:

Research Question 1: Is there a difference in the perceptions of sexual harassment behavior of university students based on gender, age, and nationality?

Research Question 2: Does gender, age, or nationality influence attitudes toward sexual harassment?

3 Methods

3.1 Instrument

A questionnaire was designed to collect data. The questionnaire consisted of three parts. In part one, university students' perceptions of what constitutes sexual harassment behavior were measured by adapting 15 items from Nielson (1996) and Blakely et al. (1995). All fifteen statements were modified for the higher education environment. The second part of the questionnaire was designed to measure university students' attitudes toward sexual harassment and contained 13 items that were adapted from the Sexual Harassment Attitude Scale (SHAS) (Mazer and Percival 1988; Ford and Donis 1996). The SHAS measures sexist attitudes toward women. The original SHAS that was developed by Mazer and Percival (1988), which contained 25-items, was reduced to 12-items for this study. This is because the 25 questions of the SHAS scale contained general questions about sexual harassment, and so only questions that were relevant to identifying the perceptions of a student sample on sexual harassment were retained. The last question on the original SHAS scale, "women are more emotional and think less clearly than men," was divided into two items: "women think less clearly than men," and "women are more emotional than men." The third part of the questionnaire consisted of demographic questions related to participants' age, gender, education, and nationality. The 28 items were selected to represent the spectrum of major types of sexual harassment and were randomly ordered in the survey instrument and standardized in terms of length and format to limit lengthier worded items. Previous research shows that studies investigating sexual harassment have tended to exclude behaviors which are perceived to have a low potential to harass and have also provided respondents with limited responses. In attempting to deal with these issues, the survey instrument utilized in this study was designed to measure students' perceptions of a wide range of actual workplace behaviors which create varying levels of a hostile environment.

For each of the 28 items in part one and two of the survey, participants were instructed to indicate their degree of agreement with statements on a 5-point Likert scale (1 – strongly disagree; 2 – disagree; 3 – neutral; 4 – agree; 5 – strongly agree). The survey items were adapted and prepared in English and then translated into Turkish by using the back translation method. A pilot study was conducted to determine whether the English and Turkish versions of the questionnaire were understood by the participants. After confirming the questions were clear to participants, the researchers distributed the questionnaires to students on the EMU campus. The questionnaires were completed voluntarily and returned to the researcher without gathering any identifying information (i.e., name, student number).

Participants were purposively recruited and given the questionnaires on the EMU campus to yield a diverse sample in terms of gender, education level, and nationality. Potential participants were approached by the researchers on the EMU campus and informed about the purpose of the study.

3.2 Participants

Initially, 510 questionnaires were distributed; however, not all were returned or completed. The final sample consisted of 460 (male $n = 293$ (64%); female $n = 167$ (36%)) full-time university students studying in various disciplines at Eastern Mediterranean University (EMU). Students' ages ranged from 16 to over 30, with the majority of the sample ($n = 319$) reporting their age between 21–25 (69%) years of age. Four hundred and twenty-five students (92%) were studying for an undergraduate degree, while 8% ($n = 35$) of the sample were graduate students. Forty-eight percent of the respondents were students from Turkey, 23% were from Nigeria, 19% from North Cyprus (locals) and 10% were from other international countries such as Iran, Iraq, Syria, Russia, Ukraine, Tajikistan, Turkmenistan, Azerbaijan, Cameroon, and Zimbabwe.

4 Findings

4.1 Analysis of Participants' Perceptions of Sexual Harassment Behavior

To determine the extent of differences among male and female participants' perceptions of what constitutes sexual harassment behavior, an independent-samples t-test was conducted. Interestingly, of the 15 items measured, only one item, "students looking at other students in a sexual way," revealed a significant gender difference ($p < .05$) among participants' perceptions. Female participants (m = 3.95, SD = 1.016) were more likely than male participants (m = 3.80, SD = 1.118) to agree with this item as a form of sexual harassment, and male participants were more likely to disagree that the aforementioned behavior was a form of sexual harassment. The remaining 14 items showed no gender differences in participants' (dis)agreement as to whether a behavior was sexual harassment. Apart from one item, male and female participants appeared to share similar perceptions of behaviors that could be classified as sexual harassment.

To determine if respondents' perceptions of sexually harassing behavior change as students grow older, two age groups -younger (16–23 years old) and older (24+ years old) students- were formed. It was found that younger and older student groups perceived two items "students calling others names like 'slut,' 'whore,' etc." and "students forcing other students to have sex" differently (p < .01, p < .05 respectively). The older student group (m = 3.63, SD = 1.218) were more likely than the younger student group (m = 3.52, SD = 1.153) to agree that "students calling others names like 'slut,' 'whore,' etc." was sexually harassing behavior (p < 0.01). The older student group (m = 3.92, SD = 1.144) were more likely than the younger student group (m = 3.86, SD = 1.115) to agree that "students forcing other students to have sex" was sexually harassing behavior (p < .05). These findings suggest that some behaviors perceived as sexual harassment by older students may not be perceived as sexual harassment by younger students. In other words, younger students may have a narrower perception of which behaviors may be sexual harassment compared to older participants.

The effect of culture on the perceptions of EMU students on sexually harassing behavior was also examined. Respondents were grouped based on their nationalities as students from Turkey, North Cyprus, and International students. ANOVA results indicated that students from different cultures perceived three non-verbal behavior items ("Students showing, giving or leaving sexually offensive pictures, photos or messages for other students," "Students grabbing or sexually pinching other students," and "Students touching or pinching other students' private parts") significantly different (at $p < .05$ for three items). Students from Turkey and North Cyprus were more likely than international students to agree on non-verbal behaviors to be sexually harassing behavior. International students in this sample may be less likely to perceive behaviors, particularly non-verbal ones, as sexual harassment compared to students from Turkey and North Cyprus.

4.2 Analysis of Participants' Attitudes Toward Sexual Harassment

The second part of the questionnaire included statements of attitude toward sexual harassment. For the second part of the questionnaire, responses were compiled to obtain a single score of indicating participants' tolerance for sexual harassment. This was achieved by summing the scores of statements endorsing the view that sexual harassment is not a problem, and women should expect such behavior in their environment. Lower scores indicate low tolerance of sexual harassment, and higher scores indicate higher tolerance for sexual harassment. Here, data from 36 male respondents and 11 female respondents were eliminated from further analysis due to incompleteness, so the total sample for this analysis was 413 (female = 156; male = 257). Results of the mean scores of tolerance for sexual harassment by gender show that female students have a lower tolerance ($m = 37.90$) for sexual harassment than male students ($m = 42.29$), indicating that female students were more likely to view the statements listed in the questionnaire as sexual harassment. These findings indicate that female participants more often reported agreeing that the statements listed were potentially sexual harassment compared to the agreement from male participants.

Further analyses were conducted to measure whether sexual harassment attitudes differ between male and female respondents. According to t-test results, male and female EMU students perceived 7 out of 13 items of attitudes of sexual harassment significantly different (at $p < .05$). Female EMU students agreed more than male EMU students that "It is only natural for a woman to use her sexuality as a way of getting ahead" (at $p < 0.00$), "Innocent flirtations make the day interesting" (at $p < 0.01$), "Encouraging an instructor's/assistant's sexual interest is frequently used by women to improve their grades" (at $p < 0.01$), "A lot of what people call sexual harassment is just normal flirtation" (at $p < 0.01$), "All this concern about sexual harassment makes it harder for men and women to have normal relations" (at $p < .05$), "Women think less clearly than men" (at $p < .05$), "Women are more emotional than men" (at $p < .00$) are sexually harassing attitudes.

ANOVA results also showed that there were statistically significant differences between younger EMU students (16–23 years old) and older students (24+ years old) for six items at $p < .05$. Younger university students more often reported agreeing with sexually harassing attitudes, such as "It is only natural for a woman to use her sexuality as a way of getting ahead", "A lot of what people call sexual harassment is just normal flirtation", "Encouraging an instructor's/assistant's sexual interest is frequently used by women to improve their grades", "One of the problems with sexual harassment is that women cannot take a joke", "All this concern about sexual harassment makes it harder for men and women to have normal relations", "Women think less clearly than men", and "Women are more emotional than men" than older EMU students. The findings suggest that age may be an important factor in determining participants' attitudes toward sexual harassment. Older participants were less likely to agree with the statements endorsing the view that sexual harassment is not a problem compared to younger participants. Since there were no statistically significant differences in the attitudes of students toward sexual harassment based on nationality, we need to indicate that our findings do not support that culture is an important factor in determining participants' attitudes toward sexual harassment.

5 Discussion

This study aimed to identify university students' perceptions of behaviors that constitute sexual harassment and compare university students' sexual harassment attitudes based on gender, age, and nationality. The findings suggest that while there appears to be some agreement as to which behaviors constitute sexual harassment based on gender, there may be some differences in attitudes toward sexual harassment based on participants' gender. EMU students' perceptions were similar toward what constitutes sexually harassing behavior, regardless of gender. However, women were more likely than men to perceive a wider range of verbal and non-verbal behaviors as sexual harassment. This is consistent with previous findings by Rotunda and colleagues (2001). In support with previous research, results from this study indicate that female students perceive more behaviors to be indicative of sexual harassment compared to male students (Gutek et al. 1980; Popovich et al. 1986). Results also show a significant difference between male and female students' attitudes toward sexual harassment. Females who participated in the study have significantly less tolerance for sexual harassment than men. Such results may be related to the fact that men, in general, tend to be the perpetrators, whereas women tend to be the victims of sexual harassment (Ford and Donis 1996). Another possible explanation for females' lower tolerance is that they may be viewed as targets by harassers, thus making them more sensitive to sexual harassment (Blakely et al. 1995). These findings are similar to those of Ford and Donis (1996) who showed gender to be an important factor in determining attitudes toward sexual harassment, revealing a significant effect of age on perceived differences of sexual harassment attitudes. This is consistent with the findings of this study, as older respondents' tolerance was found to be lower than younger respondents, indicating that older respondents were more likely to view an item as indicative of sexual harassment compared to younger respondents.

The perceptions of sexual harassment behavior and attitudes toward sexual harassment based on the age of participants indicated differences. It is found that younger participants have a narrower perception of which behaviors constitute sexual harassment compared to older participants. Interestingly, younger participants were more likely to agree with sexists attitudes compared to older participants. As this was a cross-sectional design, it is not possible to determine whether this is a cohort effect or whether attitudes change over time. A longitudinal design would be needed to examine this premise.

The perceptions of sexual harassment behavior indicated differences by participants' nationality. A novel contribution of this study was that international participants, compared to participants from North Cyprus and Turkey, appeared to be more tolerant of which behaviors relate to sexual harassment. In other words, students from North Cyprus and Turkey appeared to be more likely to classify more behaviors as sexual harassment compared to students from other cultures.

The findings presented in this study may seem debatable, given the differences in the results for perceptions of potentially sexual harassment behaviors, and potentially sexual harassment attitudes. However, this is not unusual, as research examining gender differences in perceptions of what constitutes sexual harassment has presented mixed results. Researchers have argued that this may be due to the degree of ambiguity in the examples of the sexually oriented items being measured (Blakely et al. 1995). Offensive behaviors may be unambiguous that disagreement about its interpretation is highly unlikely. This could be the reason why the results for respondents' perceptions of potentially harassing sexual behaviors in this study showed no significant difference, while that of potentially harassing sexual attitudes showed a significant difference. Here, significant differences were found because they asked less specific questions that provided limited contextual information.

The findings from the current study are consistent with the literature, which suggests that in academic settings, both male and female perceptions of sexual harassment varied for ambiguous scenarios. When the items were highly explicit, there were higher levels of agreement between males and females; however, when the items were ambiguous, females were more likely than males to perceive the behavior as sexually harassing (Adams et al. 1983; Kenig and Ryan 1986).

It is clear that organizations have a responsibility to provide an educational environment free of sexual harassment. Pro-active steps should take into consideration gender-, age- and culture-based differences to fulfill EMU's responsibility in this regard. Specific areas that EMU might take action include training of employees and student assistants (Thacker and Gohmann 1993). Equally important is the need for EMU to investigate harassment claims quickly and thoroughly, taking appropriate disciplinary steps. Organizations that have failed to act upon claims of sexual harassment risk finding that their negligence contributed to increasing the organization's liability. Being able to understand the nature of gender-, age- and culture-based differences can do much to reduce confusion in this area.

It is recommended that the first step in eliminating sexual harassment is to develop an organizational policy that clearly states that sexual harassment will not be tolerated, providing examples of behaviors (verbal and non-verbal) that will be interpreted as sexual harassment, and the consequences of not adhering to the policy. EMU's hierarchical organization would benefit from involving students in the policy-making process since sexual harassment is often observed in relationships of unequal power (MacKinnon 1979). It would be desirable to include male and female student perceptions of different ages and cultures in the policy-making process.

Another recommendation is to educate employees and students about the policy, to increase sensitivity to behaviors that may be perceived to be sexual harassment. As part of sexual harassment prevention training, organizations should sensitize employees at all levels of the organization to the various forms of hostile environment harassment. Stressing the fact that it is the victim's perception and not the intent of the accused that will be taken into consideration, may encourage members of the organization to think about how the recipient of their actions may perceive their behaviors.

6 Conclusion

This study presents information gathered from a diverse sample of students at EMU about their views on behaviors and perceptions about sexual harassment. These findings suggest that while there appears to be some agreement as to which behaviors constitute sexual harassment, there may be some differences in people's perceptions of sexual harassment related to their gender, culture, and age. The findings indicate that female participants more often reported agreeing that the behaviors listed were potentially sexual harassment compared to male participants. Age is found to be an important factor both in participants' perceptions of sexual harassment behavior and in their attitudes toward sexual harassment. Younger participants may have a narrower perception of which behaviors constitute sexual harassment compared to older participants. Similarly, when analyzing attitudes, older participants were less likely to agree with statements endorsing sexist attitudes. Another important finding of the study was that international participants, compared to participants from North Cyprus and Turkey, appeared to be more tolerant of which behaviors constitute sexual harassment.

The findings from this study lay the foundations for developing guidelines and policies on sexual harassment at EMU. While it is desirable for organizations to establish specific definitions of sexual harassment, educating people within an organization to identify or prevent sexual harassment is essential for effectively dealing with sexual harassment cases. Without a commonly accepted, behaviorally-based definition of what constitutes sexual harassment, the degree to which the problem exists within an organization cannot be accurately assessed, and the problem cannot be effectively addressed. Organizations, such as academic institutions, need to establish clear sexual harassment policies and procedures to effectively prevent, identify, and handle sexual harassment cases (Witkowska and Menckel 2005). Without a clear behavioral–based definition of what constitutes sexual harassment, sexual harassment cases may not be effectively prevented, evaluated, and managed. From a practical perspective, the findings could be used to establish a list of behaviors that could serve as a guideline for establishing sexual harassment cases.

A limitation of this study was that participants' personal experiences of sexual harassment on the school premises, the types of harassment they may have experienced, and their views of whether sexual harassment is a problem at the institution were not collected. Such information would have been useful for the researchers in making comparisons between age, gender, and culture to examine potential relationships with the behaviors identified as sexual harassment and students' experiences. However, the researchers did not want to risk causing distress for any participants as a result of completing the survey. Another limitation may be that participants were responding in socially desirable ways, which may explain why no significant difference was found in male and female perceptions of sexual harassment behaviors. This study's use of a Likert style response scale may aide the identification of behaviors and perceptions that could be creating and sustaining a hostile school environment. For example, students may agree with the statement "Most of the men are sexually teased by women whom they interact," without considering this as sexual harassment. Though such behaviors are not typically reported, such behaviors may hurt the victim's productivity, absenteeism, and career success.

Future research could investigate perceptions of sexual harassment using a more qualitative approach. This study was limited in terms of the items participants were asked to respond to, and therefore, it is likely that many other relevant behaviors and attitudes about sexual harassment may have been missed. Interviews with a diverse sample of participants in terms of age, gender, and nationality could facilitate establishing a more encompassing set of guidelines for preventing, identifying, and managing sexual harassment incidences.

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Failure Mode and Effect Analysis (FMEA) of Vertical Axis Wind Turbines

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Abstract. Failure Mode and Effect Analysis (FMEA) is a widely used risk assessment approach for identification, quantification, and mitigation of potential failures in systems, products, processes, designs, and projects. Previous research efforts have focused on FMEA of Horizontal Axis Wind Turbines (HAWT)s, but there is a lack of application of FMEA for the failure analysis of Vertical Axis Wind Turbines (VAWT)s. This paper aims at the enhancement of reliability of VAWTs by applying system FMEA augmented with Fuzzy Logic (FL), and Dempster-Shafer (D-S) theory. A total of 12 probable failure modes have been identified, quantified and prioritized. The application of Fuzzy-FMEA and DS-FMEA approach based on three experts' opinions accommodates the diversity of opinions and accounts for the uncertainty in decision making, due to any lack of knowledge and experience of the FMEA team.

Keywords: Vertical Axis Wind Turbine · Failure mode and effects analysis · Dempster-Shafer theory · Fuzzy rule

1 Introduction

Risk management is a mandatory requirement based on ISO 31000:2009, which provides the generic guidelines and frameworks to risk management processes. Using ISO 31000:3009 is beneficial to effectively achieve organizational objectives and utilize resources for risk treatment by identifying opportunities and threats. Failure Mode and Effect Analysis (FMEA) is an established risk management approach that prevents probable failures in the system and provides the foundation for policies and remedial measures to tackle them. FMEA was first employed in the 1960s in aerospace companies as a risk management tool during the designing phase, and afterward, this method is being used in other sectors such as automotive industry (Sharma et al. 2007). FMEA can distinguish all failure modes, while the members of the FMEA team by utilizing risk factors evaluation information, rank the risks of all distinguished failure modes in importance arrangement (Chen and Deng 2018). Previous studies on FMEA of wind turbines have focused on the components, systems, subsystems, and functional modes of Horizontal Axis Wind Turbines (HAWT)s. (Bharatbhai 2015), (Kahrobaee and Asgarpoor 2011), (Tavner et al. 2010) and (Arabian-Hoseynabadi et al. 2010) applied FMEA to investigate

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the failure of 5 MW, 3 MW, 2 MW and 2 MW HAWTs respectively. In this study, a risk assessment methodology based on FMEA is proposed for analyzing the reliability of VAWTs that have lesser number of system components. The probable failure modes are identified and quantified. Risk priority number (RPN) is used for prioritizing the risk of each failure mode by order.

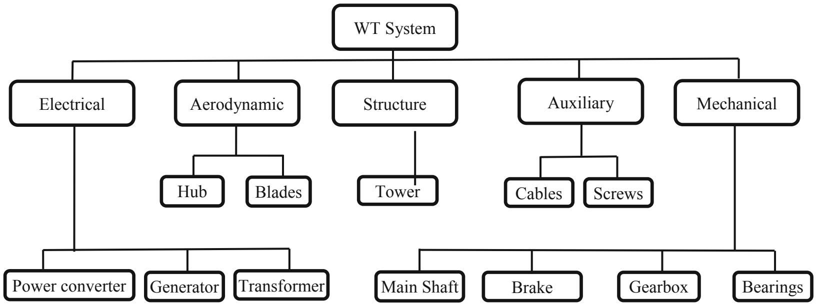

Fig. 1. System Breakdown Structure of Vertical Axis Wind Turbine

FMEA studies begin with the known, and potential failure modes at a certain level then explore its impact on the level of the sub-system. Thus this approach is bottom-up design. Moreover, a full FMEA study covers all the hierarchy levels from its bottom to the top. System Breakdown Structure of a Vertical Axis Wind Turbine is presented in Fig. 1. Ultrasonic testing, oil tracking and many other online techniques for condition monitoring as well as visual inspection are used for failure modes detection, and time-based preventive maintenance actions. Usually, a multi-disciplinary team composed of experts from different majors such as power production, operation maintenance, and design, determine the ultimate effects of each failure mode. The basic RPN is not enough when various specialists give diverse evaluations of risks to a single failure mode, which might be uncertain and imprecise. (Dinmohammadi and Shafiee 2013) applied FMEA theory on offshore WT systems using grey theory approach and fuzzy rule base. Many researchers have reported the advantages of Fuzzy based FMEA when the failure data are unreliable or unavailable and how it is a useful tool for combing the quantitative and qualitative knowledge based on field data, and experts' opinion.

In this study, the Dempster-Shafer theory is implemented to aggregate the diversity of opinions and evaluations given by several experts, risk factors and failure modes, as the results have been compared with the results obtained by Fuzzy Logic method. The proposed FMEA process is introduced with an explanation of the DS theory and fuzzy logic. The risk prioritization by application of two FMEA approaches (DS FMEA and Fuzzy FMEA) to VAWT, is presented, followed by a comparison of both approaches.

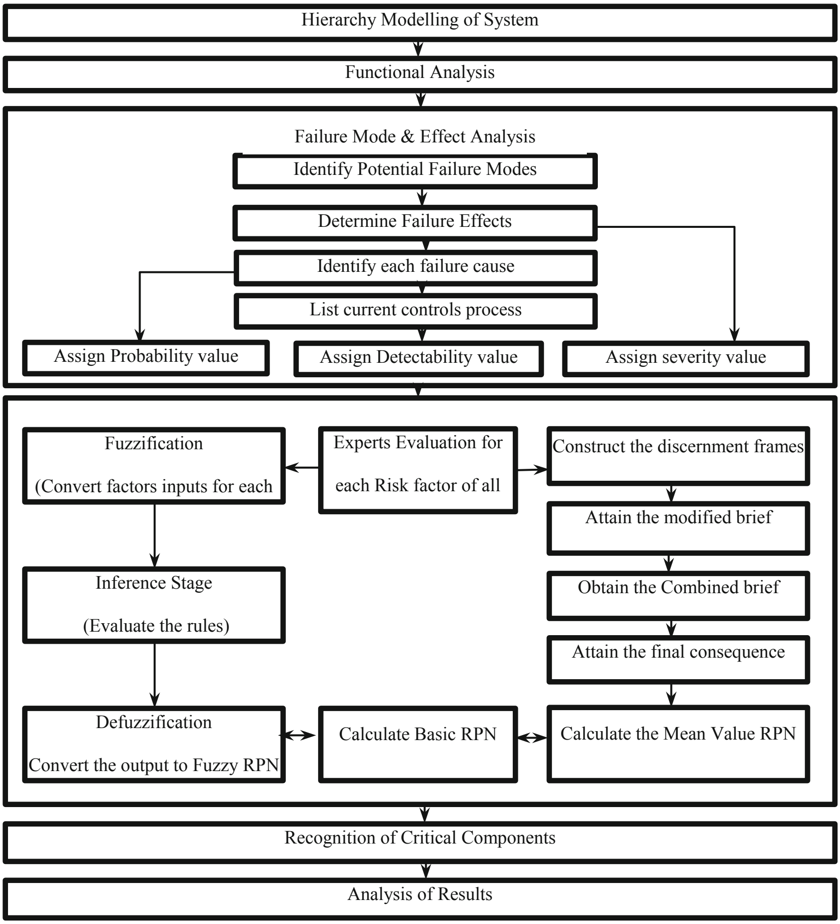

Fig. 2. Flowchart of the Fuzzy-FMEA and DS-FMEA approach

2 Methodology

2.1 FMEA Process

In the FMEA process, the main objective is to identify the critical components of the system. In other words, the aim of FMEA is (1) to recognize the failure modes occurring during a definite period of system, (2) to determine the reasons for any failure occurrence, (3) to evaluate the effects of each failure, and (4) to prioritize the failures (Sharma et al. 2005).

The proposed Fuzzy-FMEA and DS-FMEA methodology are shown in Fig. 2.

An FMEA procedure is carried out in three fundamental steps:

Step 1: By dividing the system into subsystems and components, the main modules are categorized in a bottom-up diagram, and upon the occurrence of any failure in any component, the effect chain is traceable at higher levels.

Step 2: FMEA method is evaluable both qualitatively and quantitatively.

By considering three parameters, i.e., Severity (S), Occurrence (O), and Detection (D), and allocating a number between 1 and 10, Risk Priority Number (RPN) is calculated according to Eq. (1). (Mariajayaprakash and Senthilvelan 2013; Šolc 2012; Su et al. 2014).

$$\mathrm{RPN} = \mathrm{S} \times \mathrm{O} \times \mathrm{D} \tag{1}$$

The rating criteria for FMEA risk factors are listed in Table 1. RPN shows the amount of potential risk in the observed failure modes of the system. The key parameter of basic FMEA approach is allocation of a number between 1 and 10 to every risk factor of the failure mode, and categorizing them so that the more critical is the failure, the higher is the allocated number, and the more periodic inspection of the related component is required.

Table 1. Rating criteria of FMEA (Chang and Paul Sun 2009; Chin et al. 2009; Liu et al. 2012; Xu et al. 2002)

Rating	Severity	Occurrence	Detection
10	Dangerous with no cautioning	Almost Certain	Total uncertainty
9	Dangerous with cautioning	Very High	Extremely remote
8	Extremely high	High	Remote
7	High	Moderately High	Very low
6	Moderate	Moderate	Low
5	Low	Low	Moderate
4	Extremely low	Very Low	Moderately high
3	Minor	Remote	High
2	Extremely minor	Very Remote	Extremely high
1	None	Nearly impossible	Nearly certain

Allocation of numbers in RPN method is accomplished by specialists who are experts in system functions and the impact of any failure, so two factors, i.e., the experience and knowledge of specialists are effective on the final results. Therefore, an improved parameter called Weighted RPN is utilized. The weighting is based on the following coefficients given to the obtained RPN: out of the question (1), very confident (0.9), confident (0.7), less confident (0.25), and not confident (0.1). By considering experience and knowledge in the final results, the RPN value will be a qualitative evaluation, and the numbers are just comparative in rating the critical parts of the system.

Due to numerous criticisms against the RPN method, it has not been considered as an ideal approach and has been replaced by alternative methods in FMEA. (Meng Tay and Peng Lim 2006; Puente et al. 2002; Ravi Sankar and Prabhu 2001) The most serious criticism is:

- Distinctive combinations of O, S, and D evaluations may create a similar estimation of RPN, yet their concealed risk basis might diverse completely. For instance, two distinctive failure modes with the estimations of 5, 7, 2 and 10, 1, 7 for O, S, and D, individually, will have an identical RPN estimation of 70. In any case, the concealed risk basis of the two failure modes might be completely different as a result of the diverse severities of the failure result. Therefore, this may cause the incidence of high-risk failure modes without being detected.

2.2 Dempster-Shafer Theory

Nowadays, in technical risk management and in its relative areas there are many approaches to contend with quantifying uncertainties and modelling by implementing Dempster Shafer Theory (Ji and Marefat 2003; Kukulies and Schmitt 2017; Shi et al. 2017; Zhang and Chen 2009), As the combination rule of Dempster is widely known as associative and commutative (Dempster 1967; Shafer 1976). As a result of these characteristics, evidence may be fused in any sequence, for example in the presence of different belief structures; a pair-wise combination may be executed (Certa et al. 2017). This theory is established on two models, finding a degree of beliefs for individual probability assessment and merging those above within a probabilistic framework (Chen and Deng 2018). For describing the uncertainty set in the hypothesis, the belief interval is adopted by the DS theory. Furthermore, when uncertainty, impreciseness, and incompleteness occur in the information set from several sources, this strategy is suitable to solve it.

(Yang et al. 2011) transformed the new combination rule of DS theory as

$$m^{n}_{i.jg}(C) = \left(\overline{m}^{n}_{ij} \oplus \overline{m}^{n}_{ig}\right)(C) = \begin{cases} 0, & C = \emptyset \\ \dfrac{\sum_{X \cap Y = C, \forall X, Y \subseteq \Theta_i^n} \left(\omega_{ij}.m^{n}_{ij}(X)\right) \times \left(\omega_{ig}.m^{n}_{ig}(Y)\right)}{1 - \sum_{X \cap Y = \emptyset, \forall X, Y \subseteq \Theta_i^n} \left(\omega_{ij}.m^{n}_{ij}(X)\right) \times \left(\omega_{ig}.m^{n}_{ig}(Y)\right)}, & C \neq \emptyset \end{cases} \quad (2)$$

While Θ^{n}_{i} is utilized to show the discernment frame of the nth failure mode to the ith risk factor, ω_{ij} is the relative weight, i represents the risk factor and j for the experts (Yang et al. 2011). By taking the weight into account, $\overline{m}^{n}_{ij}(.)$ can represent the new Basic belief assignment, Where, $i = O, S, D$, $j = 1, 2, \ldots, L$, L is the number of experts, $n = 1, 2, \ldots, N$, N is the number of failure modes.

The combination rule can include not only two experts, as clearly revealed in Eq. (2). For all evidence sources, the synthetic effects are represented by the final result.

$$M^{n}_{i} = M^{n}_{i1} \oplus M^{n}_{i2} \oplus \cdots \oplus M^{n}_{iL} = \left(\left(\left(M^{n}_{i1} \oplus M^{n}_{i2}\right) \oplus \cdots\right) \oplus M^{n}_{iL}\right) \quad (3)$$

2.2.1 Risk Priority Number Assume the Risk priority number has different ratings $(RPN^{1}_{n}, \ldots, RPN^{q}_{n})$ and specific probabilities $P(RPN^{1}_{n}, \ldots, RPN^{q}_{n})$ for nth failure mode based on Eq. (2). The mean value of risk priority number is required for combining the total risk of each failure mode, as shown in Eq. (4) (Yang et al. 2011).

$$MVRPN_{n} = E(RPN_{n}) = \sum\nolimits_{q} \left(RPN^{q}_{n}\right).P\left(RPN^{q}_{n}\right) \quad (4)$$

2.3 Fuzzy FMEA

The fuzzy approach can convert the capabilities of decision making and the fuzziness of the experts' evaluation of mathematical terms. Hence it is convenient for failure modes ranking by utilizing fuzzy rules (Wang et al. 2018). Fuzzy approach has various advantages (Bozdag et al. 2015) such as: it can handle both precise and imprecise information in a consistent manner, it allows combination of probability of failures occurrence, severity, and detectability in a more pragmatic manner (R. K. Sharma et al. 2005) and the risk assessment function can be varied according to the specific system under consideration (Liu et al. 2013).

However, a membership function (MF) is a curve that describes how every point in the input space is associated with a membership value somewhere from 0 to 1 and often gives the designation of μ. The input space is also known as the universe of discourse (UOD). The output-axis is a number known as the membership value between 0 and 1.

A fuzzy set is an expansion of a classical set. Assume X is the universe of discourse, and its elements are represented by x. Subsequently, a fuzzy set A in X is described as a set of ordered pairs.

$$A = (x, \; , \mu A(x)|x \in X)) \tag{5}$$

μA(x) is known as the membership function (or MF) of x in A. The membership function associates every element of X to a membership value from 0 to 1.

The if-then rule statements are employed for formulating the conditional statements that form fuzzy logic. A single fuzzy if-then rule typically is from the concept; if x is A then y is B; where, A and B are semantic values defined by fuzzy sets on the ranges X and Y, respectively. The if part of the rule "x is A" is known as the antecedent, whereas the then-part of the rule "y is B" is known as the consequent. The consequent is described by a number from 0 to 1, and the antecedent is an analysis that results in a number from 0 to 1 as well.

Conventionally, the input to an if-then rule is the present value for the input variable, and the output is a whole fuzzy set. Subsequently, the set is defuzzified; that is, allotting just one value to the output in the end. Interpreting an if-then rule comprises different parts. Firstly, the evaluation of the antecedent is performed (which involves input fuzzifying and employing suitable fuzzy operators). Secondly, the outcome obtained from the first part is applied to the consequent.

The Fuzzy RPN (based on 10 membership functions) is derived from the "if-then" rules, and it is determined based on the integer numbers allocated to S, O, and D (from 1 to 10) as well as on the steps of fuzzy logic control (Shaout and Trivedi 2013).

Step 1- Based on the combination of S (as input 1 in step 1) and O (as input 2 in step 1) values (each risk factor from 1 to 10), and according to the rules in Table 1 a fuzzy number is exploited (Shaout and Trivedi 2013). This step is as the first stage of multi-stage fuzzy architecture. The generated surface of the logic controller is shown in Fig. 3 (Jang 1993; Jang et al. 1997; Kaufmann and Gupta 1985; Lee 1990; Puente et al. 2002).

Step 2- The rules utilized in this step are the same as the previous step, and just input parameters will be the detection value of failure mode (as input 2 in step 2) and the output number of step 1 (as input 1 in step 2) (Mamdani 1976; Wang et al. 2009). This

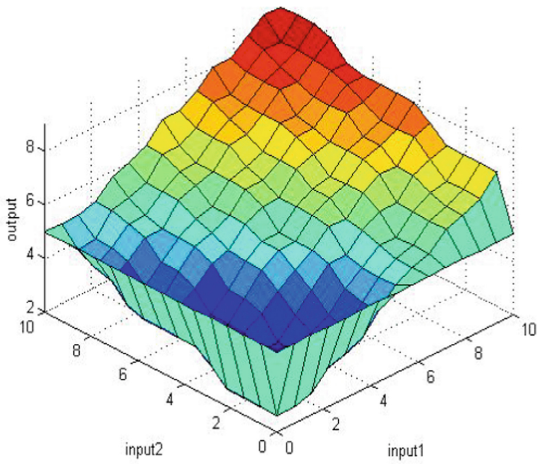

Fig. 3. Surface viewer of fuzzy controller first stage

step is the second stage of the multi-stage structure, and as far as the rules have been kept the same as step 1, the generated surface will not display any change.

3 Results

The failure modes of VAWT are identified from (Arabian-Hoseynabadi et al. 2010), (Bharatbhai 2015), (Dinmohammadi and Shafiee 2013), (Kahrobaee and Asgarpoor 2011), (Tavner et al. 2010), and (Klein and Lalli 1989). For each failure mode, values of risk factors and the amounts of DS-RPN, and Fuzzy RPN (based on 10 membership functions) are provided. The values are obtained from survey responses from three specialists who are experts in VAWT. The proposed technique is applied to failure modes and effects analysis case of VAWTs, all three risk factors, and the failure modes were evaluated by three experts exhibiting diversity in their evaluations. In Table 2, all evaluations are listed regarding 12 components.

As shown in Table 2, the most critical failures of the system are gearbox, blades, and generator, which obtained the highest ranking numbers (between 1st to 2nd rankings at each approach). Also, the trend of scored numbers in analysis of each implemented approach is very similar, and it shows the same risk importance for the recognized failure modes of the system.

4 Discussion

By application of Dempster-Shafer theory and Fuzzy logic, the accuracy of results was increased, and aggregation of team members' opinions had the same effect at an elevation of precision in final findings.

Concerning fuzzy logic and Dempster Shafer theory, the risk priority number rank of all 12 components is demonstrated in Figs. 4 and 5. Although both ranks showed the

Table 2. FMEA table for VAWT

System /Component	Failure type	EXPERT 1			EXPERT 2			EXPERT 3			DS-RPN	MVRPN	Rank (RPN)	Fuzzy Logic	MV Fuzzy Logic	Rank (Fuzzy logic)
		S	O	D	S	O	D	S	O	D						
Brake system	Mechanical failure (Cyclic Fatigue)	2 :60% 1 :40%	2 :10% 1 :90%	7	2 :75% 1 :25%	2 :60% 1 :40%	7	2 :80% 1 :20%	2 :90% 1 :10%	7	15.493 5.194 0.416 0.139	21.24	9	2.33 2.33 2 2	2.165	7
Main shaft	Fracture and thermal	2 :75% 1 :25%	3 : 80% 2 : 20%	7	2 :40% 1 :60%	3 :90% 2: 10%	7	2 :20% 1 :80%	3 :25% 2 :75%	7	12.96 0.710 12.92 0.70	27.29	8	2.61 2 2.61 2	2.305	6
Gearbox	Fracture and cyclic fatigue	3	5	7	3	5	7	3	5	7	105	105	1	5	5	1
Cables	Corrosion and lifetime	3	2	1	3	2	1	3	2	1	6	6	11	2	2	8
Transformer	Short-circuit	3 :80% 2 :20%	5 :75% 4 :25%	4	3 :90% 2 :10%	5 :60% 4 :40%	4	3 :25% 2 :75%	5 :80% 4 :20%	4	52.44 2.208 3.04 0.128	57.816	5	2 1.61 2 1	1.6525	9
Generator	Overheating	2	5	7	2	5	7	2	5	7	70	70	3	4	4	2
Power converter	Overload	4 : 80% 3 : 20%	3 : 60% 2 : 40%	7	4 : 25% 3 : 75%	3 :90% 2 :10%	7	4 :20% 3 :80%	3 : 75% 2 : 25%	7	20.244 0.504	67.431	4	3 3	2.76	5

(*continued*)

Table 2. (*continued*)

System /Component	Failure type	EXPERT 1			EXPERT 2			EXPERT 3			DS-RPN	MVRPN	Rank (RPN)	Fuzzy Logic	MV Fuzzy Logic	Rank (Fuzzy logic)
		S	O	D	S	O	D	S	O	D						
											45.549			2.7		
											1.134			2.34		
Bearings	Lifetime	3 : 90% 2 : 10%	2 : 75% 1 : 25%	4	3 :20% 2 :80%	2 : 60% 1 :40%	4	3 :80% 2 :20%	2 :40% 1 :60%	4	16.146	20.279	10	1.61	1.305	10
											2.691			1.61		
											1.236			1		
											0.206			1		
Blades	Mechanical failure (Cyclic Fatigue)	3 :40% 2 :60%	5 :20% 4 :80%	7	3 : 60% 2 : 40%	5 :75% 4 :25%	7	3 : 90% 2 : 10%	5 :40% 4 :60%	7	31.119	87.65	2	2.67	2.835	4
											49.86			3		
											2.5641			2.67		
											4.1087			3		
Hub	Mechanical failure (Cyclic Fatigue)	2	5	4	2	5	4	2	5	4	40	40	7	3	3	3
Screws	Corrosion	1	2 :80% 1 :20%	1	1	2 :25% 1 :75%	1	1	2 :60% 1 :40%	1	1.332	1.666	12	1	1	11
											0.334			1		
Tower	Fracture and fatigue	4 : 60% 3 : 40%	5 :10% 4 :90%	4	4 : 75% 3 : 25%	5 : 20% 4 : 80%	4	4 :20% 3 :80%	5 : 25% 4 : 75%	4	0.416	56.464	6	2	2	8
											32.95			2		
											0.288			2		
											22.81			2		

highest importance for the gearbox, there was a difference in the prioritization of several components, such as blades and generator, the fuzzy logic prioritized the generator over blades, but DS showed the opposite. In such uncertainty, these components should be treated similarly. The results are consistent with the practical engineering background and other similar research on failure analysis of wind turbines (Certa et al. 2017; Wang et al. 2018) thereby, demonstrating the efficiency and effectiveness of the DS-FMEA and Fuzzy-FMEA.

5 Conclusion

In this research, the System Failure Mode and Effect Analysis (FMEA) approach based on Dempster Shafer evidence theory (DS-RPN), Fuzzy RPN (based on 10 membership functions), is applied for failures prioritization of Vertical Axis Wind Turbine (VAWT).

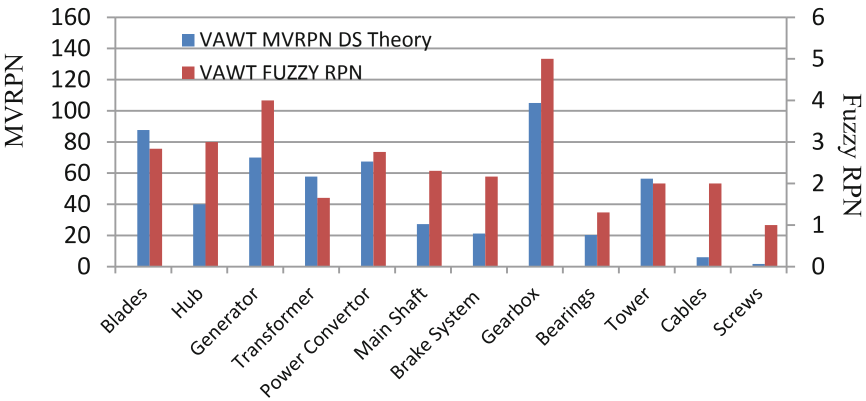

Fig. 4. MVRPN DS Theory and Fuzzy RPN for VAWT

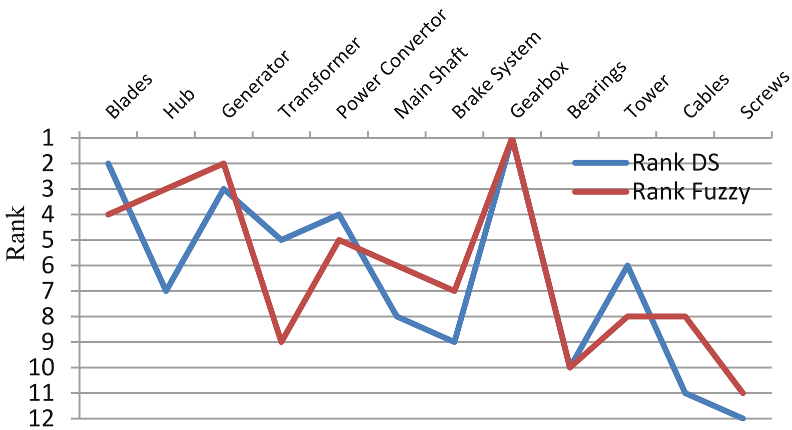

Fig. 5. Rank based on DS-FMEA and Fuzzy-FMEA for VAWT

The application of Fuzzy-FMEA and DS-FMEA approach based on three experts' opinions accommodates the diversity of opinions and accounts for the uncertainty in decision making, due to any lack of knowledge and experience of the FMEA team. D–S evidence theory is adapted to aggregate the risk evaluation information of multiple experts, which may be uncertain, imprecise, and inconsistent. Meanwhile, the uncertainty is reduced, and the accuracy is improved by increasing the number of fuzzy rules of FMEA team members' opinions. Failure modes ranking is obtained based on Mean Value RPN. Different evaluation information given by three experts on 12 components is aggregated, and the mean value RPN is attained based on Dempster-Shafer evidence theory and fuzzy logic. The most critical system failures are gearbox, blades and generator, which obtained the highest ranking numbers. However, the DSFMEA and Fuzzy FMEA have the potential to improve the reliability of VAWT.

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Research Areas and Suggestions for Sustainable Manufacturing Systems

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Abstract. Nowadays, sustainable manufacturing systems gain further awareness and importance because of considering economic, environmental, and social factors. This study presents a comprehensive evaluation to gain knowledge about sustainable manufacturing systems and related basic concepts such as circular economy, industrial symbiosis, eco-industrial parks, and life cycle assessment. Moreover, some suggestions for future research areas are presented to help to fill gaps in this field after many studies from the related literature are evaluated in detail.

Keywords: Sustainability · Sustainable manufacturing systems · Complex adaptive systems

1 Introduction

In the digital age, where market conditions are more dynamic, and customers are more active in the design, firms have started to move towards sustainable manufacturing systems. The firms must have sensitive, smart, and sustainable characteristics to be favored in the market. Being sensitive means that the firms can know the global context and detect interconnected environments that allow them to predict future situations. Being smart is to be an internet-based and a knowledge-based, and hence, a business responds to opportunities and is agile in using information. Being sustainable means that firm activities have positive economic, social, and environmental impacts. These properties are referred to as complex adaptive systems since they have many active elements that are non-linear and non-specific relationships (Chavarria-Barrientos et al. 2018).

The term sustainability was first introduced in 1987. It is expressed as the development that enables today's needs to be met without sacrificing the needs of future generations. Sustainability is explained with three dimensions as environmental, social, and economical (Garetti and Taisch 2012).

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The expected results of processes in sustainable manufacturing systems can be expressed as follows (Kishawy et al. 2018): Energy use reduction, waste reduction/disposal, product strength increase, elimination of health hazards and toxic distribution, higher production quality, recycling, reuse and remanufacturing activities, development of renewable energy sources.

The following changes can be listed to ensure sustainable manufacturing systems (Despeisse et al. 2012):

- Using resources less by significantly increasing the efficiency of natural resources,
- Transition to more biological and natural manufacturing models such as recycling, cleaner manufacturing, and industrial symbiosis,
- Moving to solution-based models such as product service systems and supply chain framework,
- Reinvesting in natural capital using a modification of inputs: the use of renewable and non-toxic materials for non-renewable and toxic.

The circular economy is a system based on reducing, reusing, recycling, and recovering materials in the manufacturing, distribution, and consumption processes (Kirchherr et al. 2017). For the transition to a circular economy, some changes in value chains of many areas such as product/production designs and related models and methods of converting waste to sources are needed. One of the key advantages of circular economy systems is that it keeps the benefit of the products as long as possible and eliminates waste. Even when a product reaches its end of life, it is kept in the economy so that its resources can be used efficiently, and it can create more value (Smol et al. 2015).

Industrial ecology aims to achieve development between industry and the environment. Industrial symbiosis is expressed as a subfield of industrial ecology (Cui et al. 2018). Sharing of by-products' resources and services among firms to add value to processes, improve costs, and environment can be expressed as industrial symbiosis (Gu et al. 2013). In an industrial symbiosis environment, one company's waste can become the raw material of another company (Albino et al. 2016). The industrial symbiosis success is based on companies that work together and have a common goal, including economic and environmental sustainability (Raabe et al. 2017).

The creation of eco-industrial parks has a positive effect on the development of industrial symbiosis, where different institutions can share common services and/or resources, thus reducing waste production and minimizing environmental impacts (Leong et al. 2017). Eco-industrial parks consist of a series of industrial symbiosis that allows the exchange of energy/materials between different industrial enterprises (Kuznetsova et al. 2016).

Life cycle assessment can be used to assess the environmental effects of a product during its overall life cycle (Shuaib et al. 2014). The object of methodologies used in life cycle analysis is to assess sustainability performance through the total product life cycle (Bilge et al. 2014).

In addition to economic and environmental sustainability, Industry 4.0 technologies can be used in creating sustainable value in social dimensions. Although the developments in the manufacturing sector have increased continuously to ensure a better standard of living for people, the recent developments in manufacturing have not been sufficiently sustainable. The developments in the manufacturing environment should also consist of preventive efforts to reduce climate change and energy resources. With intelligent devices and an intelligent manufacturing system, Industry 4.0 has technologies having the potential to reduce production waste, overproduction, and energy consumption. Manufacturing companies are connected through intelligent resources. However, the intelligent manufacturing systems, which are based on intelligent equipment such as large data centers and sensor devices, may have high energy and resource requirements that would negatively affect the environment to operate the system (Kamble et al. 2018).

In this paper, various studies and methods related to some research areas addressed in sustainable manufacturing systems are evaluated in detail. Also, the suggestions for future research areas are presented.

2 Literature Related to Research Areas

In this section, various studies in some research areas related to sustainable manufacturing systems such as industrial symbiosis, eco-industrial parks, and sustainable cellular manufacturing systems are presented chronologically.

2.1 Industrial Symbiosis

Cecelja et al. (2015) present a semantic algorithm built on ontology modeling of information in the field of industrial symbiosis to construct industrial symbiosis networks. The creation of an innovative industrial symbiosis network is achieved by separating features that characterize the relevant resources, solutions, and process optimized for the set of environmental criteria.

Albino et al. (2016) examine the formation of self-organizing industrial symbiosis networks in environments with different levels of uncertainty. In the study, industrial symbiosis networks are introduced as complex adaptive systems, and an agent-based simulation model is presented.

Yazan et al. (2016) present a guide study for the future evolution of industrial areas operating based on industrial symbiosis principles. The proposed model provides the decision maker with appropriate plans to identify and deal with the wastes.

Fan et al. (2017) propose an emergy analysis evaluating the performance of industrial symbiosis to assess economic and technological development. This study examines the industrial symbiosis applications in detail and describes the importance of these industrial symbiosis applications for the overall performance of the industrial park.

Song et al. (2018) use social network analysis for one mining industry park to analyze the amount, structure, and characteristics of the industrial symbiosis network. The authors of the study mention that many studies have dealt with optimizing the flow of materials and energy in industrial parks; however, there are fewer studies that also handled social aspects. Therefore, the study focuses on the social aspect of industrial symbiosis by using social network analysis.

Domenech et al. (2019) present an overview of industrial symbiosis developments in terms of the various factors such as a map of basic networks, size of networks, and geographic distributions.

2.2 Eco-Industrial Parks

Rubio-Castro et al. (2011) present a mathematical programming formulation including various factors such as wastewater containing many pollutants and optimization of a network for minimum total annual cost consisting of fresh water, piping and regeneration costs.

Tan et al. (2011) develop a fuzzy bi-level programming approach for designing water consolidation networks in eco-industrial park centers. With the further expansion of the model, it is possible to take into account the changes in the quality levels of flow rates and process water flows, as well as the introduction of new facilities into the eco-industrial park network.

Rubio-Castro et al. (2012) offer a mixed integer non-linear programming model to develop an eco-industrial park. The optimization method is proposed for the strengthening of multi-plant water networks and the integration of eco-industrial park into a common infrastructure.

Zhang et al. (2016) propose a generalized network optimization method for evaluating waste heat recovery opportunities in eco-industrial parks. Moreover, the method considers various factors such as energy efficiency, CO_2 emission reduction, energy balance, and investment limit.

Tiu and Cruz (2017) propose a model for eco-industrial parks using goal programming to minimize economic and environmental factors simultaneously. The economic costs mentioned in the study combine the piping and operating costs with freshwater, wastewater, and treatment costs. Moreover, the volume and quality of the water used by the eco-industrial park are taken into account as the environmental impact.

Zhou et al. (2017) develop a simulator system called J-Park Simulator for designing and operating of eco-industrial parks. The simulator can be defined as an ontology technology-based decision support system.

Ramos et al. (2018) introduce an approach for designing a utility network in an eco-industrial park. In the proposed approach, the flowchart simulation of each enterprise involved in the eco-industrial park is taken into account. Moreover, the approach considers the total annual cost and the equivalent CO_2 consumption related to the utility consumption in the eco-industrial park.

2.3 Sustainable Cellular Manufacturing Systems

Industry 4.0 forces firms to become more flexible and agile. Dynamic cellular manufacturing systems are considered to meet the requirements encountered in the transition to Industry 4.0. Also, manufacturers and managers have begun to consider environmental and social issues when designing manufacturing systems because of the growing importance of the concept of sustainability (Niakan et al. 2016).

Ghodsi et al. (2015) provide a multi-objective mathematical model to create a stable cellular manufacturing system considering the environmental impacts and costs related to the system. The model proposed in their study considers two objectives: The first objective includes various manufacturing cost elements such as part manufacturing time costs and costs of moving parts. The second objective deals with sustainability criteria.

Aljuneidi and Bulgak (2016) present a mixed integer linear programming model that deals with the reconfiguration issues for cellular manufacturing systems with different periods. In their study, an integrated approach is presented for design issues in sustainable manufacturing systems. In their model, three main cost items that are machine costs, manufacturing and remanufacturing costs, and returned products costs for remanufacturing are minimized.

Niakan et al. (2016) deal with dynamic cell formation problem and present a bi-objective mathematical model for this problem that takes into account worker assignment and environmental and social criteria. In the first objective function of the model, the production and labor costs are minimized while the second objective function minimizes the total production waste such as energy, chemicals, raw materials, and CO_2 emissions.

Aljuneidi and Bulgak (2017) offer an integrated approach that considers remanufacturing, recycling, disposing options needed for sustainable manufacturing system design. Moreover, the mixed integer linear programming model presented in their study includes reconfiguration issues for cellular manufacturing systems.

Iqbal and Al-Ghamdi (2018) aim to save energy consumed in a machine shop environment by optimizing production process assignments and grouping of machines in various cells.

3 Methods Applied in Related Research Areas

Some methods used in research areas related to sustainable manufacturing are presented in this section.

3.1 Eco-Efficiency Approach

The eco-efficiency approach aims to ensure continuous improvement. Moreover, this approach provides efficiently use of resources and energy. The environmental and economic aspects of activities are measured by using the eco-efficiency approach. Eco-efficiency can be defined as a ratio between value and environmental impact (Ferrera et al. 2017).

The method of evaluating resource efficiency considers the basic design elements in the value stream mapping. The activities of value added and non-value added in a processing system are determined. In this approach, efficiency analysis is ensured, and the system performance is measured by evaluating process parameters such as time, energy, and water (Ferrera et al. 2017).

3.2 Optimization Approaches

The optimization approach offers a variety of mathematical programming techniques to gain a best or optimum solution for a problem. In general, optimization problems can be divided into four groups, including constrained/unconstrained, single variable/multi-variable, one criterion/multi-criteria, and linear/non-linear problems (Hersh 2006).

Galal and Moneim (2015) aim to find the optimum product mix to maximize the sustainability of a manufacturing plant. To determine the product mix of the manufacturing plant and maximize the proposed sustainability index, including economic, environmental, and social impacts, they develop a mixed integer non-linear programming model.

The goal programming models can be used as optimization approaches like integer programming models. In a goal programming model, the aim is to ensure a solution that minimizes the deviations from the goals based on the priorities (Hersh 2006). As seen in the study of Kinoshita et al. (2016), for sustainable manufacturing systems, the goal programming can be used for different objective functions such as recycling rate and cost. Kinoshita et al. (2016) propose a selection of environmental and economic disassembly parts according to the goal programming with recycling rate and cost. Their model has two different objectives that are minimizing total recycling cost and maximizing total recycling rate.

3.3 Meta-heuristic Approaches

Some problems addressed in sustainable manufacturing can be expressed as non-polynomial hard that cannot be solved optimally in polynomial time. Therefore, heuristic or meta-heuristic algorithms can be used as solution methods (Ferrera et al. 2017). Meta-heuristic algorithms are generally conducted to calculate near-optimal results of problems that cannot be easily or in no way solved using other techniques that make up most of the problems (Bozorg-Haddad et al. 2017). Meta-heuristic algorithms consist of various algorithms such as tabu search, ant colony optimization, simulated annealing, particle swarm optimization, and genetic algorithm.

The genetic algorithm that is one of the algorithms inspired by natural process is one of the best-known evolutionary algorithm (Bozorg-Haddad et al. 2017). Al-Kindi and Atiya (2018) present a genetic algorithm approach including three different objectives, minimizing manufacturing cost, minimizing carbon dioxide emissions, and maximizing recycling rate, which aims to optimize high sustainability performance.

Non-dominated sorting genetic algorithm is an evolutionary algorithm generally used in multi-objective problems (Niakan et al. 2016). Niakan et al. (2016) propose a hybrid meta-heuristic approach that includes a non-dominated sorting genetic algorithm and multi-objective simulated annealing. In their study, sustainable multi-period cell formation problem with the economic, environmental, and social factors is considered.

The particle swarm optimization algorithm can be used as one of the most common approaches based on swarm intelligence (Bozorg-Haddad et al. 2017). Zhou and Shen (2018) deal with the optimization problem of material delivery tasks in mixed model assembly lines and present an energy efficient scheduling method. They develop a particle swarm optimization algorithm with taboo for solving the problem.

Energy efficient scheduling approaches are used for improving the energy efficiency of manufacturing companies (Gahm et al. 2016). Dai et al. (2013) propose an energy efficient scheduling methodology considering maximum completion time and total energy consumption in a flexible flow shop. They also present a genetic-simulated annealing algorithm.

3.4 Simulation Approaches

A simulation model that takes the decision variables as inputs can be expressed as the computational-related imitation of a real-world system over time (Bozorg-Haddad et al. 2017). However, in the study of Ferrera et al. (2017), some main shortcomings related to the simulation method in the environmental assessment of manufacturing systems are mentioned as follows: Special resource allocation is rarely provided. Materials and direct emissions are not taken into account. High efforts are required for data collection and modeling. There is a lack of methodological guidance in practice. The level of detail is not sufficiently scalable.

Sproedt et al. (2015) develop a simulation-based approach to integrate eco-efficiency improvements into manufacturing systems. Fraccascia and Yazan (2018) propose an agent-based model for simulating self-organizing industrial symbiosis networks using three different scenarios aiming to measure environmental and economic contribution.

Baysan et al. (2019) present a methodology that includes energy value stream mapping, experimental design, and simulation to reduce energy consumption and also aims to improve the energy efficiency of manufacturing systems using lean tools and techniques.

4 Suggestions for Future Research Areas

In this section, some future research suggestions are listed to fill gaps in sustainable manufacturing systems. Due to the importance of sustainable manufacturing systems, the number of studies in the related literature is expected to increase in the future. Some suggestions indicated by various authors in the related literature are presented in Table 1.

Table 1. Some suggestions for future research areas related to sustainable manufacturing

Suggestions
• Considering life cycle assessment and stochastic demand for sustainable manufacturing (Galal and Moneim 2015) • Considering uncertain conditions in dynamic, sustainable cellular manufacturing systems and innovative algorithms to compare the results (Ghodsi et al. 2015) • Establishing a social network model that connects firms (Albino et al. 2016) • Including more factors such as intercellular and intracellular movement costs and recycling option, developing more (re)configuration strategies for hybrid cellular (re)manufacturing systems and generating meta-heuristic approaches (Aljuneidi and Bulgak 2016) • Considering various social and environmental factors such as occupational diseases and job severity and including uncertain, stochastic, and possibilistic parameters (Niakan et al. 2016) • Considering dynamic modeling techniques in industrial symbiosis (Yazan et al. 2016) • Considering meta-heuristic approaches for real size problems and including multi-objectives simultaneously for sustainable manufacturing systems (Aljuneidi and Bulgak 2017) • Increasing resource sharing in eco-industrial parks and focusing on optimization approaches that also consider multi-period and resiliency factors (Tiu and Cruz 2017) • Considering models that also include renewable energies (Ramos et al. 2018)

Additionally, some studies should focus on developing and using a framework and system performance measures, including various sustainability concepts for providing sustainable manufacturing systems. Moreover, some approaches can be addressed together with Industry 4.0 technologies such as cloud manufacturing, big data, and machine learning due to having the potential to solve some problems in sustainable manufacturing systems.

5 Conclusion

New industries and firms are established because of the rapidly growing world population and its demand, and hence, more products enter the markets (Ahmad and Wong 2018). Manufacturing sector consumes a large amount of energy and natural and environmental resources to meet the growing needs (Ahmad and Wong 2018). Therefore, sustainable manufacturing systems that include economic, social, and environmental factors are becoming increasingly important. In this study, many studies from related literature are evaluated in detail after basic concepts related to sustainable manufacturing systems are defined. These studies are presented by grouping as industrial symbiosis, eco-industrial parks, and sustainable cellular manufacturing systems, and then some methods used in the related research areas are mentioned. In conclusion, some future suggestions for research areas shown in Table 1 and other future recommendations that may be helpful to fill the gaps in sustainable manufacturing systems are stated.

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Binary Satin Bowerbird Optimizer for the Set Covering Problem

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Abstract. The set covering problem (SCP) is one of the most studied NP-hard problems in the literature. To solve the SCP efficiently, this study considers a recently proposed bio-inspired meta-heuristic algorithm, called satin bowerbird optimizer (SBO). Since the SBO was first introduced for the global optimization problem, it works on a continuous solution space. To adapt the algorithm to the SCP, this study introduces a binary version of the SBO (BSBO). The BSBO simply converts real value coded solution vector of the SBO to binary coded solution vector by applying a binarization procedure. In addition to binarization procedures, a solution improving operator is employed in the BSBO to transform infeasible solutions into feasible solutions and remove redundant columns to reduce solution cost. The performance of the proposed BSBO is tested on a well-known benchmark problem set consists of 65 instances. With regards to the best-known solutions of the instances, efficient results are obtained by the proposed BSBO by finding near-optimal solutions. Furthermore, standard deviations of the runs demonstrate the robustness of the algorithm. As a consequence, it should be noted that the proposed solution approach is capable of finding efficient results for the SCP.

Keywords: Set covering problem · Satin bowerbird optimizer · Bio-inspired meta-heuristic algorithm

1 Introduction

The set covering problem (SCP) is one of the well-known combinatorial problems and simply defined as finding a subset of columns in a zero-one matrix such that they cover all the rows of the matrix at minimum cost. Since many real-life problems are modeled by the basis of the SCP, several exact and heuristic solution approaches have been introduced in this field (Caprara and Toth et al. 2000). However, exact solution approaches, such as branch-and-cut algorithm (Fisher and Kedia 1990), and branch-and-bound algorithm (Balas and Carrera 1996), are limited to solve small-sized problems in reasonable computational times because the SCP is NP-hard in the strong sense (Garey and Johnson 1979). Therefore, most of the researchers have been focused on developing a heuristic algorithm to find efficient results for the SCP.

Among the meta-heuristic algorithms, genetic algorithm (Beasley and Chu 1996), simulated annealing algorithm (Brusco and Jacobs et al. 1999), tabu search algorithm

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(Caserta 2007) are the most popular ones. The structures of these algorithms allow easy adaptation to SCP. On the other hand, many recent algorithms, which are first designed for solving global optimization problems, have been adapted to solve SCP. Ren and Feng et al. (2010) proposed an ant colony optimization. Naji-Azimi and Toth et al. (2010) used the electromagnetism meta-heuristic, which is integrated with a local search procedure. Sundar and Singh (2012) introduced an artificial bee colony algorithm based hybrid algorithm. Crawford and Sot et al. (2014) developed a binary coded firefly algorithm. Lu and Vasko (2015) assumed the teaching-learning based optimization algorithm. Lanza-Gutierrez and Crawford et al. (2017) proposed a binary cat swarm optimization algorithm and analyzed the effects of the binarization techniques on the algorithm performance.

With regards to the current literature on the SCP, this paper considers a recently proposed bio-inspired meta-heuristic algorithm to solve SCP, which is called satin bowerbird optimizer (SBO). The SBO was introduced by Moosavi and Bardsiri (2017) for the global optimization problems. Since the original version of the SBO works on the continuous solution space, the binary SBO (BSBO) is developed by integrating a binarization procedure to represent a solution for the SCP. In addition to the binarization step of the BSBO, a solution improving operator is operated to obtain efficient results for the considered problem. In this context, this study contributes to the literature by introducing the binary version of the SBO. Since the SBO is a recent meta-heuristic algorithm introduced for the global optimization problems, the algorithm has not been considered for the SCP to best of author's knowledge. Furthermore, the performance of the BSBO is tested on a well-known benchmark problem set, and its efficiency is demonstrated with statistical significance tests.

The rest of the paper is organized as follows. First, the SCP is defined, and its model formulation is given. Following the problem definition and model formulation, details of the SBO and proposed BSBO are introduced. Then, the computational results of the proposed algorithm are presented. Finally, conclusions with future research perspectives are given.

2 Problem Definition and Model Formulation

The SCP is a fundamental combinatorial problem and is shown to be NP-hard (Garey and Johnson 1979). The SCP has been known as a basic version of many real-life optimization problems, such as routing, location, distribution, scheduling, manufacturing, assignment, etc. (Ceria and Nobili 1998). The SCP can be simply defined as finding a set of solutions at the lowest possible cost to cover a set of needs (Soto and Crawford et al. 2018). In this context, the mathematical model of the SCP is formulated as follows.

Notations

I Set of rows to be covered, $I = \{1, 2, \ldots, m\}$
J Set of columns, $J = \{1, 2, \ldots, n\}$
a_{ij} Coverage matrix, and a_{ij} is equal to 1 if row i is covered by column j, $\forall i \in I$, $\forall j \in J$
c_j Cost of column j, $\forall j \in J$

Decision Variables

x_j Binary decision variable and equal to 1 if column i is part of the solution, $j, \forall j \in J$

With regards to notations and decision variables described above, the mathematical model of the SCP is formulated as follows.

$$Min\, z = \sum_{j \in J} c_j x_j \tag{1}$$

s.t.

$$\sum_{j \in J} a_{ij} x_j \geq 1 \quad \forall i \in I \tag{2}$$

$$x_j \in \{0, 1\} \qquad \forall i \in I \tag{3}$$

Equation (1) presents the objective function of the model, which aims to minimize the sum of the costs of the selected columns that cover all rows. Constraints (2) provide that each row is covered at least one column. Finally, the decision variables of the model are defined in constraints (3).

3 Satin Bowerbird Optimizer

The SBO is a recently proposed bio-inspired meta-heuristic algorithm introduced by (Moosavi and Bardsiri 2017) to estimate software development effort efficiently. Additionally, the original version of the SBO considered solving several real-life optimization problems, such as congestion management (Chintam and Daniel 2018), solid oxide fuel cell parameter estimation (El-Hay and El-Hameed et al. 2018), wind speed forecasting (Tian and Hao et al. 2018). The SBO takes its inspiration from the attraction of the male bowerbirds to the female bowerbirds for mating by constructing a bower. Similar to most of the bio-inspired meta-heuristic algorithms, the SBO employes a set of operators, such as initialization, fitness evaluation, new solution generation, mutation. Distinct from the existing approaches, the SBO uses elitism strategy and gives more weight to the elite individual while generating a new solution. Furthermore, a normal distribution based mutation operator is used in the algorithm instead of a uniform distribution. In this context, the main operators of the SBO are described as follows.

Initialization
The SBO starts with a randomly generated population consists of NB bowers. Let $\boldsymbol{X}_i = \left\{x_{i,1}, x_{i,2}, \ldots, x_{i,D}\right\}$ represents the i^{th} bower, where D is the problem size. Each bower is generated by using Eq. 4 where $i = 1, \ldots, NB$ and $k = 1, \ldots, D$. x_k^L and x_k^U are the lower and upper bounds of parameter k, respectively. Finally, $rand$ is a uniformly distributed random number.

$$x_{i,k} = x_k^L + rand\left(x_k^U - x_k^L\right) \tag{4}$$

Fitness Evaluation

The fitness of each bower is calculated by using Eq. 5 where $f(\boldsymbol{X}_i)$ is the cost function of bower i. Then the bowers are sorted based on their fitness value in descending order.

$$fit_i = \begin{cases} \frac{1}{1+f(\boldsymbol{X}_i)}, & f(\boldsymbol{X}_i) \geq 0 \\ 1 + |f(\boldsymbol{X}_i)|, & f(\boldsymbol{X}_i) < 0 \end{cases} \tag{5}$$

To prevent the experience of best bowerbird in population, elitism is applied for the population. To do this, the position of the best bower built by birds is identified as elite.

New Solution Generation

In each iteration, SBO starts to generate a new population by calculating the probability of the bowers to identify their attractiveness by using Eq. 6.

$$Prob_i = \frac{fit_i}{\sum_{n=1}^{NB} fit_n} \tag{6}$$

Following the probability calculation step, new changes at any bower are calculated by using the Eqs. (7) and (8).

$$x_{i,k}^{new} = x_{i,k}^{old} + \lambda_k \left(\left(\frac{x_{j,k} + x_{elite,k}}{2} \right) - x_{i,k}^{old} \right) \tag{7}$$

$$\lambda_k = \frac{\alpha}{1 + Prob_j} \tag{8}$$

In Eq. (7), $\boldsymbol{X}_{elite}$ is the elite bower of the current population, and $\boldsymbol{X}_j$ is the target bower, which is calculated by the roulette wheel selection procedure. Finally, λ_k is the attraction power in the goal bower, which is controlled by the greatest step size parameter α.

Mutation

The mutation procedure is carried out by applying random changes to the bowers with a certain probability, which is described as $P\_mutation$ in this study. The random changes on the bower are determined by Eq. 9 where $N(0, 1)$ is a standard normal distributed random number and σ is a proportion of space width which is calculated by using Eq. 10. The σ in Eq. 10 is controlled by parameter z, which is the percent of the difference between x_k^L and x_k^U.

$$x_{i,k}^{new} = x_{i,k}^{old} + (\sigma \times N(0, 1)) \tag{9}$$

$$\sigma = z \times \left(x_k^U - x_k^L \right) \tag{10}$$

Sorting and Selection

At the end of each iteration, the fitness values of newly generated bowers are evaluated. Then, the bowers from the old population and newly generated bowers are combined and re-sorted concerning their fitness. The new population is formed by removing the last NB bowers from the sorted population. Finally, the elite is updated if the first bower in the new population is fitter than the existing elite.

4 Proposed Algorithm

The proposed BSBO considers the main operators of the original version of the SBO and converts the continuous solution vectors to a binary solution vector while evaluating the fitness of bowers in the algorithm. Furthermore, a solution improving operator is employed in the algorithm to transform infeasible solutions into feasible solutions and remove redundant columns to reduce solution cost. Algorithm 1 presents the main steps of the proposed BSBO, where the details of discretization and solution improving operators of the algorithm are given in the following sub-sections.

Algorithm 1. Main steps of the BSBO

```
Initialization
Fitness evaluation and sorting
Identify the best bower as the elite
Repeat
    Probability calculation
    For Each Bower
        Determination of new changes
        Mutation
    End For
    Binarization of continuous solution vector
    Solution improvement
    Evaluation of bowers
    Re-sorting and selection
    Update elite bower
Until the termination criterion is satisfied
```

4.1 Binarization

One of the critical issue for the continuous meta-heuristic algorithms while solving the SCP is the discretization procedure to represent a solution for the problem. In this context, there exist several techniques to convert continuous solution to binary solution, which can be classified into two main groups (Crawford and Soto et al. 2017): (i) two-step binarization techniques, (ii) continuous-binary operator transformation techniques. In the proposed BSBO, the two-step binarization techniques are taken into account to convert continuous solutions to binary solutions since the continuous-binary operator transformation techniques require to redefine the operators of the algorithm operators.

Distinct from the continuous-binary operator transformation, the two-steps binarization techniques work with the continuous operators of the algorithms. In the first step of the binarization operator, real value coded elements of the solution vector are converted to a probability value to identify the position of the element by using a transfer function. In this context, two types of transfer functions are used in the literature: S-shape and V-shape. Following the transfer function, the second step of the two-steps binarization techniques transforms the elements of the solution vector into a binary vector by following a binarization rule.

The proposed BSBO starts with a randomly generated binary coded population, where each bower of the population provides a feasible solution for the SCP. Following the initialization step, new positions of the bowers are determined according to the new solution generation procedure of the SBO in each iteration. Since the new position generating mechanism of the original SBO produces continuous variables, a two-step binarization technique is employed to transform the continuous solution vector of the bowers into binary coded vectors. In the first step of the binarization, a V-shape function given in Eq. 11 is taken into account.

$$T\left(x_{ik}^{new}\right) = \left| \frac{x_{ik}^{new}}{\sqrt{1 + \left(x_{ik}^{new}\right)^2}} \right| \tag{11}$$

$T\left(x_{ik}^{new}\right)$ in Eq. 11 is the probability of changing the position of k of the i^{th} bower.

In the second step of the binarization step, positions of the bowers are converted to binary values by applying the following rule:

$$x_{ik}^{new} = \begin{cases} complement\left(x_{ik}^{old}\right) & if\ T\left(x_{ik}^{new}\right) \geq rand(0,1) \\ 0 & otherwise \end{cases} \tag{12}$$

4.2 Solution Improving Operator

The binarization operator of the proposed algorithm described in the previous sub-section provides binary solution vectors for the SCP corresponding to their continuous solution vector. However, a binary solution vector of newly generated bower does not always represent a feasible solution for the SCP in case there exists at least one uncovered row in the solution. On the other hand, a solution, which provides a feasible solution for the SCP, can include redundant columns. A redundant column can be defined as the column which does not affect the feasibility of the solution when it is deleted in the solution. Therefore, the solution improving operator introduced by (Beasley and Chu 1996) is carried out to transform infeasible solutions into feasible solutions and remove redundant columns to reduce solution cost after binarization step.

In the solution repair mechanism, first, a ratio for each column (φ_j) is calculated by using the Eq. (13). The unfeasible solutions are repaired by covering the columns of the solutions that had the lower φ_j.

$$\varphi_j = \frac{c_j}{number\ of\ uncovered\ rows\ which\ column\ j\ covers} \tag{13}$$

After the feasibility of the solution is guaranteed, redundant columns are removed from the solution. The pseudo code of the solution improving operator is given in Algorithm (2).

Algorithm 2. Pseudo code of the solution improving operator

```
α_i  The set of columns that cover row i, ∀i ∈ I
β_j  The set of rows that covered by column j, ∀j ∈ J
S  The set of columns in a solution
U  The set of uncovered rows
ω_i  The number of columns that cover row i, ∀i ∈ I
For Each i in U //in increasing order of i
    Find the first column j in increasing order of j ∈ α_i that minimizes φ_j
    Add j to S and set ω_i = ω_i + 1, ∀i ∈ β_j
    U = U − β_j
Next
For Each j in S //in decreasing order of j
    If ω_i ≥ 2 Then
        S = S − j
        ω_i = ω_i − 1, ∀i ∈ β_j
    End If
Next
Return S
```

5 Computational Results

In computational studies, the performance of the proposed BSBO is tested on a well-known SCP benchmark problem set available from OR-Library introduced by (Beasley 1990). The benchmark problem set consists of 65 different sized instances, which are divided into 11 groups. Each group contains 5 or 10 instances. Table 1 summarizes the characteristics of these groups, where the last column labeled "Density" shows the percentage of non-zero entries in the matrix of each instance.

All experiments are performed on a workstation equipped with a 3.4 GHz Xeon E5-2643v3 and 64 GB RAM. For the computations, the parameters of the BSBO are set to the values given by, Moosavi and Bardsiri (2017) such as $NB = 50$, $\alpha = 0.94$, $z = 0.02$, and $P\_mutation = 0.05$. Additionally, each run is terminated at the end of 1000 iterations. With regards to these parameter settings, 30 independent runs are performed for each problem. Table 2 summarizes the results of the BSBO based on the problem groups, where detailed results of the computations are given in the Appendix from Tables A.1, A.2, A.3, A.4, A.5, A.6, A.7, A.8, A.9, A.10 and A.11.

Each row in Table 2 presents the average results of the problem sets, where the columns labeled "Best" and "Mean" are the best and average results of the runs, respectively. The quality of a solution is evaluated by the gaps between the BSBO result and best-known solution in the literature which is given in the column labeled "OPT/BKS." $Gap_B\%$ indicates the gap between the best solution of BSBO and best-known solution, while $Gap_M\%$ is used to show the gap between the average result of BSBO and best-known solution. It should be noted that some of the best-known solutions are the optimum solutions. Finally, the last two columns show the average computational time of 30 runs and the standard deviation of the results, respectively.

Table 1. Details of the test instances

Instance set	Number of instance	Number of rows (m)	Number of columns (n)	Cost range	Density (%)
4	10	200	1000	[1, 100]	2
5	10	200	2000	[1, 100]	2
6	5	200	1000	[1, 100]	5
A	5	300	3000	[1, 100]	2
B	5	300	3000	[1, 100]	5
C	5	400	4000	[1, 100]	2
D	5	400	4000	[1, 100]	5
NRE	5	500	5000	[1, 100]	10
NRF	5	500	5000	[1, 100]	20
NRG	5	1000	10,000	[1, 100]	2
NRH	5	1000	10,000	[1, 100]	5

With regards to the best-found solutions of the BSBO, gaps between the BSBO and best-known solutions are close to zero. In particular, $Gap_B\%$ varies between 0–1% for the first seven problem sets. For the larger problem sets (such as NRE, NRF, NRG, and NRH), the gaps slightly increase with up to 4.13%. Similar to the best-found solutions of the BSBO, gaps between the average results of the BSBO and best-known solutions are quite low.

On the other hand, computational times of the experiments show that most of the results are obtained in less than 30 s. For only the last two problem sets, computational times of the BSBO are more than 30 s. Finally, the standard deviations of the results demonstrate the robustness of the proposed algorithm, where most of the results are obtained with small deviations. As a result of the computational studies, it should be expressed that the proposed BSBO is capable of obtaining efficient results for the SCP by finding near-optimal solutions.

6 Conclusions

In this paper, a binary version of the recently introduced satin bowerbird algorithm is proposed to solve the set covering problem. The BSBO simply considers the original procedures of the SBO for new solution generation and converts real value coded solution vector to a binary coded solution vector by applying a binarization procedure. Furthermore, a solution improving operator is employed in the algorithm to transform infeasible solutions into feasible solutions and remove redundant columns to reduce solution cost. In computational studies, the proposed BSBO is tested on a well-known benchmark problem set consisting of 65 different-sized instances. Results of the algorithm are compared to best-known solutions of the instances, where most of them are reported as optimal solutions in the literature. Comparisons between the BSBO solutions and best-known

Table 2. Summary of the BSBO results on SCP instances

Instance Set	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time (s)	Std.
4	510.0	510.0	0.00	515.8	1.10	5.6	36.2
5	257.2	257.6	0.16	261.0	1.42	10.2	11.1
6	144.2	144.6	0.29	148.9	3.12	6.1	9.0
A	241.4	241.8	0.16	246.2	1.93	14.7	12.3
B	75.2	75.2	0.00	77.8	3.39	12.9	5.7
C	224.6	225.0	0.17	229.4	2.11	16.9	11.3
D	64.2	64.4	0.32	67.1	4.30	14.6	3.4
NRE	28.4	28.8	1.36	30.1	5.56	16.7	1.1
NRF	14.0	14.4	2.76	14.9	6.32	16.2	0.2
NRG	166.4	170.6	2.45	176.2	5.56	32.0	15.2
NRH	59.6	62.2	4.13	65.6	9.12	32.2	3.1

solutions show that the proposed algorithm is capable of finding near-optimal solutions for most of the instances. Furthermore, almost all best-found results of the runs are equal to best-known solutions of the instances. As a result of the computational studies, it can be expressed that the proposed binary version of the SBO can be efficiently applied for the set covering problem and its variations.

As future work, this study can be extended by integrating efficient local search procedures to improve the solution quality of the BSBO. Additionally, the effects of different binarization techniques can be analyzed. On the other hand, the proposed approach can be compared to the existing solution methodologies proposed for the SCPs. Finally, the performance of the proposed solution approach can be tested on other SCP variants.

Appendix

Table A1. BSBO results in SCP instances (Set 4)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
4.1	429	429	0.00	431.7	0.63	5.7	5.6
4.2	512	512	0.00	519.5	1.44	5.4	88.0
4.3	516	516	0.00	522.7	1.28	5.9	52.2
4.4	494	494	0.00	498.3	0.86	5.7	18.0
4.5	512	512	0.00	517.3	1.02	5.4	49.5
4.6	560	560	0.00	564.5	0.80	5.4	18.0
4.7	430	430	0.00	433.6	0.83	5.4	7.9
4.8	492	492	0.00	496.6	0.93	5.3	18.9
4.9	641	641	0.00	651.9	1.67	5.4	56.5
4.10	514	514	0.00	521.8	1.49	5.9	47.6
Average	510.0	510.0	0.00	515.8	1.10	5.6	36.2

Table A2. BSBO results in SCP instances (Set 5)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
5.1	253	254	0.39	258.4	2.09	10.1	15.0
5.2	302	303	0.33	311.6	3.08	9.9	27.6
5.3	226	228	0.88	229.2	1.40	10.3	2.2
5.4	242	242	0.00	244.1	0.86	9.8	8.3
5.5	211	211	0.00	212.5	0.71	9.7	3.4
5.6	213	213	0.00	216.6	1.66	9.9	18.2
5.7	293	293	0.00	296.4	1.15	10.2	6.1
5.8	288	288	0.00	292.5	1.54	11.1	17.0
5.9	279	279	0.00	280.5	0.53	10.1	5.3
5.10	265	265	0.00	268.3	1.23	11.0	8.0
Average	257.2	257.6	0.16	261.0	1.42	10.2	11.1

Table A3. BSBO results in SCP instances (Set 6)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
6.1	138	140	1.43	143.6	3.90	6.5	8.7
6.2	146	146	0.00	150.5	2.99	5.9	9.2
6.3	145	145	0.00	149.5	3.01	6.4	7.3
6.4	131	131	0.00	133.2	1.65	5.0	3.4
6.5	161	161	0.00	167.8	4.05	6.7	16.6
Average	144.2	144.6	0.29	148.9	3.12	6.1	9.0

Table A4. BSBO results in SCP instances (Set A)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
A.1	253	254	0.39	257.3	1.67	15.2	6.8
A.2	252	252	0.00	259.1	2.74	15.0	21.0
A.3	232	233	0.43	236.9	2.07	14.7	10.5
A.4	234	234	0.00	239.6	2.34	14.5	20.9
A.5	236	236	0.00	238.0	0.84	14.1	2.1
Average	241.4	241.8	0.16	246.2	1.93	14.7	12.3

Table A5. BSBO results in SCP instances (Set B)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
B.1	69	69	0.00	72.5	4.83	12.9	7.2
B.2	76	76	0.00	79.1	3.92	13.0	7.8
B.3	80	80	0.00	82.0	2.44	12.9	3.1
B.4	79	79	0.00	82.4	4.13	12.9	6.9
B.5	72	72	0.00	73.2	1.64	13.0	3.7
Average	75.2	75.2	0.00	77.8	3.39	12.9	5.7

Table A6. BSBO results in SCP instances (Set C)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
C.1	227	229	0.87	231.8	2.07	16.5	4.8
C.2	219	219	0.00	224.6	2.49	16.9	17.3
C.3	243	243	0.00	247.9	1.98	18.9	10.9
C.4	219	219	0.00	224.3	2.36	16.2	13.3
C.5	215	215	0.00	218.6	1.65	16.2	10.0
Average	224.6	225.0	0.17	229.4	2.11	16.9	11.3

Table A7. BSBO results in SCP instances (Set D)

Instance	OPT/BKS	Best	Gap_B%	Mean	Gap_M%	Time	Std.
D.1	60	60	0.00	62.6	4.15	13.8	4.4
D.2	66	66	0.00	68.2	3.23	15.0	3.2
D.3	72	72	0.00	75.2	4.26	15.6	2.5
D.4	62	63	1.59	65.4	5.20	14.3	2.9
D.5	61	61	0.00	64.0	4.69	14.4	4.0
Average	64.2	64.4	0.32	67.1	4.30	14.6	3.4

Table A8. BSBO results in SCP instances (Set NRE)

Instance	OPT/BKS	Best	Gap_B%	Mean	Gap_M%	Time	Std.
NRE.1	29	29	0.00	29.9	3.01	16.9	1.3
NRE.2	30	31	3.23	32.2	6.83	15.9	0.5
NRE.3	27	28	3.57	29.4	8.16	17.3	1.5
NRE.4	28	28	0.00	29.9	6.35	16.3	0.9
NRE.5	28	28	0.00	29.0	3.45	17.3	1.4
Average	28.4	28.8	1.36	30.1	5.56	16.7	1.1

Table A9. BSBO results in SCP instances (Set NRF)

Instance	OPT/BKS	Best	Gap_B%	Mean	Gap_M%	Time	Std.
NRF.1	14	14	0.00	14.7	4.76	16.5	0.2
NRF.2	15	15	0.00	15.4	2.60	15.9	0.2
NRF.3	14	15	6.67	15.4	9.09	16.3	0.2
NRF.4	14	14	0.00	14.9	6.04	16.6	0.1
NRF.5	13	14	7.14	14.3	9.09	15.8	0.2
Average	14.0	14.4	2.76	14.9	6.32	16.2	0.2

Table A10. BSBO results in SCP instances (Set NRG)

Instance	OPT/BKS	Best	Gap_B%	Mean	Gap_M%	Time	Std.
NRG.1	176	181	2.76	186.8	5.78	33.3	18.8
NRG.2	154	157	1.91	163.5	5.81	31.4	17.9
NRG.3	166	170	2.35	174.8	5.03	31.5	10.4
NRG.4	168	172	2.33	177.9	5.56	32.1	11.7
NRG.5	168	173	2.89	178.0	5.62	31.8	17.2
Average	166.4	170.6	2.45	176.2	5.56	32.0	15.2

Table A11. BSBO results in SCP instances (Set NRH)

Instance	OPT/BKS	Best	$Gap_B\%$	Mean	$Gap_M\%$	Time	Std.
NRH.1	63	66	4.55	69.3	9.09	32.4	4.2
NRH.2	63	66	4.55	69.3	9.09	32.0	3.7
NRH.3	59	62	4.84	65.4	9.79	32.1	2.5
NRH.4	58	61	4.92	63.3	8.37	32.4	1.9
NRH.5	55	56	1.79	60.6	9.24	32.3	3.1
Average	59.6	62.2	4.13	65.6	9.12	32.2	3.1

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Crew Constrained Home Health Care Routing Problem with Time Windows and Synchronized Visits

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Abstract. Population aging, rise in the prevalence of chronic diseases worldwide, and growing health care costs have substantially increased the demand for home health care (HHC) in recent years. To gain a competitive advantage in the market and lower public expenditure, HHC service providers and governmental institutions mainly focus on increasing service quality while decreasing their costs. These objectives have resulted in various challenging optimization problems that have been widely studied in the past few years, including routing and scheduling problems. In this paper, we study an HHC routing and scheduling problem with time windows, where service is provided to patients requesting different types of care using a limited crew. We first provide the mixed integer programming formulation of the problem. Then, we perform a computational study to investigate the benefits of allowing synchronized visits to patients. Our results show that synchronized visits guarantee HCC service to all patients in some instances which are otherwise infeasible, and may reduce the total travel distance in other cases.

Keywords: Home health care · Synchronization · Vehicle routing problem

1 Introduction

The global increase of chronic diseases, population aging, and continuous changes in the health care systems are all implications of the significant increase in demand for home health care (HHC) services. Given a choice between care in an institution or at home, most people would prefer to stay in their own home (World Health Organization 2011). Older people (aged 65 or over) constituted 19.2% of the total population in the EU-28 in 2016, which indicates a 2.4% increase in the last decade. This increasing trend is projected to continue and reach 30% by the year 2080 (EUROSTAT 2015). The population of Americans aged over 65 is projected to more than double from 40.2 million in 2010 to 88.5 million in 2050 (Vincent and Velkoff 2010). Health spending accounts for nearly 10% of GDP in the European Union (OECD 2016), of which up to 5% is spent on HHC services (Genet et al. 2012). While the general view among Europeans is that health care services should be provided and controlled by the governments, the integration of HHC services into governmental institutions is a long-term process, so

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private companies have been filling the gap. In 2014, more than 4.9 million patients received service from home health agencies in the United States, and around 8% of the registered long-term HHC service providers had for-profit ownership (Harris-Kojetin et al. 2013).

The aim to reduce public expenditures without sacrificing from the service quality and to gain competitive advantage have made HHC routing and scheduling problems popular in the operations research (OR) literature in recent years. To lower costs, effective planning of HHC operations is a necessity. Optimizing the assignment of personnel by planning their travel routes and arrival time at each patient, and scheduling their working times are some of the challenging problems addressed by researchers within the HHC context. Although HHC routing and scheduling problems are relatively new, they are closely related to well-studied problems such as technician routing, logistics management, workforce routing, and scheduling problems. A comprehensive review of recent work on HHC routing and scheduling can be found in Fikar and Hirsch (2017).

In this paper, we extend the Crew Constrained Home Care Routing Problem with Time Windows (CC-HCRPTW) introduced by Tozlu et al. (2015). In this problem, limited HHC crew provide different types of care to patients within specific time windows. The HHC services offered to patients can be categorized into two groups. The first group includes services such as nursing, vaccination, blood pressure measurement, blood sugar measurement, insulin injections, etc., which are provided by a nurse. The second group includes assisting older people, home life aids, bathing, etc. An aide provides these services. Some of the patients need both of these services; hence, they should be served by both a nurse and an aide. It is also possible that the service required by a patient must be provided by two care providers simultaneously, e.g., when the patient is unable to move and needs a bath.

Some patients only require a single type of care which can be provided by a vehicle which rides only a nurse (or aide). A vehicle carrying both a nurse and an aide would be able to provide service to any patient type. The requirement of different types of services by a patient closely relates the problem at hand to the technician routing problem introduced by Dutot et al. (2007) where technicians with different skill levels are assigned to teams to meet the skill requirements of the interventions in the telecommunication sector. Although the assignment, scheduling and routing tasks in our problem are highly complex, which makes it a challenging combinatorial optimization problem, HHC service providers usually manage these complex tasks manually, which results in potentially sub-optimal solutions and high organizational efforts (Wirnitzer et al. 2016).

In this study, we introduce CC-HCRPTW with Synchronization (CC-HCRPTWSync) and highlight the advantages of allowing synchronized visits to patients. To the best of our knowledge, this particular vehicle routing problem (VRP) variant where synchronized visits are allowed has not been studied in the literature.

Bredström and Rönnqvist (2008) is the first study that addressed HHC routing and scheduling problem with time windows considering synchronization constraints. In this paper, the authors proposed a mathematical formulation for a real-world application considering minimization of total travel time, maximization of the sum of preferences of customers and minimization of the difference between the longest and the shortest service times among the vehicles to optimize the workload balance. A local branching approach was proposed to solve this multi-objective optimization problem. The authors also proposed a branch-and-price algorithm and constructed benchmark instances, of which 44 out of 60 were solved to optimality.

A generalization of VRP with synchronization was presented by Dohn et al. (2011), which is referred to as VRP with Time Windows and Temporal Dependencies. The authors study more general requirements such as maximum and minimum overlap and gap between the starting and ending time of visits in addition to standard synchronization. The objective function minimizes the total transportation costs. A branch-and-cut-and-price algorithm was proposed and tested on instances derived from the well-known benchmark instances of Solomon (1987) for VRPTW.

Our problem differs from those in the literature as we consider a heterogeneous fleet where the number of crew available is limited.

2 Problem Description and Formulation

Given a central office (depot) and a set of patients, the patients are classified as type 1, type 2 or type 3, where the type 1 patients need to be served by a nurse, type 2 patients by an aide and type 3 patients by both. The service time for a patient depends on the type of the patient and should start within the assigned time window. In other words, the time window restricts the earliest and latest time to start the service at that patient. The time-window constraint does not only provide a better quality service but also makes sure that time-sensitive HHC tasks such as insulin injection, blood taking, provision of medication are performed on time (Fikar and Hirsch 2017).

Based on the type of personnel it carries, a vehicle can also be classified as type 1, type 2, or type 3. A type-1, type-2, or type-3 vehicle carries a nurse, a home health aide, or both, respectively. As mentioned earlier, a type-3 vehicle can provide service to all types of patients, whereas a type-1 (type-2) vehicle can only serve type-1 (type-2) patients. Each vehicle starts its tour at the central depot, serves a set of patients and returns to the central depot before the end of the shift. We assume that the numbers of nurses and aides available are limited, i.e., we have two types of limited resources.

The aim is to minimize the total distance traveled while providing HHC to all the patients with an appropriate type of vehicle within the predefined time window. The distance minimization objective is used because the vehicles are generally provided by a third-party company and are charged by the total trip distance.

2.1 Mathematical Formulation

We begin by introducing the necessary notation. Let $V = \{1, \ldots, n\}$ denote the set of patients, and vertices 0 and $n+1$ denote the depot representing the start and end of each vehicle route, respectively. The sets including the depot are denoted as $V_0 = V \cup \{0\}$ and $V_{n+1} = V \cup \{n+1\}$ and the set including all the nodes is denoted as $V_{0,n+1} = V \cup \{0\} \cup \{n+1\}$. Thus, CC-HCRPTW can be defined on a complete directed graph $G = (V_{0,n+1}, A)$ with a set of arcs $A = \{(i, j) | i, j \in V_{0,n+1}, i \neq j\}$. Each arc $(i, j) \in A$ is associated with a distance d_{ij} and a travel time t_{ij}. A patient $i \in V$ is of type r_i, where $r_i \in \{1, 2, 3\}$.

Each patient is assigned a service time s_i and a time window $[e_i, l_i]$. The former indicates the amount of time units that service will be provided to the patient i, while the latter states that the care at patient i can start as early as e_i and as late as l_i. The time window for the depot is denoted by $[e_0, l_0]$, where e_0 is the start time of service from the depot and l_0 is the restriction on the latest time to arrive at the depot at the end of the shift. The set of patients of type r is denoted as T_r and $T_{r,0} = T_r \cup \{0\}$. If a nurse (aide) is assigned to a vehicle, it is called a type-1 (type-2) vehicle. A vehicle carrying both a nurse and an aide is referred to as a type-3 vehicle.

The binary decision variable x_{ijr} takes the value of 1 if arc (i, j) is traversed by a vehicle of type r, and 0 otherwise. The decision variable q_i keeps track of the arrival time to vertex i. The number of available nurses and aides are h_1 and h_2, respectively, and referred to as the crew (resource) limits. Thus, following Tozlu et al. (2015), the mixed integer program of the CC-HCRPTW can be formulated as follows:

$$\text{Minimize} \sum_{i\in V_{0,n+1}} \sum_{j\in V_{n+1}, j\neq i} \sum_{r\in R} d_{ij} x_{ijr} \tag{1}$$

subject to

$$\sum_{i\in V_0, i\neq j} x_{ij1} + \sum_{i\in V_0, i\neq j} x_{ij3} = 1, \forall j \in T_{1,0} \tag{2}$$

$$\sum_{i\in V_0, i\neq j} x_{ij2} + \sum_{i\in V_0, i\neq j} x_{ij3} = 1, \forall j \in T_{2,0} \tag{3}$$

$$\sum_{i\in V_0, i\neq j} x_{ij3} = 1, \forall j \in T_{3,0} \tag{4}$$

$$\sum_{i\in V_0, i\neq j} x_{ijr} = \sum_{i\in V_{n+1}, i\neq j} x_{ijr}, \forall j \in V, \forall r \in R \tag{5}$$

$$\begin{aligned} q_i + x_{ijr}\big(t_{ij} + s_i\big) - L\big(1 - x_{ijr}\big) \le q_j, \\ \forall i \in V_0, \forall j \in V_{n+1}, j \neq i, \forall r \in R \end{aligned} \tag{6}$$

$$e_j \le q_j \le l_j, \forall j \in V_{0,n+1} \tag{7}$$

$$\sum_{j\in V_{n+1}} x_{0j1} + \sum_{j\in V_{n+1}} x_{0j3} \le h_1 \tag{8}$$

$$\sum_{j\in V_{n+1}} x_{0j2} + \sum_{j\in V_{n+1}} x_{0j3} \le h_2 \tag{9}$$

$$x_{ijr} \in \{0, 1\}, \forall i \in V_0, \forall j \in V_{n+1}, j \neq i, \forall r \in R \tag{10}$$

$$q_i \ge 0, \forall i \in V_{0,n+1} \tag{11}$$

The objective function (1) minimizes the total distance traveled. Constraints (2)–(3) ensure that the care is provided to the patients exactly once by a vehicle carrying the appropriate personnel. Constraints (2) make sure that type-1 patients are served by a type-1 or type-3 vehicle, whereas Constraints (3) guarantee the service to type-2 patients by a type-2 or type-3 vehicle. Constraints (4) enforce that only type-3 vehicles provide care to type-3 patients. Flow conservation is ensured by Constraints (5) while time feasibility for arcs leaving patients or the depot is satisfied by Constraints (6). Constraint (7) make sure that the time windows of the patients and depot are not violated. Sub-tours are eliminated by maintaining the schedule feasibility concerning time considerations through Constraints (6) and (7). Constraints (8) and (9) guarantee that the total crew assigned to the vehicles does not exceed the available number of nurses and aides, respectively. Binary decision variables are defined in Constraints (10), and the non-negativity restriction on the arrival times is imposed by Constraints (11).

The model can be easily modified to handle other relevant objective functions, such as minimizing the total number of health care personnel (12) or the total number of vehicles (14) as follows:

$$min \sum_{i \in V_{n+1}} \left(x_{0j1} + x_{0j2} + 2x_{oj3} \right) \tag{12}$$

$$min \sum_{i \in V_{n+1}} \sum_{r \in R} x_{ojr} \tag{13}$$

3 CC-HCRPTW with Synchronization

It is possible to use limited resources more efficiently by serving a type-3 patient by type-1 and type-2 vehicles simultaneously. Essentially, by allowing synchronization, we are enlarging the feasible region. A similar idea was suggested by Labadie et al. (2014). A type-3 patient who needs both a nurse and an aide can be served by a type-1 and type-2 vehicles simultaneously. Furthermore, with an easy but eloquent modification to our model, synchronized visits can be imposed by replacing Constraints (4) with the following constraints:

$$\sum_{i \in V_0, i \neq j} x_{ij3} + \frac{1}{2} \left(\sum_{i \in V_0, i \neq j} x_{ij1} + \sum_{i \in V_0, i \neq j} x_{ij2} \right) = 1, \forall j \in T_{3,0} \tag{14}$$

$$\sum_{i \in V_0, i \neq j} x_{ij1} \leq 1, \forall j \in T_{3,0} \tag{15}$$

$$\sum_{i \in V_0, i \neq j} x_{ij2} \leq 1, \forall j \in T_{3,0} \tag{16}$$

Constraints (14) makes sure that a type-3 patient is served either by a single type-3 vehicle or by a pair of type-1 and type-2 vehicles visiting her simultaneously. Constraints (15) and (16) guarantee that only one vehicle of type 1 and type 2 visits a type-3 patient.

Figure 1 highlights how allowing synchronized visits can reduce the number of vehicles and crew needed to provide service to a set of patients. Patients 1 and 2 are of type-1 and need to be served by a nurse, while patients 4 and 5 are type-2 and need an aide. Patient 3 is a type-3 patient who requires both a nurse and an aide. The solution

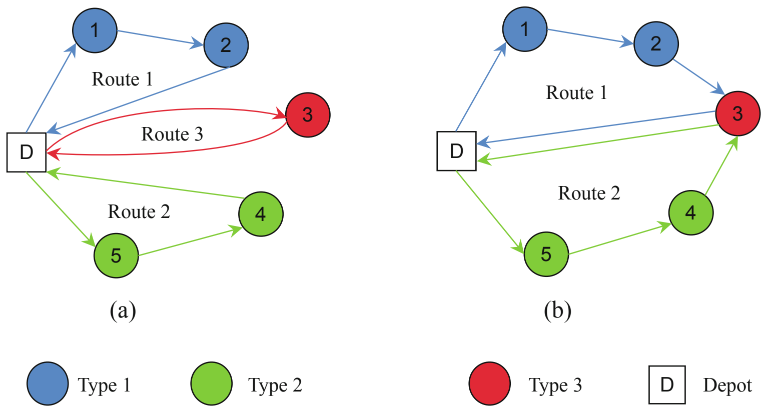

Fig. 1. An illustrative example of CC-HCRPTW and CC-HCRPTWSync: (a) synchronized visits are not allowed, (b) synchronized visits are allowed

in Fig. 1(a), where synchronized visits are not allowed, shows that a type-1 vehicle provides service to patients 1 and 2 through Route 1, a type-2 vehicle serves patients 4 and 5 through Route 2, and a type-3 vehicle serves patient 3 through Route 3. In total, three vehicles accompanied by two nurses and two aides are required to provide service to the patients. In Fig. 1(b), where synchronized visits are allowed, a type-1 vehicle serves patients 1 and 2 while a type-2 vehicle serves patients 4 and 5, and both vehicles simultaneously provide service to patient 3 before returning to the depot at the end of their routes. Note that the service at a synchronized patient begins within its time windows when both resources are present, meaning that one of the vehicle types may have to wait for the other to arrive to begin the service. One can notice that the number of vehicles needed to serve all the patients is reduced by one when synchronization is allowed. Moreover, only one nurse and one aide are needed, which shows a more effective utilization of available resources. CC-HCRPTW is infeasible for any instance where the available resources (h_1, h_2) are less than (2,2) (i.e. (1,1), (1,2) and (2,1) cases) whereas the corresponding CC-HCRPTWSync versions are all feasible. This also shows the benefit of allowing syncronized visits to patients under tight resources.

4 Experimental Design

4.1 Instance Generation

To show the advantages of synchronization, we selected a subset of Solomon 25-node instances, namely R201, RC101, RC105, adapted them to our problem. We used the same coordinates and time windows as in Solomon data and ignored the demand information. To make the data compliant to our problem, we needed to assign each customer a type and a corresponding service time. The types are assigned such that the probability of synchronized visits is relatively high. Each instance was expanded into five groups, namely G1, G2, G3, G4, G5, in which the percentage of patients with care types 1, 2 and 3 differs as given in Table 1.

Table 1. Percentage of each care type in instance groups

Group	Type of care		
	1	2	3
G1	60%	32%	8%
G2	48%	36%	16%
G3	48%	28%	24%
G4	32%	28%	40%
G5	28%	24%	48%

In the first group of instances, 60% of the patients require type-1 care only, 32% require type-2 care only, and the remaining 8% require both type-1 and type-2 cares. Similarly, the information for the other groups is as given in Table 1. The service times of type-1, type-2, and type-3 patients are 10, 40, and 45 min, respectively.

Determining the number of available nurses and aides is a challenging problem. On the one hand, if the crew constraints are too tight, we may end up with infeasible instances. On the other hand, if these constraints are too loose, the instances may no longer become challenging.

To determine meaningful crew sizes, we first solved the HCRPTW model by minimizing the total amount of each resource separately as well as minimizing the sum of resources by using CPLEX solver. Minimizing the sum of the resources provides us a "lower bound" on the number of resources. The "upper bound" is obtained by minimizing the total traveled distance. For each instance, we then determine four different crew settings following these lower and upper bounds for the number of nurses and aides. In the first setting, the crew size h_1 and h_2 are set to the optimal resources obtained from minimizing the total distance traveled. For the second setting, the resource limits are set to the optimal resource values obtained from minimizing the sum of h_1 and h_2. For the remaining two settings, the resource limit is tight in one resource type and loose in the other. Thus, the total number of instances we generated is $3 \times 5 \times 4 = 60$.

4.2 Experimental Environment and Parameter Settings

The MILP was coded in Java and solved using IBM ILOG CPLEX Version 12.6.2. For all experiments, we used a 64-bit server equipped with Intel Xeon E5-2640 v3 2.6 GHz processor running on a Windows 7 Professional virtual machine with 16 GB RAM.

5 Results

In this section, we compare the results for CC-HCRPTW with those obtained for CC-HCRPTWSync. Note that the objective function value (ofv) of CC-HCRPTW is an upper bound for the ofv of CC-HCRPTWSync. When the crew sizes are limited, allowing synchronized visits can improve the optimal ofv of CC-HCRPTW, and in some cases, an infeasible instance with a specific crew configuration can become feasible. Table 2 shows the results for 10 selected instances among 60. The computation times are in seconds. We should note that in this paper, we only present the results of problems that benefit from the utilization of synchronized visits. In all of our instances, either a single patient or at most two type-3 patients are visited simultaneously by a type-1 and type-2 vehicle. For larger instances, the probability of having more patients visited simultaneously may increase.

Table 2. Advantages of allowing synchronized visits

Instance	h1	h2	No sync			Sync			
			Status	ofv	Time	Status	ofv	Time	imp. (%)
P1	2	2	Optimal	71781	8.59	Optimal	67284	18.76	6.68
P2	4	7	Optimal	80357	0.15	Optimal	70937	0.11	13.28
P3	6	6	Optimal	82493	0.14	Optimal	78171	0.31	5.53
P4	7	7	Optimal	77754	7.00	Optimal	77280	30.50	0.61
P5	7	8	Optimal	75483	0.55	Optimal	75343	0.81	0.19
P6	5	6	Infeasible			Optimal	72380	3.21	
P7	6	7	Infeasible			Optimal	71026	0.20	
P8	6	6	Infeasible			Optimal	88228	0.92	
P9	5	5	Infeasible			Optimal	69024	184.93	
P10	5	6	Infeasible			Optimal	73099	520.79	

In instances P1–P5, we observe that the total distance traveled can be reduced by up to 13.28%. On the other hand, instances P6–P10, which are infeasible in the case of CC-HCRPTW become feasible when synchronized visits are allowed. Note that an instance may be feasible for different sets of crew sizes in CC-HCRPTWSync whereas all the corresponding CC-HCRPTW cases are infeasible because synchronized visits are not allowed. One such example is instance P8 for which CC-HCRPTW is infeasible for resource levels (5,6), (6,6) and (6,7) where the first number indicates the number of nurses and the second the number of aides. This shows that allowing synchronized visits can enable the service provider company to successfully offer service to patients, especially when the number of nurses and aides are limited or low on a specific day.

6 Discussion and Conclusion

In this study, we first discussed the Crew Constrained Home Care Routing Problem with Time Windows and formulated its mathematical programming model. Next, we extended this problem by allowing synchronized visits to the patients and presented its mathematical programming formulation.

For this problem, we created challenging instances involving 25 patients by solving the HCRPTW model with different objectives to determine different resource levels.

We performed computational tests to investigate the benefit of allowing synchronized visits. Our results revealed improvements in 10 instances out of 60. In five instances that are infeasible to CC-HCRPTW, feasible optimal solutions are obtained by allowing synchronized visits. In the remaining five instances, CC-HCRPTWSync improves the objective function value of that of CC-HCRPTW. It should note that the advantages of synchronized visits can be more significant in real-world large size problems, which would offer more opportunity to visit patients simultaneously.

Further research on this topic may focus on performing computational experiments on an extended set of data. Since the problem is intractable for large size instances, a heuristic/metaheuristic method can be devised to tackle CC-HCRPTW as well as its extension to CC-HCRPTWSync.

Finally, the problem has several interesting extensions which deserve further investigation, e.g. vehicle routing where the personnel is allowed to use multiple modes of transport, vehicle routing with split service when a type-3 patient can be served by a nurse and an aide at different times, vehicle routing where the fleet is comprised of electric vehicles, as well as the time-dependent and stochastic VRP variants of the problem.

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Multi-criteria Group Decision Making in the Selection of CNC Woodworking Machinery

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Abstract. The machine selection process has been an important issue for companies for many years. The wrong selection of the machine leaves a negative result on the efficiency, precision, flexibility, and sensitive production capacity of the company, and this leads to many problems. In this study, a real case application in a company that serves in the wood industry sector is carried out for the process of CNC woodworking machine selection. First, the main criteria and sub-criteria affecting machine selection are defined. For the decision-making process, 3 senior executives of the company are considered as decision-makers (DM). During the evaluation of alternatives under these criteria, the AHP method, one of the most popular Multi-Criteria Decision Making (MCDM) methods, is used. A sensitivity analysis is also conducted for a different scenario to see the change in the rankings of alternatives.

Keywords: Analytical hierarchy process · Multi-criteria group decision making · CNC machine selection

1 Introduction

The woodworking industry began to develop rapidly in the late 1970s and is still in progress today. Although our country tries to continue the competition with the leading companies in this sector, the dependence on the imported industrial machines is still considered as a problem. Most of the investments in the wood sector are made by imported machines coming from abroad. Considering that the competitiveness of our companies around the world is directly proportional to the quality and cost of the product they produce; it is seen that it is very important to keep operational efficiency at the optimum level. In all these factors, the cost of machinery investment is very critical. If the right choices are made by the companies in the selection of machinery, the resources

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will be used optimally in terms of finance, quality, and efficiency. This, in turn, will be effective in competition and will make positive contributions to the country's economy.

The machinery used in wood processing or furniture production, which is the subgroup of the forest products industry, is generally referred to as woodworking machines. Woodworking machines were mostly mechanically controlled up to 25–30 years ago. The wood industry, which has previously used traditional machines, has started to use special software machines by making them computerized as a result of R & D studies. These types of machinery, called CNC (Computer Numeric Control). In the wood industry, the machinery and equipment in the processing of wood and its conversion to furniture vary according to the way and feature of the wood. First of all, the machines used in the process of cutting the wood, which is the raw material of the wood industry, from the forest into logs and then turning it into wood, veneer or derivative materials will be excluded. The process up to here can be called as the forest products industry. In this study, the machines which are used in the process of turning the material taken from the forest to industrial products and reaching to the final consumer in the furniture industry taken into consideration.

By the usage of CNC machines in the furniture industry, the measurement accuracy and standardization are increased, and the cycle time of the product is decreased. Also, the flexibility of the production is increased by the CNC control of some machines. In this study, the selection process of CNC machines used in furniture, auxiliary materials or semi-finished production lines produced from flakeboard or MDF (Medium Density Fiberboard) material, which are called panel manufacturing in the wood industry, are handled. A real case application is carried out in a company for the process of CNC woodworking machine selection by considering the capacity and constraints of the enterprise. After determining the necessary criteria by the experts, the alternative machines are evaluated in terms of these criteria by three decision makers (DMs). In this process, the Factory manager, Production manager, and Sales manager are considered as DMs. Later, the evaluations of the DMs are aggregated, and the best CNC machine is selected using the Analytic Hierarchy Process (AHP), one of the Multi-Criteria Decision Making (MCDM) methods.

The purpose of MCDM methods is to keep the decision-making mechanism under control in cases where the number of alternatives and criterion is high, and to achieve the decision result as easily and quickly as possible. Also, companies using modern decision-making methods pioneer global business relationships and have competitive advantages in managing these relationships. The AHP, one of the most widely used MCDM tools, is the process of developing numerical values to rank each decision alternative according to the degree of meeting the criteria (Saaty and Ergu 2015). The AHP method answers the questions "which one to choose?" or "what is the best?" by choosing the best alternative that meets all the criteria of the decision maker. The implementation of the AHP method is shaped by four basic principles. Decomposition, pairwise comparison, synthesis of priorities, and the final decision based on the mixed composition. These basic principles also constitute the steps of AHP. This method, first introduced by Myres and Alpert in 1968, was improved by Saaty (1977) as a model and used in the solution of decision-making problems. AHP is based on pairwise comparisons through the criteria that affect the decision, and the significance values of the decision points in terms of these criteria, using a predefined comparison scale on a given decision hierarchy. In the literature, there are plenty of studies using AHP in different areas such as selection, evaluation, decision making, etc. Karim and Karmaker (2016) presented an integrated approach of AHP & TOPSIS methods for machine selecting process. This structure involves identifying the weights of the criteria by using AHP and ranking the alternatives by using TOPSIS. Camci (2018) proposed a hesitant fuzzy analytic hierarchy process (HFAHP) model consisting of 4 main criteria and 11 sub-criteria for CNC router selection in woodwork manufacturing. Ozdagoglu et al. (2017) introduced a new machine selection process considering the Fuzzy Analytic Hierarchy Process (AHP) method. The company's machine selection process is also analyzed, given the criteria obtained from the company by comparing the machine vendors. Farhan et al. (2016) developed a model of analytic hierarchy process (AHP), to assist in selecting suitable machine configurations for special purpose machines (SPMs) from available alternatives. This study reduced the time required for designing SPMs.

2 Methodology

The machine selection process has been an important issue for companies for many years because the incorrect selection of the machine leaves a negative result on efficiency, precision, flexibility, and the company's responsive production capacity and cause many problems. The machines used in the production of wooden furniture can be examined in two main groups according to the attribute of furniture production such as machines for the production of solid wood or panel furniture. In both process types, CNC machines are used to process the material. In this study, only CNC machines used in panel furniture production is discussed.

In the decision-making process of CNC woodworking machine, the basic requirements related to the machine are determined first by taking into consideration the whole process. Thus, some of the alternatives are eliminated. Later, the needed features are determined according to the machine's required operations. These features are sorted in order of importance. Among these features, those that are considered indispensable and those who influence the efficiency and work quality of the machine are selected. In a decision-making environment, these selected features are considered as criteria and used to evaluate the alternatives. In this way, it is aimed to select the most suitable machine from a set of alternatives, which is appropriate for at least one purpose or criterion.

2.1 Identifying the Main Criteria and Sub-criteria

Within the scope of this study, firstly, the criteria to be taken into consideration in the selection of CNC surface treatment machine and horizontal sizing machine which is required in a factory that produces panel furniture is defined. The criteria discussed in the selection process of the CNC woodworking machine are grouped into three main headings; Technical factors, Operator-related factors, and Financial factors. Their categorization is shown in Table 1.

Table 1. Criteria took into account to select the best CNC woodworking machine

Main criteria	Sub-criteria
C1: Technical factors	C11: Number of axes
	C12: Stiffness
	C13: Motor power
	C14: Tool change speed
	C15: Control unit performance
	C16: Processing accuracy
	C17: Workspace and height
	C18: Magazine number and capacity
	C19: Machine sled system
C2: Operator-related factors	C21: Easy part connection
	C22: Setting time
	C23: Ease of use of the program
	C24: Easy error detection
	C25: Job security
C3: Financial factors	C31: Cost
	C32: Service
	C33: Payment method
	C34: Maintenance cost

2.2 The Application of AHP Method

After the identification of the criteria, the hierarchy of the problem is constructed in different levels containing the goal, criteria, and sub-criteria. The alternative machine brands are determined as Wekke, Morbildelli, SCM, and EAS by the company. The selection hierarchy for the best CNC woodworking machine is given in Fig. 1.

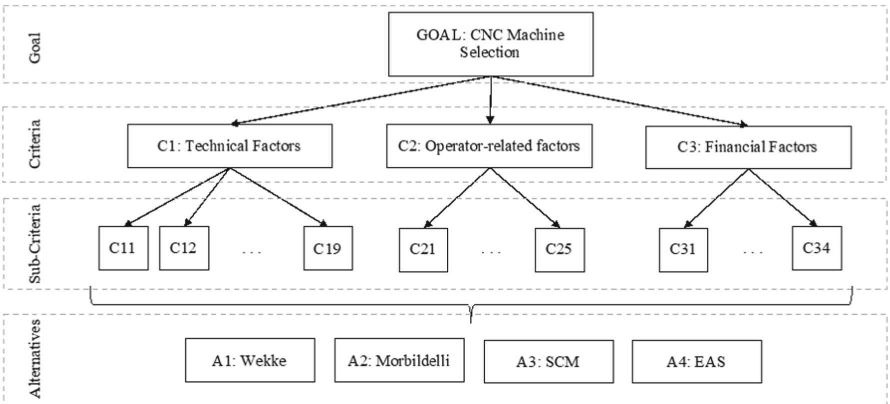

Fig. 1. The selection hierarchy of the best CNC woodworking machine

At this stage, the values to be given about the criteria that will affect the decision at all levels of the hierarchical structure should be converted into a matrix. Since there are 4 different machine alternatives determined by the company, it is necessary to make a pairwise comparison of these alternatives under each sub-criterion. Thus, the relative importance of each item in this structure will be determined. In this evaluation process, Saaty's nine-point scale, shown in Table 2, is used by the DMs. Unlike the other criteria, the number of axes, motor power, working space, magazine number and capacity, and cost criteria does not change according to the machine. Hence, these criteria are weighted by using benefit points instead of pairwise comparison.

Table 2. Saaty's nine-point scale (Saaty 1980)

Level 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

3 Results

For the CNC woodworking machine selection process, the 4 alternative types of machinery are evaluated under 3 main criteria, and 18 sub-criteria. The relevant matrices were filled by the DMs for the selection of the most suitable alternative by the AHP method. To make the decision process more accurate, 3 different decision makers, Factory manager, Production manager, and Sales manager, are referred. The comparison matrices generated separately by each DM are aggregated using a geometric mean. The aggregated pairwise comparison matrix of the main criteria in terms of CNC machine selection goal is created, weights of the main criteria are calculated and given in Table 3.

Table 3. The weights of the main criteria in level 1 of AHP

Main criteria	Weight
Technical factors	0,43
Operator-related factors	0,20
Financial factors	0,37

According to this analysis, "Technical factors" is the most important main criterion which affects the CNC woodworking machine selection from DMs' perspective.

Table 4 indicates the evaluation of four alternatives in terms of the nine sub-criteria of “Technical factors.” For this main criterion, “C12: Stiffness”, “C16: Processing accuracy” and “C19: Machine sled system” are the most important criteria among all.

Table 4. Evaluation of sub-criteria of Technical factors

Technical factors	C11	C12	C13	C14	C15	C16	C17	C18	C19
Weights of sub-criteria	0,03	0,24	0,06	0,02	0,05	0,24	0,07	0,03	0,25
A1: Wekke	0,25	0,575	0,349	0,271	0,62	0,627	0,234	0,353	0,425
A2: Morbidelli	0,25	0,088	0,233	0,506	0,159	0,185	0,281	0,235	0,238
A3: SCM	0,25	0,276	0,233	0,162	0,125	0,094	0,313	0,235	0,239
A4: EAS	0,25	0,061	0,186	0,061	0,097	0,094	0,172	0,176	0,097

Table 5 shows the evaluation of four alternatives in terms of the five sub-criteria of “Operator-related factors.” For this main criterion, “C25: Job security” is considered as the most important criteria among all by the DMs’.

Table 5. Evaluation of sub-criteria of Operator-related factors

Operator-related factors	C21	C22	C23	C24	C25
Weights of sub-criteria	0,07	0,23	0,25	0,10	0,36
A1: Wekke	0,591	0,451	0,124	0,192	0,588
A2: Morbidelli	0,172	0,374	0,452	0,183	0,241
A3: SCM	0,157	0,101	0,367	0,346	0,122
A4: EAS	0,08	0,074	0,057	0,279	0,049

The evaluation of four alternatives in terms of the four sub-criteria of “Financial factors” is shown in Table 6. For this main criterion, “C31: Cost” is taken as the most important criteria among all by the DMs’.

Table 6. Evaluation of sub-criteria of Financial factors

Financial factors	C31	C32	C33	C34
Weights of sub-criteria	0,52	0,14	0,23	0,11
A1: Wekke	0,17	0,07	0,05	0,05
A2: Morbidelli	0,22	0,36	0,19	0,14
A3: SCM	0,25	0,48	0,19	0,26
A4: EAS	0,35	0,09	0,57	0,56

Table 7. Ranking the alternatives

Sub-criteria	Criteria weight (Cw)	Sub-criteria weight (Sw)	Cw * Sw	Wekke (A1)	Morbidelli (A2)	SCM (A3)	EAS (A4)
C11	0,43	0,03	0,01	0,25	0,25	0,25	0,25
C12	0,43	0,24	0,10	0,57	0,09	0,28	0,06
C13	0,43	0,06	0,03	0,35	0,23	0,23	0,19
C14	0,43	0,02	0,01	0,27	0,51	0,16	0,06
C15	0,43	0,05	0,02	0,62	0,16	0,12	0,10
C16	0,43	0,24	0,10	0,63	0,18	0,09	0,09
C17	0,43	0,07	0,03	0,23	0,28	0,31	0,17
C18	0,43	0,03	0,01	0,35	0,24	0,24	0,18
C19	0,43	0,25	0,11	0,42	0,24	0,24	0,10
C21	0,20	0,07	0,01	0,59	0,17	0,16	0,08
C22	0,20	0,23	0,05	0,45	0,37	0,10	0,07
C23	0,20	0,25	0,05	0,12	0,45	0,37	0,06
C24	0,20	0,10	0,02	0,19	0,18	0,35	0,28
C25	0,20	0,36	0,07	0,59	0,24	0,12	0,05
C31	0,37	0,52	0,19	0,17	0,22	0,25	0,35
C32	0,37	0,14	0,05	0,07	0,36	0,48	0,09
C33	0,37	0,23	0,08	0,05	0,19	0,19	0,57
C34	0,37	0,11	0,04	0,05	0,14	0,26	0,56
Result				0,335	0,230	0,231	0,203

Finally, the alternatives are ranked using the evaluation values under defined weights of criteria/sub-criteria. As seen in Table 7, Alternative 1: Wekke machine is selected as the best CNC woodworking machine by the rate of 0,335. The ranking of the alternatives is A1 > A3 > A2 > A4.

4 Discussion

In this section, a sensitivity analysis is performed by creating different case scenarios to take into account the different situations related to the machine selection process. On the current situation of the machine to be selected;

- Scenario 1: A more difficult and complex material will be processed. For this reason, it is assumed that the weight of C15 (Control unit performance), C23 (Ease of use of the program) and C18 (magazine number and capacity) criteria increase by 20–25%.
- Scenario 2: Parts with larger dimensions will be processed. For this reason, the weights of C17 (Workspace and height), C12 (Stiffness), and C13 (Motor power) will be increased by 20%.

- Scenario 3: The importance of the C25 (Job security) criteria will be increased by 25%.
- Scenario 4: It is assumed that the importance of C31 (Cost) and C33 (Payment method) criteria increased by 20% due to the sudden fluctuation in foreign exchange prices.
- Scenario 5: It is assumed that the manufacturer producing machinery interrupted the work due to the financial crisis and slowed down its activities. Therefore, the weight of the C32 (Service) and C34 (Maintenance cost) criteria will increase by 20%.

Table 8. Sensitivity analysis for different scenarios

Weight						
Sub-criteria	Current state	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
C11	0,013	0,013	0,013	0,013	0,013	0,013
C12	0,104	0,104	0,125	0,104	0,104	0,104
C13	0,028	0,028	0,033	0,028	0,028	0,028
C14	0,01	0,01	0,01	0,01	0,01	0,01
C15	0,021	0,026	0,021	0,021	0,021	0,021
C16	0,104	0,097	0,071	0,104	0,104	0,104
C17	0,032	0,032	0,038	0,032	0,032	0,032
C18	0,011	0,013	0,011	0,011	0,011	0,011
C19	0,105	0,105	0,105	0,105	0,105	0,105
C21	0,013	0,013	0,013	0,013	0,013	0,013
C22	0,046	0,046	0,046	0,046	0,046	0,046
C23	0,051	0,061	0,051	0,033	0,051	0,051
C24	0,021	0,011	0,021	0,021	0,021	0,021
C25	0,073	0,073	0,073	0,091	0,073	0,073
C31	0,192	0,192	0,192	0,192	0,231	0,174
C32	0,051	0,051	0,051	0,051	0,024	0,062
C33	0,084	0,084	0,084	0,084	0,101	0,084
C34	0,04	0,04	0,04	0,04	0,012	0,048
Results						
A1: Wekke	0,335	0,334	0,33	0,344	0,339	0,333
A2: Morbidelli	0,23	0,233	0,229	0,226	0,228	0,231
A3: SCM	0,231	0,232	0,237	0,227	0,224	0,234
A4: EAS	0,203	0,201	0,204	0,203	0,208	0,203
Ranking						
A1: Wekke	1	1	1	1	1	1
A2: Morbidelli	3	2	3	3	2	3
A3: SCM	2	3	2	2	3	2
A4: EAS	4	4	4	4	4	4

As a result of the sensitivity analysis performed under different scenarios, it is observed that there is not any significant change in the order of ranking of the alternatives. As seen in Table 8, WEKKE brand machine is the best choice while EAS brand machine is the last one. There is only some replacement between MORBIDELLI and SCM machines according to the scenarios.

5 Conclusion

Turkey is an efficient location in terms of raw materials and potential customers. Accordingly, the furniture sector also follows a developing path in our country. This situation causes the manufacturers of furniture machines in the world to show great interest to our country. This means an increase in machine alternatives. As the alternatives increases, the selection process becomes difficult or different elements come to the fore, and wrong machine purchases or faulty investments are in question. In this context, using analytical methods in the selection of machine is an indispensable necessity for selecting the most suitable machine for the capacity and expectations of the enterprise. The direct impact of production on this issue will also have significant impacts on employee motivation.

In this study, CNC woodworking machine selection process to be performed in a company serving in the wood industry sector is handled. The main criteria and sub-criteria affecting machine selection are defined. During the evaluation of alternatives under these criteria, the AHP method, which is one of the multi-criteria decision making (MCDM) methods, is used. As a decision-maker (DM) in this decision-making process, 3 people working as senior executives are selected.

In the implementation of the AHP method, the criteria are firstly defined, and a hierarchy of criteria is established. The most suitable machine is selected using pairwise comparison matrices and normalization technique. Then, a sensitivity analysis is conducted by creating scenarios with different situations. Thus, changes in the ranking of alternative machines under different conditions are monitored.

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A Mathematical Model and an Artificial Bee Colony Algorithm for In-Plant Milk-Run Design

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Abstract. As a result of the product diversification, many types of components are used in the products' bill-of-materials. Consequently, smaller quantities of many different types of components are needed to be distributed. All these factors complicated the part-feeding to the assembly lines. In this study, a mathematical model is developed for an in-plant milk-run material supply system that periodically distributes multiple parts by using multiple vehicles to the stations of the assembly lines. This model is called the Multi-Vehicle Milk-Run Model. As the proposed mathematical model is NP-hard, an Artificial Bee Colony Algorithm is developed to solve the large instances. The proposed ABC Algorithm is tested based on the optimum solutions (where available) and the best-known feasible solutions of different sized instances of a real washing machine assembly plant. Hence, the performance of the ABC Algorithm is validated.

Keywords: In-plant milk-run · Part feeding · Artificial Bee Colony Algorithm · Mathematical model

1 Introduction

Lean logistics stipulates elimination of non-value adding steps through the inbound, outbound, and in-plant logistics activities (Baudin 2004). As a result of the product diversification, several models of the same product are assembled through the assembly lines, and many different types of components are used in products' bill-of-materials. Consequently, smaller quantities of different types of components are needed to be distributed, to the stations. All these factors complicated the part-feeding to the assembly lines.

In the literature, three in-plant parts feeding approaches are mentioned; namely, line-stocking, kitting, and sequencing (Limere et al. 2012). Line stocking refers to parts distribution and stocking beside the assembly line, in buffer areas. Kitting concerns grouping of optional parts that are commonly used in some of the products (Satoglu and Ucan 2015). Besides, sequencing requires components to be put into order according to the mixed-model sequence followed in the assembly line (Sali et al. 2015). Also,

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Kanban-coordinated milk-run systems are proposed where kanbans showing the parts requirement are collected frequently (once in each cycle time), and the full boxes required by the stations are distributed by following a certain route (Satoglu and Sahin 2013). This is a better alternative to the line-stocking, since it triggers replenishment of small quantities of the required parts, only when and as much as needed. In parts-feeding literature, many studies exist where a decision among the part-feeding modes is made (Limere et al. 2012; Sali et al. 2015; Limere et al. 2015; Sali and Sahin 2016; Caputo et al. 2015). Besides, mathematical modeling approaches are proposed where routing and scheduling problems are intended to be solved, simultaneously (Kilic and Durmusoglu 2013; Satoglu and Sahin 2013). Alternatively, scheduling and tow-train loading problems are formulated together where the routes are predetermined (Fathi et al. 2015). Another modeling approach is fixing the service cycle times and constructing the routes. However, constructing the routes and deciding the service cycle times optimally is rather challenging, and only a limited number of heuristics or meta-heuristic studies exist. So, authors believe that there is a certain gap in this field.

Besides, most of the papers used mathematical modeling techniques. Only two studies employed a Matheuristic for the solution (Volling et al. 2013), (Emde and Boysen 2012). Generic heuristics are also employed in six studies. Specifically, Satoglu and Sahin (2013) proposed a decomposition based heuristic where scheduling and routing problems are solved sequentially. Similarly, Golz et al. (2012) proposed a two-stage heuristic, by first deriving the transportation orders and then the assignment of orders to tours based on capacity and due dates. Particle swarm optimization algorithm (Fathi et al. 2015), tabu-search (Emde and Gendreau 2017), ABC algorithm (Zhou and Peng 2017), and the Neighborhood Search (Emde and Schneider 2018) are the meta-heuristics employed to solve the models. Based on this review, it is clear that the Meta-heuristic algorithms were rarely used in past studies, for solving this complex problem. So, the proposed ABC Algorithm contributes to filling this gap.

So, in this study, a mathematical model for an in-plant milk-run system that periodically distributes multiple parts by using multiple vehicles to the stations of the assembly lines is developed. This problem is called Multi-Part Multi-Vehicle Milk-run Model (MV-MM), and it is NP-hard since it converges to the TSP by assuming a fixed planning horizon. In order not to cope with the non-linear versions of the problem (Satoglu and Sahin 2013), a linear model was formulated. However, the model is still NP-hard. Therefore, to solve the large instances of the proposed MV-MM, an Artificial Bee Colony (ABC) Algorithm is developed, that is also a novel aspect. The proposed mathematical model is tested by using different sized instances of a real washing machine plant's milk-run system. For the instances where the mathematical model could not be solved, the Matheuristic Algorithm (Buyukozkan et al. 2019) developed before is used to generate some best known feasible solutions. Besides, the ABC Algorithm is used for solving each instance, and its high performance is validated.

The paper is organized as follows: In Sect. 2, the relevant literature is reviewed. Later, in Sect. 3, the multi-vehicle milk-run model is proposed. In Sect. 4, the formerly developed Matheuristic Algorithm and the novel ABC Algorithm are explained. Then, in Sect. 5, a real case of in-plant logistics of a washing machine assembly plant is explained. Later, the instances generated based on this real data and the results obtained by the solving the MV-MM, the Matheuristic, and the ABC algorithm are discussed, in Sect. 6. Finally, the Conclusion is presented.

2 The Proposed Mathematical Model

In this study, a Multi-Vehicle Milk-Run Model (MV-MM) is proposed, for parts feeding to the assembly lines. In earlier formulations, the objective function and some of the constraints are non-convex (Satoglu and Sahin 2013). As the objective is a non-convex minimization function, the optimum solution could not be reached. To prevent coping with a non-convex non-linear model during the solution, a linear mathematical model is proposed in this study. In Table 1, the sets and the parameters of the model are denoted. Later, the model is presented.

Table 1. Sets and parameters of the mathematical model

Sets	Parameters
S: Set of customers	Ψ_v: Fixed cost of using each vehicle
S+ = S ∪ {r}, where r: the central depot	Ctc: Value of the cycle time-c
V: Set of vehicle tours	tij: Distance between customers i and j
P: Set of parts	ϑ: Speed of the vehicle
C: Set of cycle times	δ: Cost of the vehicle per meter traveled
i: Node index (i∈S+)	ηip: Unit inventory holding of part-p
j: Node index (j∈S+)	φi: Fixed cost of a batch-order for node-i
p: Part index (p∈P)	Bp: Weight of a full-box of part-p
v: Vehicle index (v∈V)	Vp: Volume of a box of part-p
	dip: Demand rate of node-i for part-p
	LUjp: Load-unload time required per container for part -p at the node-j
	KVv: Maximum Volume of boxes that the vehicle-v can carry
	Kv: Capacity of a vehicle tour-v
	Ki: The capacity of the node-i
	Tmin: The minimum cycle time
	Tmax: The largest cycle time

The Decision Variables:

$$X_{ijv} = \begin{cases} 1, & if\ customer - j\ is\ visited\ just\ after\ customer - i,\ in\ vehicle\ tour - v; \\ 0, & otherwise \end{cases}$$

Zijpv = Load on the vehicle belonging to the remaining customers after vehicle-v visits customer-i to deliver part-p;

$$Y_v = \begin{cases} 1, & if\ vehicle\ tour - v\ is\ employed; \\ 0, & otherwise \end{cases}$$

$$T_{cv} = \begin{cases} 1, \; if\, tour - v\, is\, repeated\, once\, in\, every\, cycle\, time - c; \\ 0, \qquad otherwise \end{cases}$$

$$S_{ijcv} = \begin{cases} 1, \; if\, vehicle - v\, travels\, from\, i\, to\, j\, in\, cycle\, time - c. \\ 0, \qquad otherwise \end{cases}$$

The model formulation is presented below:

$$Min. \sum_{v\in V}\left[\Psi^v Y^v + \sum_{c\in CT}\sum_{i\in S^+}\sum_{j\in S^+}\left[t_{ij}\delta\frac{S_{ijcv}}{Ct_c}\right] + \sum_{i\in S}\sum_{p\in P}\sum_{c\in CT}\sum_{j\in S^+}\left(\eta_{ip}\frac{d_{ip}}{2}Ct_c S_{ijcv} + \varphi_{ip}\frac{S_{ijcv}}{Ct_c}\right)\right] \tag{1*}$$

Subject to:

$$\sum\nolimits_{v\in V}\sum\nolimits_{j\in S^+} X_{ijv} = 1; \, (i\in S)(i\neq j) \tag{2}$$

$$\sum\nolimits_{v\in V}\sum\nolimits_{j\in S^+} X_{1jv} \geq 1 \tag{3}$$

$$\sum\nolimits_{i\in S^+} X_{ijv} - \sum\nolimits_{k\in S^+} X_{jkv} = 0; \, (j\in S^+)(v\in V) \tag{4}$$

$$\sum_{i\in S^+}\sum_{\substack{j\in S^+\\ j\neq i}}\frac{t_{ij}X_{ijv}}{\vartheta} + \sum_{j\in S^+}\sum_{p\in P} Z_{1jpv}LU_{1p} + \sum_{\substack{i\in S\\ i\neq j}}\sum_{j\in S^+}\sum_{p\in P}\sum_{c\in C} LU_{jp}d_{jp}Ct_c S_{ijcv} \leq \sum_{c\in CT} Ct_c T_{cv}; \, (v\in V) \tag{5*}$$

$$\sum\nolimits_{p\in P} Z_{ijpv}B_p \leq K^v X_{ijv}; \, \left(j\in S^+\right)\left(i\in S^+\right)(v\in V) \tag{6}$$

$$\sum\nolimits_{p\in P} Z_{ijpv}V_p \leq KV^v.X_{ijv}; \, \left(i\in S^+\right)\left(j\in S^+\right)(v\in V) \tag{7}$$

$$\sum\nolimits_{p}\sum\nolimits_{i\in S^+} d_{jp}Ct_c S_{ijcv} \leq K_j; \, (j\in S)(c\in C)(v\in) \tag{8}$$

$$\sum\nolimits_{i\in S^+} Z_{ijpv} - \sum\nolimits_{k\in S^+} Z_{jkpv} = d_{jp}\sum\nolimits_{i\in S^+}\sum\nolimits_{c\in CT} S_{ijcv}Ct_c; \, (j\in S), \, (p\in P), \, (v\in V) \tag{9}$$

$$X_{1jv} \leq Y_v; \, (v\in V)(i\in S) \tag{10}$$

$$X_{iiv} = 0; \, (v\in V)\left(i\in S^+\right) \tag{11}$$

$$T_{cv} \leq Y_v; \, (c\in C)(v\in V) \tag{12}$$

$$T_{cv} + X_{ijv} \leq 1 + S_{ijcv};\ \left(j \in S^{+}\right)\left(i \in S^{+}\right)(v \in V)(c \in C) \tag{13}$$

$$T_{cv} + X_{ijv} \geq 2S_{ijcv;};\ \left(j \in S^{+}\right)\left(i \in S^{+}\right)(v \in V)(c \in C) \tag{14}$$

$$X_{ijv} \in \{0, 1\};\ \left(j \in S^{+}\right)\left(i \in S^{+}\right)(v \in V)$$

$$Y_{v} \in \{0, 1\};\ (v \in V)$$

$$T_{cv} \in \{0, 1\};\ (c \in CT)(v \in V)$$

$$Z_{jipv} \geq 0;\ \left(j \in S^{+}\right)\left(i \in S^{+}\right)(v \in V)(p \in P)$$

$$S_{ijcv} \in \{0, 1\};\ \left(j \in S^{+}\right)\left(i \in S^{+}\right)(v \in V)(c \in C)$$

The objective function given by Eq. (1*) aims to minimize the fixed vehicle usage cost, total material handling cost (that is inversely proportional with the cycle time), total inventory holding cost and total fixed ordering cost. Constraints (2) stipulate that each node must be linked to exactly a single node (including the depot) by a single vehicle. Constraints (3) imply that more than one vehicle can depart from the central depot. Constraints (4) are the traditional flow balance constraints. Constraints (5*) require that the total traveling time and all loading-unloading times spent by a vehicle at the depot and nodes must be smaller than the cycle time of that vehicle. Constraints (6) and (7) imply that the amount of load on the vehicle cannot be greater than its weight and volume capacities of the vehicle, respectively. Constraints (8) require that the total amount of commodities delivered to a node cannot be greater than the (buffer) capacity of that node. Here, the term $Ct_c * d_{jp}$ implies the delivery amount of part-p to the station-j. Constraints (9) imply that the quantity delivered to a node must be equal to its requirement if it is visited by the vehicle-v. Here, the delivery quantity for a node is computed by the product of the demand rate of that node and the selected cycle time of the vehicle route that this node is assigned to. These constraints also serve as sub-tour elimination constraints. Constraints (10) stipulate that if there is a vehicle-v departing from the depot, that vehicle's binary variable is equal to one implying that it is utilized. Constraints (11) stipulate that a node cannot be linked to itself. Finally, Constraints (12) mean that if a vehicle is used in a certain cycle time-c, that vehicle's corresponding binary variable must be equal to one. At last, the sign restrictions are defined. This mathematical model is non-linear because of the structure of the objective function and Constraints (5*), (8), and (9), due to the multiplication of T_{cv} and X_{ijv}. In the past versions of the similar model, the cycle time variables were continuous, and the problem was a non-convex minimization problem (Satoglu and Sahin 2013). So, a linear model was formulated in this study, not to deal with a non-linear and non-convex model. However, the model is still NP-hard, and a heuristic approach is needed to solve the problem, especially for large instances. So, the proposed Artificial Bee Colony Algorithm is the contribution of this study that is explained in the following section.

3 The Matheuristic Algorithm and the Artificial Bee Colony Algorithm

In this section, the Matheuristic that was developed before is shortly explained. It is employed for finding a feasible solution of the MV-MM, for the larger instances where the MV-MM cannot reach an optimum solution. First, we explain the properties of Matheuristics and Meta-Heuristics. Next, the Matheuristic Algorithm proposed before (Buyukozkan et al. 2019) and the novel ABC Algorithm are explained in this section. Matheuristics are heuristic algorithms that are based on the interoperation of metaheuristics and mathematical programming techniques (Boschetti et al. 2009). In other words, mathematical models are solved in some iterations, and these solutions are fed into the following steps of the whole algorithm, but the optimality is not guaranteed. However, meta-heuristic algorithms employ concepts derived from artificial intelligence, biological, natural and physical sciences (Osman and Kelly 1996), to improve their performance of searching the solution space, and find the optimal or near-optimal solutions, in short computational times.

3.1 The Matheuristic Algorithm

Authors formerly developed the single-vehicle version of the proposed mathematical model that is linear and called it a single-vehicle milk-run model (SV-MM). A Matheuristic Algorithm was also developed, by Buyukozkan et al. (2019) that solves the SV-MM and iteratively includes a new vehicle if the capacity of a route is exceeded, and continues until all nodes are assigned to a route. So, in this study, this Matheuristic is employed to reach only feasible but probably sub-optimal solutions of the instances where no optimum could be found by solving the big size instances of the proposed MV-MM. Hence, a benchmark could be found to test the performance of the proposed ABC Algorithm. So, the Matheuristic and the proposed ABC Algorithms are alternative means of solving the same problem, and their performances are compared in the computational results section.

3.2 Proposed Artificial Bee Colony Algorithm

The Artificial Bee Colony (ABC) algorithm is a meta-heuristic method which seeks solutions to optimization problems by mimicking the nutritional search behaviors of the bees in nature (Karaboga and Akay 2009). The ABC has been employed for the problems related to the assembly lines, and promising results were achieved (Buyukozkan et al. 2016). In this study, the ABC algorithm is implemented for solving the multi-vehicle milk-run-model for the assembly lines. The pseudocode of the proposed ABC Algorithm is shown in Fig. 1.

The algorithm starts with the creation of scout bee codes as much as the number of scout bees, consisting of a randomly generated station order and cycle times. Note that the code has cycle time values as much as the maximum number of vehicles because the model assumes that each vehicle works based on a single cycle time.

To associate a randomly generated scout bee code with a solution, it must be processed in the Route Generating Function (RGF). RGF is developed to determine which

```
Proposed Bee Algorithm
Define the parameters (Number of scout bees, followers and iteration)
Generate random initial solution as much as scout bees , by RGF
Hold the best solution
Do (Until reach the iteration limit)
   For each scout bee
       For each follower
         Choose neighborhood search method randomly (change either station order or
cycle time)
         Generate a neighbor (follower) for selected scout bee by the selected method
       Next follower
         Compare all followers with the scout bee and select the best one as new scout bee
   Next scout bee
   Compare the scout bees with the best solution and hold the best one
Loop
Bring the best solution as final solution
```

Fig. 1. The pseudocode of the proposed Artificial Bee Colony Algorithm

vehicle will serve which station in which cycle time. For the objective function value, an improved version of the function proposed by Satoglu and Sahin (2013) is used. This function assigns stations to the vehicles respectively by considering the capacity restrictions. If all stations can be assigned successfully, the objective value is calculated as given in Eq. (1*). Otherwise, the objective value is equal to a large penalty value. RGF works as follows:

First, the RGF tries to assign the first station for the first route by selecting the first cycle time. Thus, the demand rate value of the considered station for the selected cycle time is calculated. According to this demand rate, it is checked whether the station buffer stock capacity is exceeded. If so, then there is no valid solution for the scout bee. In this case, the scout bee is penalized with a penalty number, and the calculation is terminated.

If the station capacity restriction is satisfied, the total load volume and weight are calculated using the demand rate value. These values are used to check vehicle capacity restriction. If the vehicle capacity is exceeded, then the considered scout bee is invalid since the handled station is the first station of the route. Therefore, the scout bee code is penalized with a penalty point, and the calculation is terminated. If vehicle capacities are also satisfied, the total loading and unloading time is calculated based on the demand value. This duration is summed with the transportation time between the warehouse and the station so that the total required time is obtained. The required time value obtained is compared with the cycle time. If the cycle time is exceeded, the scout bee code is penalized as in the previous case, since the considered station is the first station of the route. If all the constraints mentioned above are satisfied, the first station is assigned to the first route and RGF continues with the next station. The next station considered is tried to be assigned to the current route of the existing vehicle, and the constraints are checked by following the order as mentioned above. If all the constraints are satisfied, the considered station is included in the route of the existing vehicle and algorithm continues with the next station. If the station capacity or cycle time limit is exceeded, the handled station is tried to be assigned as the first station of the first route of a new vehicle. If only vehicle capacity constraints are exceeded, the handled station is tried to be assigned as the first station of the new route of the present vehicle.

The RGF is completed when all the stations are assigned to a route. Thus, a solution is generated for a scout bee, and then the objective value for this scout bee is calculated by Eq. (1*).

In the "Generate random initial solution" section of the ABC algorithm, the objective function values are obtained by applying the RGF for all scout bees. After that, the ABC algorithm generates new neighbor bee codes as many as the number of followers for each scout bee in the iteration cycle. Then objective values for each follower bees are calculated by using RGF. After that, each follower bee is compared with its own scout bee and the bee code with smaller objective value is saved as a new scout bee. In this way, the ABC algorithm continues by changing the scout bees with a better one until the end of the iterations. When the iteration limit is reached, the ABC algorithm brings the best scout bee code obtained so far.

The ABC algorithm uses two different methods to generate the neighbor bee codes mentioned above. The first method involves randomly selecting two stations from the station list of the bee code and replacing them with each other. In the second method, two randomly selected cycle times in the bee code are swapped with each other. For each neighbor, only one of these methods is used randomly and applied to the scout bee code.

4 A Real Application in White Goods Industry

In-plant distribution of various components/parts of white (durable) goods is considered in this study. There are usually several variants of a specific type of component that complicates the distribution service to the assembly lines.

To satisfy the requirements of the stations on time, and to decrease the transportation and inventory holding costs, cyclic replenishment of goods is required. Currently, the factory employs twelve forklifts to manage the part feeding, based on direct delivery. This caused intensive vehicle traffic inside the plant, and occupational safety problems started to arise. Besides, limited buffer capacities and tight layout constraints forced the plant managers to redesign the in-plant material supply system. Therefore, an in-plant milk-run system was intended to be designed to serve the single-model assembly lines.

There are four assembly lines, each comprised of 25 stations. In this study, to make an initial pilot design, only seven stations of each assembly line are considered. Therefore, 28 stations and the depot that comprises 29 nodes included in the problem. The vehicle delivers goods to a single point (buffer area) from which the goods are sent manually to the relevant stations. To design the milk-run system, the cycle time of distribution must be decided, the delivery quantities of all parts must be determined according to the leveled weekly production plan, and the service routes must be constructed. First, the requirements of the four single-model assembly lines associated with the fifteen parts are computed based on the pace of production of each line and the quantity of parts in a box. The plant's net available production time in a shift is seven hours. The paces of production of the lines (from the first to the fourth one) are 1550, 1300, 1250 and 600 products/shift, respectively. These target production quantities are multiplied by the

Table 2. The inventory holding cost, volume, weight and demand value of the parts

Component code number	Quantity in a Box	Number needed for each product	Inventory holding cost (per box)	Volume (m^3/box)	Weight for a full box (kg)	Line-1			Line-2			Line-3			Line-4		
						Required parts (per min)	Number of boxes Required	Station number	Required parts (per min)	Number of boxes required	Station number	Required parts (per min)	Number of boxes required	Station number	Required parts (per min)	Number of boxes required	Station number
1	128	1	5	0.0464	13.50	18.688	0.0146	2	1.6384	0.0128	7	16.384	0.0128	12	0.9344	0.0073	17
2	175	1	5	0.0464	13.50	11.725	0.0067	2	1.05	0.0060	7	0.8225	0.0047	12	0.245	0.0014	17
3	250	1	5	0.0464	13.50	0.6	0.0024	2	0.35	0.0014	7	0.475	0.0019	12	0.25	0.001	17
4	125	1	3	0.0336	10.27	18.625	0.0149	3	1.6375	0.0131	8	16.375	0.0131	13	0.9375	0.0075	18
5	158	1	3	0.0336	10.27	17.538	0.0111	3	1.4062	0.0089	8	12.798	0.0081	13	0.474	0.003	18
6	30	1	4	0.0725	10.00	1.863	0.0621	4	1.629	0.0543	9	1.629	0.0543	14	0.933	0.0311	19
7	40	1	4	0.0725	10.00	1.164	0.0291	4	1.048	0.0262	9	0.816	0.0204	14	0.236	0.0059	19
8	60	1	4	0.0725	10.00	0.582	0.0097	4	0.354	0.0059	9	0.468	0.0078	14	0.234	0.0039	19
9	60	1	10	0.0912	15.16	1.866	0.0311	5	1.632	0.0272	10	1.632	0.0272	15	0.936	0.0156	20
10	100	1	10	0.0912	15.16	1.17	0.0117	5	1.05	0.0105	10	0.82	0.0082	15	0.24	0.0024	20
11	140	1	10	0.0912	15.16	0.588	0.0042	5	0.35	0.0025	10	0.476	0.0034	15	0.238	0.0017	20
12	40	1	7	0.0552	25.60	1.864	0.0466	6	1.628	0.0407	11	1.628	0.0407	16	0.932	0.0233	21
13	50	1	7	0.0552	25.60	1.745	0.0349	6	1.4	0.0280	11	1.28	0.0256	16	0.47	0.0094	21
14	20	1	2	0.008	2.00	3.606	0.1803	22	3.024	0.1512	24	2.908	0.1454	26	1.396	0.0698	28
15	14	1	3	0.008	2.00	3.605	0.2575	23	3.024	0.2160	25	2.908	0.2077	27	1.396	0.0997	29

number of required parts per product according to the bill-of-materials and divided by the available production time (430 min). Hence, the required number of parts per minute by each assembly line is computed. These required quantities are divided by the quantity of parts per box for each component type. As a result, the numbers of boxes required per minute (d_{ip}) are found and shown in Table 2.

After the demand quantities have been calculated, the next step is to determine the T_{min} and T_{max} values. To reach an applicable design, T_{min} was assumed as 15 min, based on the opinions of the factory managers. To decrease the solution space, the T_{max} was limited to the 150 min. Please note that the values of weight (B_p) and volume (V_p) of the parts are also presented in Table 2. The station number columns in Table 2 express the station that requests the part. As shown in Table 2, the distribution of fifteen different parts to 28 stations from the central depot is considered.

5 Results and Discussion

For this real problem setting, seventeen sub-problems with different numbers of parts and stations are generated, to test the proposed mathematical model, Matheuristic and the Meta-Heuristic. The Cplex solver was run on an i5-M430 CPU 2.27 GHz personal computer, to solve the mathematical models. The results are presented in Table 3. The proposed MV-MM model could be solved for the first three problems. For the rest of the problems, the solver could not reach the optimum solution within 20000 s time limit. Using the proposed Matheuristic, merely feasible solutions are reached, in shorter computational times compared to the mathematical model.

We can conclude that as the problem size becomes larger, the solution quality of the Matheuristic becomes better. However, the Matheuristic could reach only a (feasible) solution, for the first nine problems, in 4000 s time limit. For the rest, it took more time, and the Matheuristic was terminated. This is because the Matheuristic employs the single-vehicle milk-run model, that is already NP-hard. So, to alleviate this difficulty, the ABC Algorithm is proposed. The last two columns of Table 3 show its results. We conclude that the proposed ABC Algorithm could reach qualified results in very short computational times, for all of the problems. For the problems 1–9 except for problem-4, the ABC Algorithm was able to reach the best known feasible solutions found by the Matheuristic. For the problem-4, the ABC Algorithm reached a better solution than the Matheuristic. However, it does not guarantee optimality. The ABC reached good solutions in less than two minutes for all of the instances for which the mathematical model and the Matheuristic could not reach any solution, within the given computational time limits. The difference between the computational times of the ABC Algorithm, while solving instances 9 and 10 is high. This is probably due to the increase in both the number of types of parts to be distributed and the number of stations.

The results found by the solution of instance-17 (biggest instance) are summarized in Table 4. This instance consists of 29 stations and 15 components (parts). The ABC Algorithm obtains a solution with three vehicles for this problem, such that each vehicle has only one route. The vehicle routes (including the stations assigned) are given in the third column of Table 4. The maximum load weights carried by the vehicle are given

Table 3. Results of the mathematical model, matheutistic and the ABC algorithm

Instance number	Number of parts	Number of stations	Multi-vehicle mathematical model		Mat-heuristic algorithm		Proposed ABC algorithm	
			CPU time (s)	Total cost (optimum)	CPU time (s)	Total cost	CPU time (s)	Total cost
1	13	6	17.49	168,5	9.59	168.51	0.11	168,51
2	13	11	243.78	219	14.19	218.99	0.18	218,99
3	13	13	4585.48	227,1	45.24	227.05	0.34	227,05
4	13	16	–	–	281.10	262.21	0.44	261,31
5	13	17	–	–	809.49	266.94	0.68	266,94
6	13	18	–	–	710.03	272.32	0.74	272,32
7	13	19	–	–	1414.47	278.1	2.41	278,1
8	13	20	–	–	3463.07	286.98	2.65	286,98
9	13	21	–	–	3207.09	293.75	2.80	293,75
10	15	22	–	–	–	–	340.58	404,67
11	15	23	–	–	–	–	199.36	428,99
12	15	24	–	–	–	–	282.4	435,89
13	15	25	–	–	–	–	391.8	456,94
14	15	26	–	–	–	–	221.88	464,42
15	15	27	–	–	–	–	212.68	480,67
16	15	28	–	–	–	–	199.47	590,66
17	15	29	–	–	–	–	235.32	599,93

Table 4. The solution of the proposed meta-heuristic for the instance-17 of the real problem

Vehicle	Route	Weight of the load (kg)	Volume of the load (m^3)	Cycle time (min)	Total load-unload & travel time (min)
1	1 - 29 - 20 - 18 - 21 - 19 - 15 - 26 - 16 - 9 - 14 - 11 - 7 - 13 - 12 - 27 - 1	180.87	0.72671	20	19.73940
2	1 - 4 - 5 - 3 - 8 - 2 - 23 - 22 - 6 - 25 - 1	118.564	0.48093	20	19.64735
3	1 - 24 - 10 - 28 - 17 - 1	53.207	0.26479	45	12.15025

in the fourth column. In the fifth column, the maximum load volumes are also given. Since the volume capacity of each vehicle is 3.6 m^3, it is clear that the solution does not exceed the volume limit, as well. The sixth column of the table shows the selected cycle time values for each vehicle route in minutes. The seventh column shows the time requirements for the total travel and loading-unloading operations to meet the demands of each station assigned to each route. As shown in the table, the total required times don't exceed the cycle time of each route. This solution of the ABC Algorithm was reached in 70.27 s.

6 Conclusion

In this study, a mathematical model is developed for an in-plant milk-run material supply system that periodically distributes *multiple parts* by using *multiple vehicles* to the stations of the assembly lines. This model is called the *Multi-Vehicle Milk-Run Model (MV-MM)*. The decision variables used in the objective function are all binary, and the model could be linearized. So, this linear formulation of the MV-MM enhanced the solution of the problem. Besides, to solve large instances of the proposed *MV-MM*, an ABC Algorithm is developed, that is also a novel aspect.

Based on real data of a washing machine assembly plant, seventeen instances are generated. The MV-MM could be solved only for small-sized instances, due to the problem complexity. A single-vehicle and linear mathematical model developed before, and the Matheuristic that iteratively solves the single-vehicle model is used to obtain feasible solutions for larger instances. This Matheuristic model has solved medium-sized instances, but it was unable to solve large-scale instances, in a given time limit. Therefore, the proposed ABC algorithm was employed for the solution. This algorithm has been successful in obtaining quality solutions for all instances, and reached all of the best known feasible solutions, in much shorter computational times. However, optimality is not guaranteed. In future work, different meta-heuristics can be employed for a solution. Besides, multi-objective models are rare for in-plant milk-run systems optimizations. Models aiming minimization of the buffer stocks, maximization of the vehicle utilization, or other objectives at the same time can be developed, in future studies.

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Predicting the Medical Tourism Demand of Turkey

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Abstract. There is an emerging need in understanding the trends and determinants of the medical tourism industry, which have a significant impact on the host country's economy. Turkey's popularity as an international tourism destination combined with the expertise of Turkish medical professionals and advanced technology available in the leading medical facilities make Turkey one of the most popular travel destinations for medical tourism. While the expanding literature on medical tourism offers conceptual and theoretical knowledge on this topic, the number of empirical studies is somewhat limited. Forecast of medical tourism demand is a critical input into decisions related to investments in healthcare, tourism, and transportation infrastructure. This study models Turkey's medical tourism demand incorporating several factors. Due to the relatively high number of indicators and a small number of observations, Partial Least Squares Regression (PLSR) was employed to predict the response, and the results were compared with those of the Ordinary Least Squares (OLS) estimation. The empirical findings are expected to help policy makers and practitioners to deepen their understanding of medical tourism demand for Turkey.

Keywords: Medical tourism demand · Demand forecasting · Partial Least Squares Regression (PLSR)

1 Introduction

Medical tourism is the type of healthcare tourism where patients receive treatment and/or rehabilitation in medical centers outside their country of residence. Medical tourism is especially preferred by travelers who seek to obtain medical care during their holiday. Medical tourists are traveling to other countries, especially for plastic surgery, dental procedures, ophthalmologic care, assisted reproductive technology, and other surgical procedures. Countries providing medical tourism services benefit from the generation of foreign exchange revenues through not only medical services but also through travel, tourism, and insurance services; new job opportunities in all these various fields and utilization of existing excess capacity of (private) hospitals and hotels (Bookman and Bookman 2007; Whittaker et al. 2010; Lunt et al. 2011). Turkey's popularity as an international tourism destination combined with the expertise of Turkish medical professionals, advanced technology available in the leading medical facilities and multilingual patient assistants attract medical travelers to Turkey (Omay and Cengiz 2013).

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Medical tourism differs from traditional international medical travel where the patient travels for advanced medical treatment that is not available in his/her own country (Horowitz et al. 2007). Medical tourists want to take advantage of shorter waiting times in the destination country, relatively low medical intervention costs, availability of well-recognized medical professionals, and the opportunity to discover new countries and touristic locations simultaneously (Connell 2006, Hopkins et al. 2010). Usually, medical tourists make decisions on their destination based on recommendations from their surrounding community. Hence, word of mouth is an important tool in medical tourism marketing. Turkish medical tourism organizations make use of this fact by television advertisements, particularly in Europe, to build a broad awareness about medical tourism opportunities and to appeal to medical tourists to visit Turkey.

Medical tourism investments in Turkey have gained importance following the announcement of incentives to encourage 'foreign currency earning services and operations' in 2015 (Resmi Gazete No. 29450 2015). The incentives aim to increase the foreign currency earnings and service revenues and to enhance the international competitiveness of the medical tourism industry in Turkey. Thus, accurate forecasting of medical tourism demand is important not only to formulate efficient strategies to stimulate demand but also to improve resource efficiency. Medical tourism demand forecasts are a significant input into decisions related to investments in healthcare, tourism, and transportation infrastructure. While demand is an important factor in policy making and long term planning, predicting medical tourism demand remains a major challenge. Medical tourism demand is affected by various complex factors such as political, economic, and other unpredictable events. Studies in the related literature focus on the effects of gross domestic product (GDP) of the origin and/or host countries, consumer price index (CPI), foreign exchange rates, public investment in medical facilities, private expenditure on health, price of medical tourism, number of medical professionals in the host country, number of hospitals in the host country, seasonality, risk events such as political crises and epidemics, crime rate in the host country, and marketing campaigns of the host country (Loh 2015; Johnson and Garman 2015; Tang and Lau 2017). Approaches adopted in previous studies for forecasting medical tourism demand mainly include time series econometrics (Loh 2015; Johnson and Garman 2015; Tang and Lau 2017) and grey forecasting (Lin et al. 2009; Huang 2012; Dang et al. 2016). Countries selected as the host country are Thailand (Lin et al. 2009), India, Singapore, and Thailand (Huang 2012), USA (Johnson and Garman 2015), Russia (Vetitnev et al. 2016), South Korea (Dang et al. 2016), and Malaysia (Tang and Lau 2017; Tang and Abdullah 2018). Different from others, Loh (2015) studied Canada as the origin country. Although Turkey is one of the top 10 destinations around the world for medical travel (Health-tourism.com 2019; Stephano 2019), there have been no published studies on forecasting medical tourism demand for Turkey.

This study aims to predict the demand of Turkey's medical tourism industry by incorporating multiple factors. For this purpose, a literature review was conducted to reveal the factors affecting medical tourism demand, and the main indicators that are relevant to Turkey's medical tourism demand were identified. Accordingly, data was collected from multiple sources. Due to the limited number of observations, and a relatively large number of indicators, Partial Least Squares Regression (PLSR) was employed to predict the response. The study concludes with a discussion of the results. The empirical findings are expected to help policymakers and practitioners improve their understanding of Turkey's medical tourism demand.

2 Literature Review

An accurate prediction of demand is an important input in policy-making and short and long term planning, thus, establishing accurate models for predicting medical tourism demand is essential. Medical tourism demand is affected by various complex factors. The search in the SCOPUS database using the search string (KEY((“healthcare tourism”) OR (“health tourism”) OR (“medical tourism”) OR (“medical travel”) OR (“health travel”)) AND TITLE-ABS-KEY((forecasting) OR (“time series”))) limited to results in English produced ten results, only seven of which were somehow related to medical tourism demand prediction (Lin et al. 2009; Johnson and Garman 2015; Loh 2015; Vetitnev et al. 2016; Dang et al. 2016; Tang and Lau 2017; Tang and Abdullah 2018). The literature review was extended to cover all studies on medical tourism, and since medical tourism is a sub-area of the tourism industry, studies referring to factors affecting the international tourism demand were also considered. Table 1 below provides a summary of the factors influencing medical and international tourism demand. Instead of an exhaustive list of all studies on the subject, a small collection of key publications that were cited in this study is given.

We identified three distinct factors that are likely to affect medical tourism demand for Turkey. The first set of indicators are related to the fulfillment of the medical needs of the patients. The likelihood of receiving a diagnosis and treatment abroad will depend on the extent of the host country's available and accessible health infrastructure (i.e., number of hospitals, number of accredited hospitals, availability of advanced medical technology, experienced medical professionals, number of licensed tourism facilities and amount of investments in health, tourism and travel infrastructure). Next are the economic indicators related to the host country's economy, which are the main determinants of the health and travel expenses that patients will have to pay for. Thus, the price attractiveness of the host country is dependent on the price index, GDP, exchange rates, and economic confidence index, and so on. Finally, reflections of social, political, and environmental events on tourism demand in Turkey are taken into account.

Table 1. Factors affecting tourism demand as a result of the literature review

Authors	Factors affecting tourism demand
Ferrer and Medhekar (2012)	Cost, waiting time and privacy
Kumar et al. (2012)	The increasing level of surgeons' professionalism, proper diagnostic technology, surgery costs, traveling expenses, exchange rate
Singh (2013)	Local primary doctors' recommendations, medical facilities and services, hotels and food/beverage quality, general tourism supply, governmental policies, and laws
Khan and Banerji (2014)	Increasing population, growing lifestyle-related health issues, cheaper costs for treatment, thrust in medical tourism, improving health insurance penetration, increasing disposable income, government initiatives and focus on Public-Private Partnership (PPP) models
Lin (2014)	Policies, government support, price and quality, infrastructure, healthcare needs of the destinations, international/regional economy instability, cross-cultural competence
Johnson and Garman (2015)	Economic indexes of the origin country, travel cost to the host country, health index of the origin country, healthcare expenses in the host country
Loh (2015)	per-capita GDP of the host country, the medical price index for private health expenditure, and public and private investment in health facilities as proportions of the total health expenditure
Untong et al. (2015)	Risk events, seasonality, economic growth of origin country, the price index of the host country, the price index of competing host countries
Vetitnev et al. (2016)	Currency rate, gross domestic product, life expectancy, income per capita, household spending, cost of tourist services, gross regional product, investment in the regional economy, sanatorium branch income, regional income per capita
Tang and Lau (2017)	Income, price, exchange rate, SARS outbreak, safety, medical quality, manpower, medical facilities
Rokni et al. (2017)	Promotional activities, policy-making and action regulation
Azimi et al. (2018)	Staff, service, process, price, facilities and promotion
Yu et al. (2018)	Quality, cross-industry cooperation, government certification, marketing awareness, and key leader
Medhekar et al. (2019)	Less waiting time for surgery, healthcare quality and accreditation, staff/surgeons expertise, healthcare information, hospital facilities and services, patient safety, travel risk, surgical costs, and holiday opportunity

3 Methodology

3.1 Partial Least Squares Regression

In Multiple Linear Regression (MLR), the primary interest would be obtaining unbiased coefficient estimates for the predictor variables in hand, and several assumptions must be met for that purpose. Absence of multicollinearity is one of these assumptions, which would, in turn, lead to insignificant parameter estimates due to inflated standard errors. PLSR overcomes this issue following a route similar to that in Principal Components Analysis (PCA). However, PLSR is essentially interested in better predicting the response rather than producing consistent parameter estimates (Abdi 2003).

Having been effectively applied in a wide range of fields such as comparative molecular field analysis, statistical process control, tumor classification, spatial analysis in brain images, and marketing (see Mevik and Wehrens 2007), bioinformatics, chemometrics, and behavioral science (see Sampson and Bookstein 2005), PLSR is a relatively new technique that is adopted when the number of predictor variables is larger than the number of observations in a study and/or predictor variables are collinear. PLSR allows for more than one dependent variable and relates to canonical correlation in this respect. On the other hand, it resembles PCA as it also builds upon the idea of dimension reduction. The origins of PLSR can be traced back to the 1960s; however, the technique has drawn the greatest attention in the last two decades. PLSR differs from MLR in estimating the beta coefficients. Instead of using all the predictor variables available, PLSR creates latent features that are a linear combination of them, and the estimation is done using these orthogonal latent features. In this section, we focus on model building in PLSR with one response variable. For a precise and simple mathematical description of PLSR, interested readers are referred to Ng (2013).

The way the projection is done distinguishes PLSR from similar methods such as Principal Components Regression (PCR). In general, an MLR model can be expressed as follows:

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \varepsilon_i \text{ for } i = 1, 2, \ldots, n \text{ and}$$
$$\varepsilon_i \sim N\left(0, \sigma^2\right)$$

which can be rewritten as $\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{\varepsilon}$ in matrix form, where $\boldsymbol{y}$ is a $n \times 1$ vector of responses, $\boldsymbol{X}$ is a $n \times (k + 1)$ matrix of predictor values, $\boldsymbol{\beta}$ is a $(k + 1) \times 1$ vector of beta coefficients, and $\boldsymbol{\varepsilon}$ is a $n \times 1$ vector of error terms. OLS aims to find the vector $\boldsymbol{\beta}$ that would minimize the sum of squared residuals, $\boldsymbol{\varepsilon^T \varepsilon}$. The OLS coefficients can thus be written as $\boldsymbol{\beta_{OLS}} = \left(\boldsymbol{X^T X}\right)^{-1} \boldsymbol{X^T y}$. If the predictor variables are collinear or the number of parameters to estimate $(k + 1)$ is larger than the number of observations available (n), the number of linearly independent rows (or columns) of $\boldsymbol{X^T X}$ will be less than $(k + 1)$. Consequently, the inverse of $\boldsymbol{X^T X}$ does not exist, and the OLS estimation fails. PLSR offers a solution to this problem by finding latent features from $\boldsymbol{X}$ that are relevant for both $\boldsymbol{X}$ and $\boldsymbol{y}$ (Abdi 2003). Thus, what PLSR does is very similar to what Principal Component Analysis (PCA) does; however, the latter is an undirected technique, so it reduces the dimension of $\boldsymbol{X}$ without considering $\boldsymbol{y}$. In PLSR, $\boldsymbol{X}$ is sequentially decomposed into a set of orthogonal latent features such that the covariance between the predictor variables and the response is maximized. This part is no different than PCA. Mathematically, the matrix of orthogonal scores, $\boldsymbol{T}$, is written as

$$\boldsymbol{T} = \boldsymbol{X}\boldsymbol{W}$$

where $\boldsymbol{W}$ denotes the matrix of weight vectors corresponding to predictor variables. The sizes of matrices $\boldsymbol{T}$ and $\boldsymbol{W}$ are based on the number of latent features retained and the number of columns in them can at most equal k. Then, the decomposition of $\boldsymbol{X}$, namely $\boldsymbol{T}$, is used to predict $\boldsymbol{y}$ (Abdi 2003):

$$\boldsymbol{y} = \boldsymbol{T}\boldsymbol{P} + \epsilon$$

Here, $\boldsymbol{P}$ is a $r \times 1$ matrix of loadings of $\boldsymbol{T}$ for $r \leq k$, and ϵ is a $n \times 1$ vector of error terms. Thus, the PLS coefficients can be found by $\boldsymbol{\beta}_{\boldsymbol{PLS}} = \boldsymbol{W}_{\boldsymbol{k}+1\times\boldsymbol{r}}\boldsymbol{P}_{\boldsymbol{r}\times 1}$.

Different from the OLS procedure, the PLS coefficients are estimated using an algorithm; they are not optimized (Izenman 2008). The most popular such algorithms offered in the literature are Nonlinear Iterative Partial Least Squares (NIPALS) (Wold 1975) and SIMPLS (de Jong 1993). Both the NIPALS and SIMPLS produce same results when there is only one response variable. The latter is faster and easier to interpret since it is not interested in breaking down the data sets into pieces (de Jong 1993). We do not delve into much deeper explaining these two algorithms; however, interested readers are referred to Rosipal and Krämer (2006) for details on the statistical properties of PLSR.

PLSR makes fewer assumptions regarding the distribution of data and variables, and the parameter estimates become consistent with increased sample size (Chin 1995). It also easily handles missing data (Russolillo 2009). Even though PLSR has several advantages over traditional methods, it also has some drawbacks. First of all, the latent features created by using the predictor variables do not always have a straightforward interpretation (Park et al. 2002). Secondly, it cannot easily integrate categorical predictors into the model. There are extensions to PLSR to include nominal data, one of which was proposed by Russolillo (2009). Note also that β_{PLS}'s are only asymptotically unbiased (Russolillo 2009), so they are interpretable when the sample size is large enough. However, one can still benefit from PLSR when the sole purpose is prediction rather than estimation.

Alternatively, neural networks can be employed as a way to handle collinear variables (Tobias 1997); however, when the sample size is limited, this type of models may not perform well in prediction. Ridge regression and stepwise regression are also strong alternatives to overcome the multicollinearity problem; however, they introduce several assumptions on data and variables. Considering all these advantages and disadvantages, we preferred PLSR over other alternatives in predicting the medical tourism demand of Turkey.

4 Data and Variables

Quarterly data used in this study were collected from online sources, and it covers the years 2003 through 2017 (60 data points). Table 2 describes each variable, whereas Table 3 presents the Pearson's correlations among the continuous variables along with their means and standard deviations. The dependent variable (DV) and PV01 through PV10 were obtained from Turkish Statistical Institute (turkstat.gov.tr), PV11 and PV12 were obtained from Central Bank of the Republic of Turkey (tcmb.gov.tr), and PV13 was taken from Dilek and Dilek (2013) and www.tarihtebugun.org. Thirteen of the 78 Pearson's correlations were found insignificant at $\alpha = 0.10$, which were given in bold in Table 3. Approximately 79% of the significant correlations can be considered as high (greater than 0.70) and 7.7% of them as small or moderate (smaller than 0.50). Thus, multicollinearity would undoubtedly be an issue if these predictor variables were used altogether in a traditional regression model.

Table 2. Description of variables

Variable	Description	Variable	Description
DV	Number of tourists	PV07	Trade, Transport, and Accommodation
PV01	Total Inpatient Health Inst.	PV08	Public Administration, Education, Human Health & Social Work Activities
PV02	Total Outpatient Health Inst.	PV09	Economic Confidence Index
PV03	Number of beds per 1000 inhabitants	PV10	Health Expenditures
PV04	Total number of beds	PV11	USD/TRL Exchange Rate
PV05	Gross Domestic Product (GDP)	PV12	EURO/TRL Exchange Rate
PV06	Consumer Price Index (CPI)	PV13	Social & Political Events

5 Results and Discussion

The predictor variables were standardized before building the regression models. Alternative models were estimated, and their performances were compared. Due to limited space, only the results of the four models are reported. Model I predicts the original response with PLS estimation using only the continuous predictor variables; employing PLS estimation using only the continuous predictor variables, Model II predicts a response that is the error term of a regression model in which PV13 is the only predictor variable; Model III predicts the original response using OLS estimation. In such a case, using OLS estimation is not reasonable; therefore, we also predict the original response using stepwise OLS estimation (Model IV). Nevertheless, we report the results of Model III for comparison. All of the models are overall significant at $\alpha = 0.05$ ($F_{\text{Model I}} = 15.10$, $F_{\text{Model II}} = 14.08$, $F_{\text{Model III}} = 31.29$, $F_{\text{Model IV}} = 57.29$). Leave-one-out cross-validation was performed to measure the predictive ability of the models. The procedure used 59 of the 60 observations available to estimate the parameters and then predicted the value of the observation that was left out. The difference between this prediction and

Table 3. Descriptive statistics and correlations

Variable	Mean	SD	DV	PV01	PV02	PV03	PV04	PV05	PV06	PV07	PV08	PV09	PV10	PV11
DV	4,6206	20538												
PV01	1,388.50	132.10	0.55											
PV02	19,948	9,774	0.55	0.95										
PV03	2.60	0.10	0.54	0.90	0.92									
PV04	192,285	18,345	0.64	0.94	0.95	0.97								
PV05	356.90	199.50	0.74	0.83	0.87	0.86	0.94							
PV06	324.22	28.38	−0.49	**−0.22**	−0.33	−0.26	−0.37	−0.55						
PV07	79,648,036	42,897,203	0.76	0.82	0.85	0.84	0.92	1.00	−0.55					
PV08	39,467,798	21,987,296	0.74	0.86	0.90	0.89	0.97	0.98	−0.53	0.98				
PV09	99.37	13.48	**−0.03**	**−0.11**	**0.01**	**−0.03**	**−0.04**	**0.03**	**0.08**	**0.04**	**−0.01**			
PV10	0.60	0.49	0.73	0.87	0.88	0.90	0.97	0.97	−0.48	0.97	0.99	**−0.02**		
PV11	69,924	32,721	0.72	0.67	0.74	0.77	0.85	0.93	−0.73	0.93	0.94	0.92	**−0.01**	
PV12	1.88	0.70	0.74	0.77	0.81	0.83	0.91	0.97	−0.68	0.97	0.97	0.96	0.97	**0.00**

the actual value was saved, and the procedure was repeated, each time leaving a different observation out. In the end, a total of 60 such error terms were obtained, and the sum of their squares was calculated. This sum is called the PRESS index, which indicates whether over-fitting is an issue. It is used to calculate R^2-pred, a measure of the predictive power of a regression model. Similar to R^2, R^2-pred increases with the inclusion of additional predictor variables; however, it begins to decrease once a certain number of variables has been considered. This is where to stop extracting latent vectors in PLSR or introducing new predictors in MLR. Tables 4 and 5 provide the goodness-of-fit results of Models I and II. The MLR model has $R^2 = 75.14\%$ and R^2-pred $= 60.60\%$, whereas these values decrease to 66.78% and 62.80%, respectively, for Model IV. Model I has the highest R^2-pred when eight latent vectors are retained. These eight components explain 99.63% of the total variation in the predictor variables. Similarly, Model II retains nine latent vectors, which explain 99.88% of the total variation in the predictor variables. The predictive power of Model II is slightly better than that of Model I, and it performs slightly worse than Model IV regarding prediction. However, note that Model II does not predict the original response. We initially predict the original response with OLS estimation using PV13 as the only predictor, which returns a standardized beta coefficient of 0.346 (p-value $= 0.085$) and R^2-pred $= 1.25\%$. Then, we predict the standardized residuals saved at the initial step using PLS estimation and obtain the standardized coefficients given in the third column of Table 6 below. That is, the predictive ability of Model II is almost as good as that of Model IV. On the other hand, only two of the parameter estimates in Model IV are significant at $\alpha = 0.05$, and the variance inflation factors for PV05 and PV07 are far greater than the practical threshold (around 240 for both). This indicates that stepwise OLS estimation does not serve its main purpose: reliable parameter estimates.

The signs of the standardized coefficients do not differ for any predictor variable across alternate models. Models I and II emphasize the relative importance of PV05 and PV07 in the prediction of corresponding responses. Models III and IV agree with this result at $\alpha = 0.05$. All of the models also agree that PV05 and PV07 affect the response in opposite directions.

Table 4. Model selection and validation for response – Model I

Components	X variance	Error	R^2	PRESS	R^2-pred
1	78.15%	28.42	51.84%	30.44	48.40%
2	87.42%	25.25	57.21%	28.57	51.58%
3	89.40%	21.95	62.79%	26.17	55.64%
4	90.93%	21.36	63.79%	25.57	56.66%
8	99.63%	17.52	70.31%	24.84	57.90%

Table 5. Model selection and validation for response – Model II

Components	X variance	Error	R^2	PRESS	R^2-pred
1	78.13%	24.94	53.99%	26.68	50.78%
2	87.65%	22.31	58.85%	25.12	53.66%
3	89.60%	20.67	61.88%	25.16	53.58%
4	97.30%	20.49	62.20%	24.46	54.87%
9	99.88%	15.34	71.71%	21.27	60.77%

Table 6. Standardized beta coefficients

Variables	Model I	Model II	Model III	Model IV
Intercept	0	0	0.3120*	0.1700
PV01	−0.3170	−0.0827	−0.4690	
PV02	−0.6543	−0.9408	−1.0760**	
PV03	−0.2186	−0.1258	−1.1240	
PV04	0.6966	1.2941	4.0400	
PV05	−2.6680	−2.7753	−3.7000*	−3.8900*
PV06	−0.3723	−0.4868	−0.5420**	
PV07	3.0413	3.2561	4.2800*	4.6300*
PV08	2.5269	3.1983	2.0500**	
PV09	−0.0302	−0.0480	−0.0260	−0.1203
PV10	−0.4130	−1.6951	−1.9600	
PV11	−1.1271	−0.6059	−0.6260	
PV12	−0.5062	−1.1772	−1.2000	
PV13			−0.5210*	−0.2840**

*significant at $\alpha = 0.05$, **significant at $\alpha = 0.10$

The residual plots given in Figs. 1, 2 and 3 indicate no violation of the assumption that residuals produced by each alternate model are normally distributed. There are three possible outliers in the residuals produced by Model I and one in Model III. Even though PLSR does not make assumptions regarding the distribution of residuals, these findings provide enough evidence to use this technique for the prediction of the number of tourists visiting Turkey for medical purposes.

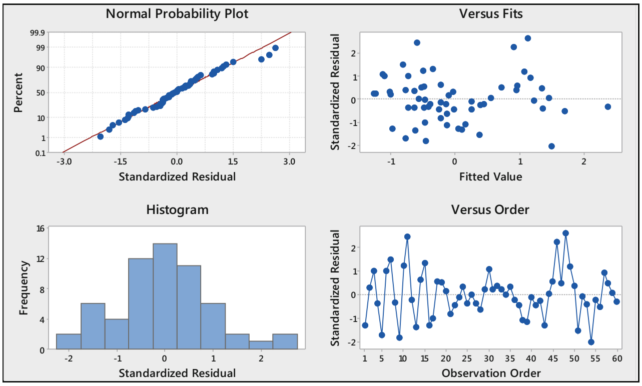

Fig. 1. Residuals plots for Model I

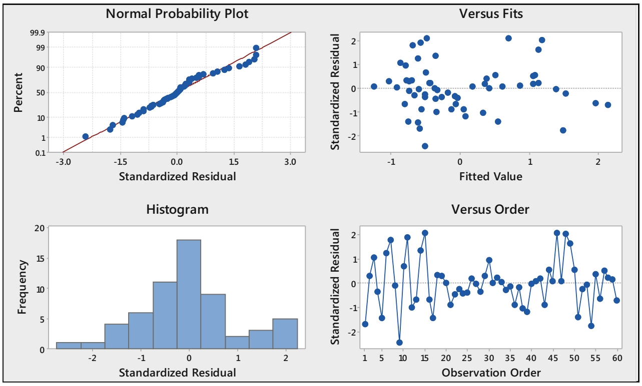

Fig. 2. Residuals plots for Model II

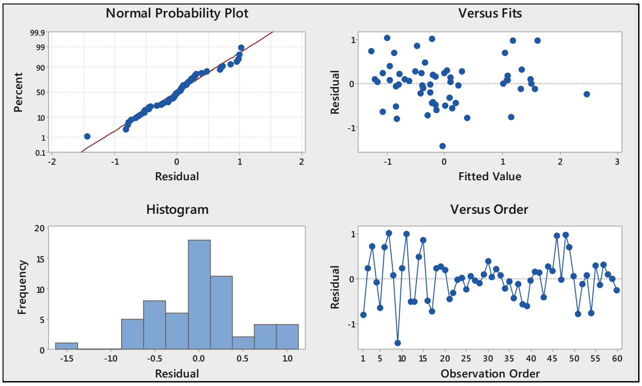

Fig. 3. Residuals plots for Model III

6 Conclusion

There is an emerging need in understanding the trends and determinants of the medical tourism industry, which has a significant impact on the host country's economy. Turkey's popularity as an international tourism destination combined with the expertise of Turkish medical professionals and advanced technology available in the leading medical facilities make Turkey one of the most popular travel destinations for medical tourism. While the expanding literature on this topic offers qualitative knowledge, empirical studies are few. This study aims to predict the demand of Turkey's medical tourism industry, considering different aspects.

Partial Least Squares Regression (PLSR) was employed to predict the medical tourism demand of Turkey due to considerably high collinearity among predictor variables. The use of PLSR is also beneficial since it makes fewer assumptions regarding the distribution of data and variables.

The empirical findings are expected to help policymakers and practitioners deepen their understanding of the trends and determinants of medical tourism demand for Turkey. Results are in line with the factors defined at the beginning of the study, which is likely to affect medical tourism demand for Turkey. These are (1) the potential to fulfill the medical needs of the patients (PV01, PV02; PV03, PV04; PV07; PV08), (2) the price attractiveness of Turkey (PV05; PV06; PV09; PV11, PV12), and (3) reflections of social and political events (PV13). The price attractiveness of Turkey driven by the indicators GDP and exchange rate, the potential to fulfill the medical needs of the patients with the amount of investments in tourism, travel, and health, and the reflections of social and political events were found to affect the demand behavior of inbound medical tourism in Turkey. The results also indicate that as the cost of medical care and travel becomes relatively cheaper, more tourists will visit Turkey for medical purposes. Additionally, the investments in medical capacity and quality (both manpower and equipment) along with the investments in tourism and travel infrastructure have significant positive effects on demand.

Practitioners and policymakers should be careful when using such a model for forecasting. The predictor variables to be used to forecast the demand for medical tourism in a specific quarter must be forecasted using a time series model or a machine learning algorithm beforehand. Thus, techniques selected to forecast the predictor variables are critically important. Researchers, in such cases, should prefer using techniques with higher predictive ability over those with better inferential power.

A possible avenue for future research could be considering some other modeling alternatives such as non-metric PLSR, principal component regression, latent root regression, and Ridge regression or retaining fewer latent vectors within a PLSR framework.

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Effects of the Awareness of University's CSR on Students' Word-of-Mouth Intentions

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Abstract. Under recent circumstances such as globalization, edu-tourism and the privatization of institutions of higher education, the resultant competition in the higher education industry has forced universities to adopt an approach that is more business-oriented to compete in and overcome the challenges of the industry. One of the major challenges facing universities is student attraction and retention, as students face little or no barrier in transferring from one university to another. As a result, universities continue to seek effective ways to remain attractive to prospective students in addition to ensuring that their current students do not leave. While corporate social responsibility (CSR) is a means for firms to improve societal well-being, it likewise offers the opportunity to have a positive reputation and competitive advantage. Studies reporting the positive effect of CSR on stakeholders' behavior are gradually increasing; thus, universities can use CSR as a part of their competitive strategy and positively influence the behavior of their students. However, for this strategy to be effective, attention has to be given to the significant role played by students' understanding and awareness of the university's CSR activities. This study investigates the association between students' awareness of their university's CSR initiatives and their intentions to recommend their university. This is particularly relevant primarily because studies that have explored the effect of CSR on stakeholders' behavior have hardly considered the higher education sector thus leaving a void in literature this study seeks to fill. The primary data for this study is obtained from a structured questionnaire survey administered to students of Eastern Mediterranean University. Based on a conceptual model developed on the theory of planned behavior (TPB), this study investigates the causative relationships among awareness of CSR activities, perceived behavioral control, subjective norm, attitude and Word-of-Mouth intention using PROCESS macro. Theoretically, the present study contributes to the existing body of knowledge in this field by recommending and empirically analyzing an extended TPB model to predict students' recommendation intentions as a result of being aware of their university's CSR activities. This study is also relevant to the managers of higher education institutions as the findings suggest they can leverage on their CSR activities to build a reputation and gain competitive advantage.

Keywords: Word-of-Mouth intention · Corporate social responsibility · Universities · Theory of planned behaviour · Higher education

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1 Introduction

The increasing expectations of universities globally to satisfy different stakeholders (such as the society, employees, parents, the government and students), and to address social and ecological issues have imposed on them huge social responsibility (Kunstler 2006). In a bid to better respond to these societal demands and expectations, universities have had to glean from the corporate experience. This explains why universities and academia at large are nowadays characterized by managerialism and corporate models, an example of which is the adoption of corporate social responsibility (CSR) strategies (Hammond and Churchman 2008).

Also, currently, universities are faced with challenges similar to that of corporations; they struggle for funds, good employees, reputation, and student enrolment (which will be clienteles in the case of corporations). As a result, higher education institutions (HEI) are embracing an approach that is more business-like; realizing the significance of corporate image, corporate identity, corporate reputation and are employing socially responsible actions as a strategy to build a reputable image and competitive advantage (Atakan and Eker 2007; Porter and Kramer 2006). Thus, high competition among universities nationally and internationally is a reality (Sanchez-Hernandez and Mainardes 2016); and in a competitive environment, marketing is essential to organizations' growth and survival. In other words, organizations in a competitive market have to remain attractive to prospective customers (which are students in the case of universities) to survive. Therefore, marketing concepts and theories that have been employed in the corporate world are now useful in the marketing of universities (Hemsley-Brown and Oplatka 2006). From this perspective, one of the new developments in the marketing of universities is social responsibility (Sanchez-Hernandez and Mainardes 2016). While CSR is a means for universities to enhance societal well-being, implementing CSR strategies provide universities with the opportunity to gain a sustainable competitive edge over competitors (Burcea and Marinescu 2011). The global dynamics and challenges of universities are also valid in the Turkish Republic of North Cyprus (TRNC). TRNC (which is our study context) is a global edu-tourism hub, and the HEI in TRNC have also begun to adopt an approach that is more business-like, as the dynamics of the country's very competitive higher education sector are not so different from the other parts of the world.

The impact of an organization's CSR activities on the attitudes and behavioral intentions of most of its stakeholder group is well documented in the literature (Rahim et al. 2011; Vahdati et al. 2015; Jung et al. 2018). This study argues that the CSR activities of universities can favorably influence the attitudes and behavioral intentions of their students. However, the effectiveness of this hinges on the students' awareness of their universities' CSR activities. Stakeholders' awareness of an organization's CSR activities is additional advantage to the organization and a prerequisite of benefits like customer retention (Ali et al. 2010; Engizek and Yasin 2017), positive word of mouth (Szymanski and Henard 2001; Zapata-Ramos and Kim 2018) and positive responses (Tian et al. 2011).

Steckstor (2012) described positive word-of-mouth intention (WOM) as the attitude of an individual to engage in complimentary WOM with other consumers. Jalilvand et al. (2017) explained WOM as a sort of informal information about services and products among persons who have used the services or products and individuals who may be interested in the services or product. WOM has been researched as possible behavioral intentions following an individual's interaction with a brand, service, product, or organization (Swanson and Davis 2003).

A few theories have been employed by researchers to predict and explain behavioral intentions. Ajzen (1991)'s theory of planned behavior (TPB), has been used to predict behavioral intentions (Wang et al. 2016). Ajzen (1991) explained that three variables jointly result in an individual's behavioral intention formation. These variables are perceived behavioral control (PBC), attitude, and subjective norms. However, scholars have reiterated over the years that one specific construct that could be added as an extension to boost the predictive ability of TPB is self-identity (Reid et al. 2018). Rise et al. (2010) describe self-identity as a prominent and persistent aspect of an individual's self-perception. This might be in the form of social categorizations that have certain expectations and meanings associated with it (e.g., perceiving oneself to be a 'socially responsible' individual might be connected to certain expectations like recommending a socially responsible organization to friends and family). Therefore, using an extended model of TPB, the present study will investigate the effect of students' awareness of their university's CSR on their word-of-mouth intentions. This is instrumental to deepening the available knowledge on CSR, as literature that has explored the influence of CSR on stakeholders' behavior have hardly considered the higher education sector thus leaving a void in literature this research aims to fill.

The current study continues with a review of relevant literature, which is followed by a development of the study's hypotheses. The methodology by which the study is carried out is presented before reporting the results of the study. In the final section, the findings of the study are discussed.

2 Literature Review

2.1 Corporate Social Responsibility Within the HEI Context

The concept of CSR has developed over the years as one of the major subject matter of the current capitalist society. Even though large corporations had been at the center of CSR research, with time and with more progressive studies, other forms of organizations such as small and medium-sized businesses, government organizations and universities were also included (Nejati et al. 2011). Within the HEI context, Vieira et al. (2018) argued that universities could have substantial environmental and social impact. Alshuwaikhat and Abubakar (2008) argued that a number of these impacts are due to the large size of these institutions, huge consumption of materials, expressive movement of vehicles and people, as well as the complex and diversified activities that make up the higher education services. Due to their significant environmental and societal impact, it is expected that universities be responsible to all their stakeholders, the environment, and the society (Nejati et al. 2011). Similarly, Dahan and Senol (2012) highlighted that because of the complexity of the operations of HEI, which constantly overlap with social interest, higher education institutions are under pressure for socially responsible practices.

The CSR actions of universities ought to address economic, environmental as well as social concerns that cannot be detached from the institution's strategic operations and planning, which is central to how the institution interacts with the society as well as other external and internal stakeholders (Chen et al. 2015). Universities are social institutions, and they are expected to contribute to the social cause, but more recently, CSR has been more important for universities as a growth strategy (Jimena et al. 2011; Nadeem and Kakakhel 2012). Jimena et al. (2011) maintain that universities are riding on the CSR wave to gain a competitive advantage in the higher education sector. One of the motivators for the CSR actions of universities is maintaining a good reputation in the highly competitive higher education sector (Nadeem and Kakakhel 2012). Some studies have also shown that if universities can effectively address the social and environmental concerns of their stakeholders, it will help them in sustaining a competitive edge (Burcea and Marinescu 2011; Dahan and Senol 2012). Students, as an important stakeholder of universities, are important players in the CSR dynamics of universities. Just as investors can provide capital; host communities of universities can provide location and infrastructure; employees can grant leadership and expertise; students can offer word-of-mouth and loyalty to socially responsible universities (Fatma and Rahman 2015). University students today are more conscious of social and environmental issues than ten years ago (Lee 2011). Thus, these students expect their universities to be socially responsible. Hence, universities have included CSR as a value proposition (Dahan and Senol 2012). Furthermore, due to the good reputation, CSR accords to universities (Burcea and Marinescu 2011; Dahan and Senol 2012); stakeholders will be more willing to identify with socially responsible universities. Student, for example, will be attracted to and be willing to identify with socially responsible universities due to its good reputation and also because there is generally an increased sense of environmental and social consciousness among students (Lee 2011). However, according to Bhattacharya and Sen (2004) the level of awareness differ among consumers yet being aware of CSR activities has been said to be a prerequisite to the benefits of CSR like purchase intention, loyalty and customer–company identification (Becker-Olsen et al. 2006; Marin et al. 2009; Tian et al. 2011).

3 Theory of Planned Behaviour

This study examined whether, and in what way students' awareness of the universities' CSR will influence their word of mouth intention. For this purpose, the TPB model (Ajzen 1991; Fishbein and Ajzen 2011) is adopted as a theoretical framework to predict word of mouth intentions of university students. Several different studies have endorsed the predictive ability of TPB in consumer behavior (Wang et al. 2016). The TPB (Ajzen 1991) essentially states that behaviors are determined by the intention of a person to perform a particular action. The intention is a reflection of cognitive planning and motivations for engaging in a behavior, and it is dependent on three significant cognitive factors: subjective norm, PBC and attitude (Ajzen 1991; Fishbein and Ajzen 2011).

Attitude is the extent to which an individual has an unfavorably or favorable appraisal of the behavior in question, which is an outcome of the person's mental processes (Ajzen 1991; Lopes et al. 2019). Kotchen and Reiling (2000) stated that attitude is the most decisive factor that governs the behavioral intention of an individual. It has been empirically proven that an individual's positive attitude towards social responsibility often leads to socially responsible behavior. For example, in the green hotel context, Han and Yoon

(2015) found that attitude leads to environmentally friendly behavior. Subjective norm is the social pressure an individual perceives him/herself to be under, which is influencing him or her to act in a particular manner or execute certain behavior. From the TPB viewpoint, the subjective norm is an important element that influences an individual's behavioral intention (Hameed et al. 2019). It is an individual's feeling regarding certain behavior from society's perspectives. If an individual feels positive regarding society's behavior, such an individual will begin to behave positively. Subjective norm has been reported to significantly influence socially responsible behaviors (Dean et al. 2012; Moser 2015). PBC is an individual's perceived ability to display a particular behavior. It is an individual's perceived difficulty or ease of executing a specific task (Hameed et al. 2019). An individual's ability is measured based on how confident such a person is as regards performing the behavior. An individual who has a belief that he/she is incapable of performing certain behavior because of the want of skills required to display the behavior is not likely to have a strong behavioral intention regardless of the effectiveness of the other TPB model variables (Zhou et al. 2013). PBC has also been empirically linked to socially responsible behavioral intention (Albayrak et al. 2013; Tarkiainen and Sundqvist 2005; Taylor and Todd 1995; Chang et al. 2014). Furthermore, these constructs have been extensively described in the literature as effective predictors of positive word of mouth intention (Fu et al. 2015).

However, taking a cue from prior studies, this study posits an extended TPB model to contain another component, in a bid to amplify the model's prognostic ability. Several researchers think that TPB requires some merger, decomposition or extension for it to support fully, and offer a reasonable defense for their proposed theoretical frameworks in predicting behavioral intentions (Dahiya and Gayatri 2017; Han 2015; Kiatkawsin and Han 2017). These scholars have specified that the predictive power of the three TPB indicators (PBC, attitude, and subjective norms) is somewhat not sufficient in predicting the behavioral intentions of moral individuals. Therefore, self-identity is considered as an inclusion to the TPB framework of this study. The explanation for the ability of self-identity to predict behavior is based on Identity Theory (IT) (Callero 1985). IT describes how a person's expectations of role-appropriate behavior can enforce his/her position in society (Charng et al. 1988). This means that when a subject matter becomes crucial to a person's self-identity, behavioral intentions are consequently attuned. In this study, the measure of self-identity is specifically denoted to as "socially responsible," which can be described as the duty to behave in a way that is beneficial to society at large (Seechi 2009; Seechi and Bui 2018). In this particular framework, socially responsible individuals have socially responsible behavioral intentions because social responsibility has turned out to be an essential part of their self-identity. Scholars have conveyed the legitimacy of adding the construct of self-identity into the TPB model in predicting intentions and behaviors (Smith et al. 2008).

4 Word-of-Mouth Intention

In the literature, a broad range of conditions has been reported to influence and be influenced by word of mouth activities, such as attitudes, perceptions, expectations, and awareness (Brown et al. 2005). According to Berry et al. (1994), much like repurchase, positive WOM is a behavioral intention that has to do to recommend. The viability of which is an offshoot of positive word of mouth since individuals like to talk about their pleasant experiences and satisfaction with services, brands and organizations with friends and family, persuading others who are prospective customers to purchase (Berry et al. 1994; Zeithaml 2000). In general, studies on WOM (e.g., Mazzarol et al. 2007) revealed that the reason for an individual to be involved in positive WOM varies. Some people are involved in positive WOM for reasons that are altruistic and philanthropic (Sundaram et al. 1998). Identification has also been reported to be a precursor of positive WOM (Brown et al. 2005; Hong and Yang 2009). That is, when an individual's schema overlaps with that of an organization, such an individual tends to identify with that organization by engaging in WOM. According to Arnett et al. (2003), when individuals say positive things about an organization to friends and family, it offers them the means to express their self-identity and the extent to which there is an overlap between the 'self' and the organization, is the extent to which a person will spread WOM concerning the organization. According to Bhattacharya and Sen (2003), people turn out to be champions of the organizations with which they identify. Although there are lots of WOM studies dating back to Katz and Lazarsfeld (1955), the limited number has sought to link WOM intentions to its precursors clearly, and they have concentrated more on the direct causality between product-related or service-related features and WOM (Hong and Yang 2009). Scholars have rarely investigated the association between organization-related attributes such as corporate social responsibility and WOM.

5 Hypothesis Development

5.1 Awareness of CSR and Attitude, Subjective Norm, Self-identity, Perceived Behavioral Control and WOM Intention

The awareness of an organization's CSR actions is a good predictor of behavior (Wigley 2008; Maignan 2001). Earlier studies (e.g., Mohr et al. 2001) reported that low knowledge and awareness of an organization's CSR initiatives is a primary issue limiting the people's positive responses to the organization's CSR activities. Increased awareness of CSR activities will influence the attitude of an individual towards the organization (Fatma and Rahman 2015). Increased awareness of the social responsibility of government is also assumed to be the reason for the positive attitudes and increased the perception of one's capability to perform socially responsible behaviors among Chinese energy consumers (Zhou et al. 2013). Awareness of an organization's CSR activities will influence an individual's perception of societal norms (Raub and Blunschi 2014) if the perception is deemed positive, the individual can be influenced to adopt a corresponding self-identity.

Therefore this study hypothesizes that:

H_1–H_4: Students' awareness of University's CSR will positively influence the students' attitude, subjective norm, self-identity and perceived behavioral control

5.2 Impact of Attitude, Subjective Norm, Self-identity and Perceived Behavioral Control on Intention

Findings from prior research confirm the ability of self-identity, subjective norms and attitude and PBC to predict individuals' behavioral intention (see Chan and Bishop

2013; Chen and Peng 2012, Han et al. 2010, Kim et al. 2013). In this study, the outcomes of an individual's PBC, subjective norm, and attitude are WOM intentions. Since a person's attitude is understood as the person's overall effect toward a particular behavior, it reveals the person's overall appraisal of the badness or goodness in carrying out the behavior after evaluating the consequences of behavioral beliefs. That is, if an individual has favorable attitudes regarding certain behavior, the person has greater chances of engaging in such behavior. On the other hand, if an individual has a negative attitude regarding certain behavior, such a person is unlikely to engage in such behavior. Hence, this study posits that

H_5: Student's attitude towards recommending a socially responsible university, will strongly influence the intention to engage in positive WOM about his/her socially responsible university

Subjective norm is based on what an individual's normative beliefs regarding what most of the people who are important to him/her think and the degree to which such a person is willing to conform to what they think (Ajzen and Fishbein 1980). In other words, if social responsibility is regarded as a virtuous deed by a person's significant others, and the person also has a high impetus to conform to his/her significant others, such a person will have stronger intention to engage in socially responsible behaviors. Therefore, if the behavior is acceptable socially, the intent to carry out the behavior is high. For this reason, this study posits that

H_6: A student's subjective norm will strongly predict the intention to engage in positive WOM about his/her socially responsible university

Conner and Abraham (2001) believe that an individual's behavior is greatly influenced by his/her self-assurance in his/her capability to display the proposed behavior. When an individual believes that they possess very little control over the performance of a certain kind of behavior due to lack of necessary resources, such an individual's intentions to engage in the behavior may be low even if they have a positive subjective norm and/or attitude about the said behavior. Consequently, the following hypothesis is developed:

H_7: A student's perceived control to act recommend a socially responsible university will positively influence the intention to engage in positive WOM about his/her socially responsible university

Consumers identify with organizations when they observe that there is an overlap between their self-identity and the organization's CSR activities (El-Kassar et al. 2019; Lichtenstein et al. 2004). Such identification is seen in more positive behavioral intention towards the organization such as continuance, positive word of mouth communication and loyalty (Bhattacharya and Sen 2004). When customers speak positively about an organization, it provides the means of expressing their self-identity (Arnett et al. 2003). Consequently, the following hypothesis is developed:

H_8: A student's self-identity as a socially responsible person will positively influence the intention to engage in positive WOM about his/her socially responsible university

Consumers' awareness of an organization's efforts to be socially responsible is likely to influence their intention to engage in positive WOM about the organization (Kang and Hustvedt 2014). Consumers are very likely to engage in positive WOM about companies they are aware of being sharing their ethical values (Maxham and Netemeyer 2003).

Handelman and Arnold (1999) argued that organizations whose customers are aware not to be violating industry norms associated with social responsibility receive positive WOM. Thus we propose that

H_9: Awareness of CSR activities will directly influence WOM intentions

6 Methodology and Results

The primary data for this study were obtained through a structured questionnaire administered to students of Eastern Mediterranean University. The survey scales of this study were drawn from different constructs' pre-existing measures and adapted to the HEI context. Subjective norm is drawn from Liang et al. (2013); Perceived behavioural control from Kim and Han (2010); positive WOM intention from Prayag et al. (2017); awareness of CSR from Raub and Blunschi (2014) and Maignan (2001); attitude from Ajzen (1991); continuance intention from Kim et al. (2013) and self-identity from Shephard et al. (1995). Demographics of the level of study, gender, and age were included in the second part of the survey questionnaire. The respondents participated voluntarily in the survey by filling the self-administered questionnaires. All responses were on a 5-point Likert scale, from "1: totally disagree" to "5: totally agree". The statistical analyses of the study were performed using AMOS 23.0 and SPSS 23.0. A confirmatory factor analysis (CFA) was first carried out to determine the quality of the measurement model (that is, the model fit), discriminant as well as convergent validity. After which, Hayes' (2013) SPSS PROCESS macro was employed in conducting the study model's path analysis. Based on George and Mallery's (2010) recommendation, other analyses, particularly the kurtosis and skewness of the distribution of the variables were also scrutinized, and all were in the −2 to 2 range, which suggests normality of the distribution. The sample consisted of 214 respondents; 57.9% male, 42.1% female. 75.7% aged 18–29 years, 21.5% aged 25–34, and 2.8% aged 35–44. 76% were undergraduate students, 19.6% were Masters Students, and 4.2% were Ph.D. students.

Outcome from the CFA revealed that the data, and the model fits: $\chi 2\,(231) = 362.142$, $p = .000$; $\chi 2/\mathrm{df} = 1.568$; CFI = .94; SRMR = .0544; RMSEA = .052. Fornell and Larcker's (1981) conditions were used to evaluate the discriminant and convergent validity of our data. Table 1 shows the standardized factor loadings, average variance extracted (AVE), internal consistency (α), and composite reliability (CR) of all constructs. Excluding two items from the subjective norm and perceived behavioral control (which were subsequently removed), the other items loaded onto their corresponding latent construct. CR values, as well as Cronbach's alphas, surpassed the 0.70 thresholds. The AVEs exceeded .50 except for that of Awareness, which is 0.481. Although 0.50 is the acceptable threshold of reliability, Malhotra and Dash (2011) argue that reliability can be established via CR alone because AVE is too strict. Hidayah et al. (2019) likewise insisted that latent variables' AVE can still be below 0.50 if its composite reliability is satisfactory.

Each variable AVE's square root was more than the inter-correlations with other variables, as shown in Table 2. Overall, these results sustained discriminant and convergent validity.

Table 1. Constructs reliability, Factors loadings, and Cronbach's Alpha

	Factor loading	CR	α	AVE
Attitude		**0.863**	**0.863**	**0.557**
Att 1	0.811			
Att 2	0.799			
Att 3	0.799			
Att 4	0.787			
Att 5	0.780			
Subjective Norm		**0.802**	**0.764**	**0.504**
SN1	-			
SN 2	0.828			
SN 3	0.749			
SN 4	0.734			
SN 5	0.676			
Perceived Behavioural Control		**0.733**	**0.698**	**0.501**
PBC 1	0.838,			
PBC 2	0.783			
PBC 3	0.552			
PBC 4	-			
Awareness of CSR		**0.73**	**0.717**	**0.481**
Aware 1	0.816			
Aware 2	0.815			
Aware 3	0.656			
Social Self-Identity		**0.74**	**0.731**	**0.59**
SID 1	0.827			
SID 2	0.788			
WOM Intention		**0.9**	**0.899**	**0.75**
Recom 1	0.878			
Recom 2	0.874			
Recom 3	0.858			

Note: (-) represent items removed during CFA

7 Hypotheses Testing

To test the hypotheses of the awareness-behavioral intention link through PBC, self-identity, attitudes, and subjective norms, a parallel multiple mediation analysis was carried out using PROCESS model 4 (Hayes 2013). Before this, an average value of

Table 2. Discriminant validity criterion and intercorrelations

	1	2	3	4	5	6
Awareness of CSR	**0.693**					
Attitude	$0.163^{\dagger}$	**0.747**				
Subjective norm	0.399^{***}	0.169^{*}	**0.71**			
Perceived behavioural control	$0.1^{\dagger}$	0.245^{**}	0.508^{***}	**0.642**		
Social self-identity	0.328^{**}	0.184^{*}	0.553^{***}	0.570^{***}	**0.768**	
WOM intentions	0.344^{***}	0.282^{***}	0.405^{***}	0.488^{***}	0.288^{**}	**0.866**

Note: $\dagger = p < .100$; $* = p < 0.05$; $** = p < 0.01$; $*** = p < 0.001$ (2-tailed). Numbers on the diagonal are the AVE's square roots.

all the items in each of the construct was calculated. All the hypothesized direct effects were supported (H_1–H_9) except for the relationship between WOM intention and social identity (H_8) (see details in Fig. 1).

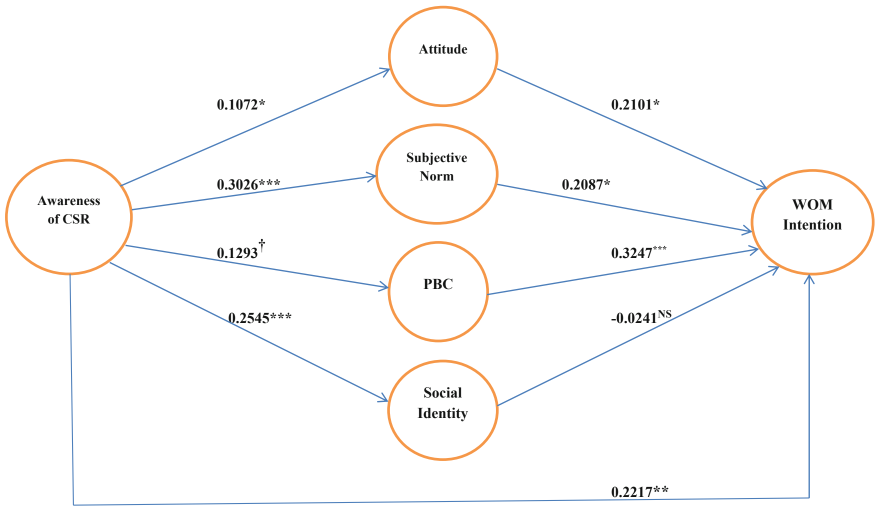

Fig. 1. Research model with analysis results. Note: $\dagger = p<.100$; $* = p< .05$; $** = p<.01$; $*** = p<.001$ (2-tailed).

The statistical significance of the tested indirect effects was provided by a 95% bias-corrected and accelerated confidence interval (BCa CI) bootstrap with 10,000 resamples. As shown in Table 3, the association between awareness of CSR and WOM intention is jointly and partially mediated by the variables of the extended TPB model (self-identity, subjective norms, perceived behavioral control and attitudes).

Table 3. Total, Direct, and Indirect Effect

	Total effect	Direct effect	Indirect effect
Awareness of CSR => WOM Intention	0.3392	0.2217	0.1175
95% BC CI	0.1815–0.4970	0.0672–0.3762	0.0132–0.2342

Note: $p < 0.01$

8 Discussion and Conclusion

The findings of this study revealed that awareness of universities' CSR activities significantly influences the WOM intention of students through a TPB model, extended to include self-identity. This is by the findings of Lee and Shin (2010) and Pomering and Dolnicar (2009), which recognize that awareness of CSR activities influences consumer behaviors. The insignificant relationship between social self-identity and WOM intention is contrary to our proposed hypothesis (H_8); failing to confirm the findings of Brown et al. (2005). This could be explained by Biddle et al. (1987) argument that self-identity, norms, and attitudes do not have the same motivational roots. People imitate norms for fear of external sanction by significant others and follow attitudes based on instrumental reasons. However, people act in harmony with their self-identity based on self-verification reasons. Another argument to support this could be that self-identity might merely be reflecting past performances of behavior and not necessarily predicting a future behavioral-intention (Rise et al. 2010). Unlike self-identity, this study confirms that PBC is a strong predictor of behavioral intentions. This finding confirms the inferences of Carfora et al. (2017).

Theoretically, the current study contributes to the existing body of knowledge in CSR research by proposing and empirically supporting an extended TPB model to predict students' WOM intentions as a result of being aware of their universities CSR activities. This further confirms the predictive ability of the TPB model in general and particularly its ability to predict WOM intentions. Also, the model tested in the present study incorporated WOM intention. This integration is important since several studies on the attitude-behavioral intention model in social responsibility, and consumer's behavior towards CSR have largely only explored purchase intentions. According to Chu and Kim (2011), WOM is critically important in our world where "friends" attitude towards corporate behavior is only a "click" away. Also, the present study contributes to the studies in higher education since only limited studies have applied the TPB in that field. This is a significant contribution largely because studies that have investigated the influence of CSR on stakeholders' behavioral-intentions have hardly considered the higher education sector.

Managerially, this study reveals that attention has to be given to the significant role played by students' understanding and awareness of their university's CSR activities as this has been empirically proven to influence their WOM intention which is an effective form of promotion and reputation building for the university. Hence, these findings provide further reassurance to universities considering or probably undetermined to invest resources in ensuring sustainable and socially responsible practices.

This study has certain limitations. One of which is the sample drawn from the student population of one university only. This makes it difficult to generalize the findings of this study. Another is that this study focused on the effect of CSR awareness on WOM intentions but has not established any association between intentions and actual behavior. Thus, future studies can examine the link between behavioral-intentions influenced by awareness of CSR and the actual behavior.

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The Effect of Working from Home on Work and Private Life: Automotive Sector Application

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Abstract. Today, the increase in the sense of independence and developments in communication technology increase the importance of working from home. Working from home is not defined as bringing home the work that the employee cannot rise to the workplace, but rather working from home by the management at a certain frequency rather than going to work. Working from home has positive and negative effects on work-life. While some studies have positive findings that working from home will improve work performance, some studies have found that being away from the workplace will decrease team performance, create obstacles for progress and adversely affect business life. One hundred eighty employees, including 66 managers of the company to apply to work from home in the Turkish automotive sector, did take part in this study. As a result of the study, it has been concluded that the increase in transportation time and frequency of working from home reduces the level of communication between the manager and the employee and contributes positively to the establishment of work-family balance. It was obtained that working at home posed a barrier to progress at both the executive and employee levels and prevented teamwork. As a result, to increase the motivation of employees to work from home, it may be suggested that companies should place systems of teamwork in their enterprises, provide the necessary technological tools for remote teamwork and establish systems that closely monitor the results of the work of workers from home in their career plans.

Keywords: Working from home · Human resource management · Work/private life · Life quality · Motivation

1 Introduction

Working from home can have both positive and negative effects on work-private life. Rupietta and Beckmann (2018) thought that the feeling of independence brought by working from home would increase employee performance. Klopries (2018) stated that smartphones and internet-connected computers provided by the sense of independence and developing technology could reduce business performance by using them for arbitrary situations (Rupietta and Beckmann 2018). Working from home will provide a quiet area to the employee and increase employee working motivation (Church 2015). The employee is unsettled by teamwork failure (Hill et al. 2003). Studies also indicate that

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working from home has an effect on motivation and job performance, but gives different results on the direction of the relationship. However, according to Rupietta and Beckmann, highly motivated employees are willing to do more for the job (Rupietta and Beckmann 2018). In this study, the effect of working from home in the automotive sector on work-private life was investigated.

Working from home is defined as working from home instead of going to work. It refers to the systematized home-work system of salaried employees (non-freelance, etc.) (Rupietta and Beckmann 2018). The necessity of bringing the work that is not within this scope to the home and working outside the office due to field work are not included in this definition.

It is seen that three different types of offices are mentioned in the literature in general. These are traditional, virtual office, and working from home (Hill et al. 2003). Traditional work is the working environment in which people go to their office and work with colleagues in the same company. Virtual office refers to a common working environment where people go to a different environment outside the company, and people from different companies can come. Working from home is defined as the maintenance of work from home.

It expresses the underlying causes of behavior characterized by motivation, willingness, and will (Lai 2011). Rupietta and Beckmann (2018) focused on intrinsic motivation while investigating the effects of working from home on motivation and work-life and stated that individuals with high intrinsic motivation provide better job outcomes. Organizational success increases with increasing motivation, which enables employees to benefit more from their talents and focus on employees towards organizational goals (Hill et al. 2003).

Working from home has numerous contributions to companies. Among its most important contributions, it can be said that employees' job performance increases, both the employee and the company have a positive financial impact and the opportunity for the best employees to overlap with the best job. According to Rupietta and Beckmann, both work and employer can benefit at the same time work from home (2018). Employees can benefit financially by avoiding traffic and dressing costs, while employers can cut office costs (Church 2015).

Every company wants to recruit and retain good employees. This leads to high costs. Working from home to do this can be good additional support. Because working from home appears to be both an additional benefit and an additional financial contribution to the employee, it provides support to connect the employee to the firm (Hill et al. 2003). At the same time, firms that offer better working opportunities are more successful in attracting more talented and hardworking employees (Rupietta and Beckmann 2018). Working from home increases the attractiveness of the company as it is seen as additional opportunities from the employees' point of view.

The aim of this research is to show the effect of work from home on the working life and private life of the employees in the automotive industry, to explain the benefits and harms of the application for the companies that may wish to apply this practice and also to show the elements to be taken into consideration when applying. However, in this study, it is aimed to show whether the effect of working from home in Turkish culture is similar to the effects in other countries.

2 The Effect of Working from Home on Work and Private Life

Work from home should not be confused with bringing work that cannot be completed within the day. According to the rules of business of home-work organizations, employees can officially do their work from home (Rupietta and Beckmann 2018).

The effect of work from home on family life is undeniable. Working from home has become an important strategy, especially for women with children, to maintain work and family balance (Loo and Wang 2018). Since there is no physical difference between work and home during work from home, problems may arise in the family-work balance of individuals. Also, when the start and end times of work is not clear, the person is likely to work too hard to become burnout. This is a factor that reduces motivation (Hill et al. 2003).

Determining the line between working from home and professional time (work at work) is very difficult for employees. Because not going to the workplace, not attending meetings and choosing clothes, may seem like a good dream for the employee, but it will be very difficult for employees to make the distinction between work and non-job responsibilities when personal responsibilities are effective (Saunders 2017). At the same time, employees try to make up their daily chores, housework, and childcare during normal working hours and extend their working hours before work in the morning or evening after work. This situation manifests itself as employees who have difficulty setting the work-to-work border (Hill et al. 2003).

There is evidence that working from home adversely affects career development (Hill et al. 2003). People working from home are less likely to be in the same physical environment and time as their colleagues and supervisors. It is, therefore, less likely to be part of the informal political network necessary for career development. For this reason, employees who spend less time in the office are worried about career prospects because of the possibility of missing promotion opportunities. Therefore, they try to neutralize this effect by working more than normal on the days they work at home, and as a result, they experience a decrease in motivation because they are burn-out (Hill et al. 2003). Making a similar observation, Church observed that there was a perception that working from home reduced the opportunities for promotion (Church 2015).

Unlike traditional office work, communication characteristics with the team also vary with work from home. Workers from home may feel that their connection with the team is diminishing by thinking that their connections to the team are diminishing (Church 2015). Some studies have shown that isolation from professional life is encountered in working from home (Hill et al. 2003). Working from home varies not only in social life but also in terms of actions taken for work. People seem to be quite happy with communication through electronic communication tools, but they prefer the office environment to give job-related feedback (Young 1995). Previous studies suggest that the lack of opportunities for social and work-related interactions may restrict people's choice of working at home (Loo and Wang 2018).

Working from home creates a feeling of more workload and increases stress (Hill et al. 2003). This is in line with the finding that Rupietta and Beckmann observed that those working at home had fewer breaks. One of the most important factors that affect the occurrence of stress in work from home is the 'Attitude of Management' (Rupietta and Beckmann 2018).

Managers are more than happy to work in front of their employees (Church 2015). Managers assume that employees do not use this situation for their benefit when they work at home, and this is due to loss of control (Church 2015). The opportunity to work from home creates a sense of independence for employees when planning and organizing work. Employees with a high sense of independence can achieve better business results without control (Rupietta and Beckmann 2018). If control is desired, a result-oriented management culture is required (Manca et al. 2018). Thus, managers can rely more on workers from home by setting specific goals (Hill et al. 2003). Giving the employee the flexibility of where the work will be done allows the person to determine how the work will be done and what situations will be done, which leads to an effective work outcome (Hill et al. 2003).

Geographical and demographic characteristics also affect working from home. The distance from the workplace was found to affect the frequency of choosing to work from home. The rate of work from home increases as it provides the necessary flexibility for childcare (Loo and Wang 2018). Nowadays, it has been observed that the responsibility of caring for the child affects both working parents. In this case, fathers need more flexibility in terms of the need to make similar contributions (Hill et al. 2003).

Although the geographical location of the workplace is seen as both the distance from the central points and the distance from home, the duration of transportation to the workplace is one of the most important factors affecting the motivation of employees to work from home. Workers from home can accept 5.7% further away from traditional workers and accept an additional workplace distance of 3% for each additional eight hours of work (de Vos Meijers and van Ham 2017).

Overall, it is clear that working from home has an impact on work/private life. In the research model, the effect of factors motivating work from home on work/private life was examined (Fig. 1).

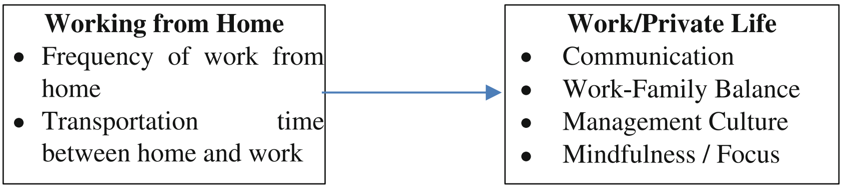

Fig. 1. Conceptual model of the study

Hypotheses:

Hypothesis 1: Working from home has a positive effect on work/ private life.
Hypothesis 2: Working from home affects work-family balance.
Hypothesis 3: People who work more often from home have higher motivation.

3 Methodology

The research was carried out using google forms without contact information. Survey respondent all participants in Istanbul (Turkey) and all employees working in the automotive sector with a sampling issue a certain number of days of the week should have rules about the execution of the company they work from home jobs.

Questionnaires measuring the perception of working from 16 houses in the questionnaire were taken from (Church 2015). It was adapted from 7 questions containing demographic information, and four questions answered only by the administrators (Church 2015). A 5-point Likert scale ranging from 1 to 5 (strongly agree-strongly disagree) was used. A total of 180 employees participated in the study, and 66 of them were in the managerial position.

4 Findings

Looking at the data set used in the study, the skewness-kurtosis values of all item collection form expressions should be within the range of ±1.96 in 0.01 significance (Hair et al. 1995) and all values were observed in the appropriate range.

Papacharissi and Rubin (2000) stated that Cronbach's Alpha values should be between 0.6–1. As a result of the reliability test of the sub-dimensions in the research model, the Cronbach's Alpha values of all dimensions were greater than 0.6.

The data were then subjected to factor analysis. In factor analysis, it was confirmed that the correlation matrices of the dimensions used in the study were greater than 0.30, and the anti-image matrices were greater than 0.50. This shows that the sub-dimensions are factorizable. As a result of factor analysis, each dimension turned into a single factor. Then, correlation analysis between factors (Table 1) was performed.

Table 1. Evaluation criteria

	Communication level	Work-family balance	Management culture	Focusing
Frequency of working from home	0,298**	0,303**	0,174	0,089
Transportation time between home and work	0,183**	0,266**	−0,039	−0,041
*p < 0,001				

After correlation analysis, regression analysis was performed between working from home sub-factors and work/private life sub-factors. In the analysis, the Durbin-Watson coefficients were confirmed to be in the range of 1.5–2.5. Collinearity between independent variables was checked with Vif and Tolerance values. Tolerance values over 0.1, Vif values below 5.3 shows that there is no collinearity between independent variables (Hair et al. 1995). These values have been confirmed to be in the appropriate range.

As seen in Table 2, a significant relationship was found between communication and the frequency of working from home. As the frequency of working from home increases, the level of communication deteriorates. Table 3 shows the results of the regression analysis between work-family balance and working from home. It was concluded that the work-family balance was positively affected as the frequency and time of working from home increased.

Table 2. Regression analysis results for communication level

	Durbin-Watson	R^2	β
Frequency of working from home	2,087	0,104	−0,270
Transportation time between home and work			−0,113
Dependent variable: communication level $p < 0{,}05$			

Table 3. Regression analysis results for Work-Family balance

Main criteria	Durbin-Watson	R^2	β
Frequency of working from home	2,188	0,129	−0,248
Transportation time between home and work			−0,198
Dependent variable: work-family balance $p < 0{,}05$			

5 Results and Conclusion

When the results of correlation and regression analysis were analyzed in our sample, there was not enough evidence to show a significant relationship between management culture and attention/focus sub-dimensions and working from home sub-dimensions. A significant but weak relationship was found between work-family balance and communication level and frequency of working from home. Similarly, a poor relationship was found between the level of communication and the frequency of working from home. In general, it can be said that there is a relationship between working from home and communication level and work-family balance, which are sub-dimensions of work/ private life variables for the automotive sector.

The second hypothesis was especially focused on work-family balance, and working from home provided a positive relationship between work-family balance. In the examples in the literature, Hill et al. (2003) showed that the most important difference between working from home and working from the office was on the work-family balance side. In this study, it was seen that the two concepts affecting motivation are related to working from home and expresses the same direction as Hill et al. (2003).

In the third hypothesis, it was stated that the frequency of working from home had a positive effect on the sub-factors of work/private life. When we look at the results, we can say that we cannot find enough evidence to reject the third hypothesis because it positively affects communication and family-balance.

When evaluated based on the sub-dimensions asked in the research, the perception of productivity in work from home in the Turkish automotive sector did not differ from the US, and the perception of the chance of rising varies downwards. The participants in the sample think that working from home may affect their chances of promotion. When the analysis results of the communication factor are analyzed, it is seen that this situation is confirmed. Working from home adversely affects Manager-Employee communication, which raises the concern that it will create problems for the employee to rise. Similarly, it was obtained from the perception that working from home can play a negative role in employee promotion.

In terms of work-family balance, the results of this study showed that the perception that work-family balance could be established more easily was positively different from other studies. This may be due to the cultural structure of the Turkish family.

In terms of the feasibility of teamwork, it was found that work from home would not affect teamwork, but in this study, it was found that both employees and managers could not make teamwork from home. We can conclude that the culture of teamwork is not fully established and that tools for teamwork in the sector need to be improved.

In this study conducted in the Turkish automotive sector, it has been concluded that the increase in transportation time and the frequency of working from home decreases the level of communication between the managers and employees while contributing positively to the establishment of work-family balance. We can say that the perception of decreasing level of communication constitutes an obstacle to progress at both the executive and employee levels. Besides, the decrease in the perception of communication level is another obstacle to teamwork. To increase the motivation of employees to work from home, it may be suggested that companies should place systems of teamwork in their enterprises, provide the necessary technological tools for remote teamwork and establish systems that will closely monitor the results of employees working from home in their career plans.

This study was performed in the Automotive Sector Employees sample in Istanbul, Turkey. In the future, it can be realized in other regions where the automotive sector is concentrated, and the general result can be reached for the Turkish automotive sector.

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Selection of Optimum Maintenance Strategy Using Multi-criteria Decision Making Approaches

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Abstract. An appropriate maintenance strategy can improve the availability and reliability levels of industries, while improper maintenance strategy can significantly reduce the effectiveness of companies. This paper aims to select the optimal maintenance strategy utilizing four decision-making techniques in a food company in Turkey. In this study, four multi-criteria decision making (MCDM) methods (Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Simple Additive Weighting (SAW) and Weighted Product (WP)) are used to determine the optimal maintenance strategy. In this context, four main criteria (safety, cost, reliability, and added-value), twelve criteria and five alternatives (corrective maintenance, time-based preventive maintenance, opportunistic maintenance, condition-based maintenance, and predictive maintenance) are defined according to focus group meetings in the company and the literature review. The obtained results are compared with each other, and then the appropriate maintenance strategies are identified.

Keywords: Maintenance strategy selection · Multi-criteria decision making · Analytic hierarchy process · TOPSIS · SAW · WP

1 Introduction

In recent years, maintenance management has been a corrective function for many companies, and maintenance has been seen as an inevitable source of cost only in emergencies. Unexpected failures can result in serious maintenance costs, high production losses, and safety hazards to people and the environment. Therefore, corrective maintenance (CM) is no longer acceptable (Bevilacqua and Braglia 2000; Wang et al. 2007). There is an urgent need to choose a suitable maintenance strategy for industries to avoid the adverse effects of the disturbances (Shafiee 2015). The choice of an optimal maintenance strategy for a system is a complex and multidimensional decision-making problem because of the data collection phase, numerous, conflicting criteria and decision-makers from various fields, as well as a variety of components and functions that need to be addressed as a systematic approach. Therefore, Maintenance Strategy Selection

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(MSS) has been accepted as a classic multi-criteria decision making (MCDM) problem (Bevilacqua and Braglia 2000).

The MCDM approach has received great interest in the field of MSS since the last half of the 2000s. MCDM methodology is applied to select the most appropriate maintenance strategies in various industries (Shafiee 2015). In MSS problem, many MCDM approaches have been proposed in the literature. Bevilacqua et al. (2000) in an Italian petrol company, Zaeri et al. (2007) and Pariazar et al. (2008) and Odeyale (2013) in a manufacturing company, Chandima et al. (2010) in the Norwegian oil and gas industry, have chosen the most appropriate maintenance strategy using the Analytic Hierarchy Process (AHP) method. Mishra et al. (2015) evaluated cost, safety, added-value, equipment and technology criteria, and CM, time-based preventive maintenance (TBPM) and condition-based maintenance (CBM) strategies with the AHP method. Elseddawy et al. (2018) selected the most appropriate maintenance strategy for a hospital with the AHP method. The study evaluates CM, TBPM, CBM alternatives, and so TBPM was obtained as the most appropriate maintenance strategy.

Shyjith et al. (2008) and Ilangkumaran et al. (2009) evaluated TBPM, reliability centered maintenance (RCM), CBM and predictive maintenance (PdM) strategies to select the optimal maintenance strategy in a textile company. In the related studies, the weights of criteria were identified with the AHP method, and the rank of alternatives was analyzed using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Shyjith et al. (2008) reached the PdM strategy as the most appropriate maintenance alternative, whereas Ilangkumaran et al. (2009) obtained TBPM maintenance strategy as the most optimal maintenance alternative. In the study of Ahmadi et al. (2010), the optimal maintenance strategy for aircraft systems was evaluated, integrating AHP methodology with TOPSIS and VIKOR methods considering CM, CBM, and revision maintenance strategies. Thor et al. (2013) applied the most appropriate MSS among CM, TBPM, PdM, autonomous maintenance (AM) and design-out maintenance (DOM) alternatives using AHP, Elimination and Choice Translating Reality English (ELECTRE), Simple Additive Weighting (SAW) and TOPSIS methods. In the four MCDM methods, TOPSIS method showed the highest potential in maintenance decision analysis.

Aghaee et al. (2012) evaluated the safety, cost, strategic and technical qualification criteria and CM, TBPM, CBM, PdM, and total productive maintenance (TPM) alternatives. It proposes a solution based on the integrated analytical network process (ANP) and the Decision-Making Trial and Evaluation Laboratory (DEMATEL) approach to assess and select maintenance strategies. Shahin et al. (2012) and Pourjavad et al. (2013) selected the most appropriate maintenance strategy evaluating CM, TBPM, CBM, DOM and TPM alternative maintenance strategies for a company in the mining sector. Shahin et al. (2012) utilized the ANP method, whereas Pourjavad et al. (2013) applied the integration of ANP and TOPSIS methods. Emovon et al. (2018) used the Delphi method to select evaluation criteria with ten experienced experts. In the decision-making process; two MCDM methods, Delphi-AHP and Delphi-AHP-PROMETHEE, were used in choosing the appropriate maintenance strategy among CM, TBPM, and CBM maintenance alternatives according to cost, security, added-value, and applicability criteria.

The motivation of this study is the need for some analytical, practical, and objective decision-making tools to select the appropriate maintenance strategy for different sectors. In this study, four MCDM methods are selected from value-based methods (such as TOPSIS, SAW, and WP), and hierarchy-based method (AHP) is employed, and the obtained analyzed results are compared to each other. Therefore, it is aimed to determine the accuracy level of optimum MSS by using many MCDM methods. There are many studies on this subject in the literature. Nevertheless, there are still some missing points. The application area of the MSS problem is limited in the literature. The study evaluates a real-world problem (in a food company) with different expert opinions while the determination of criteria and alternatives utilizing four main MCDM methods.

The rest of the paper is organized as follows. In section "Methodology", AHP, TOPSIS, SAW, and WP methodologies are summarized. In section "Application of the Model: Maintenance Strategy Evaluation in a Food Company", evaluation criteria and alternative maintenance strategies are explained, and the proposed methodology implemented and compared. Results obtained from the application are demonstrated in section "Results and Discussion." Finally, possible research directions are presented in the section "Conclusion".

2 Methodology

2.1 Analytic Hierarchy Process (AHP)

The AHP methodology was developed by Saaty (1980). AHP is a quantitative method to sort and select decision alternatives according to multiple criteria. It is a popular tool for MCDM. An AHP method includes the following basic steps (Wang et al. 2007; Cayir Ervural et al. 2018a; Ervural et al. 2019):

- Creating a hierarchy structure,
- Development of decision matrices with pairwise comparisons,
- Calculating consistency ratio (CR),
- Calculating local and global priorities from decision matrices,
- Alternatives ranking.

2.2 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS method was developed by Hwang and Yoon (1981). The basic logic of this method is that the selected alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest separate from the negative-ideal solution (NIS) (Opricovic and Tzeng 2004; Cayir Ervural et al. 2018a, b).

The TOPSIS method is as follows: (Opricovic and Tzeng 2004)

1. If there are multiple decision-makers, these decisions are aggregated using arithmetic mean (Chen 2000).

2. The weighted normalized value v_{ij} is defined in Eq. 1 as follows

$$v_{ij} = w_i \frac{f_{ij}}{\sqrt{\sum_{j=1}^{J} f_{\mathrm{i}j}^2}}, j = 1, \ldots, J; i =, \ldots, n \quad (1)$$

where w_i is the weight of the ith criterion, and $\sum_{\mathrm{i}=1}^{n} w_{\mathrm{i}} = 1$.

3. The PIS and NIS are determined as in Eqs. 2 and 3.

$$A^* = \{v_1^*, \ldots, v_n^*\} = \{(max_j v_{ij} | i \in I'), (min_j v_{ij} | i \in I'')\} \quad (2)$$

$$A^- = \{v_1^-, \ldots, v_n^-\} = \{(min v_{ij} | i \in I'), (max_j v_{ij} | i \in I'')\} \quad (3)$$

where I' is related to benefit criteria, and I'' is related to cost criteria.

4. Calculate the separation measures, using the n-dimensional Euclidean distance. The distance of each alternative from PIS and NIS is calculated using Eqs. 4 and 5 as follows.

$$D_j^* = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^*)^2}, j = 1, \ldots, J. \quad (4)$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2}, j = 1, \ldots, J. \quad (5)$$

5. The relative closeness to the ideal solution is calculated using Eq. 6 as follows.

$$C_j^* = \frac{D_j^-}{D_j^* + D_j^-}, j = 1, \ldots, J \quad (6)$$

6. Rank the preference order.

2.3 Simple Additive Weighting (SAW)

The SAW method was applied by Churchman and Ackoff in 1954. This method is one of the most widely used MCDM techniques in the literature due to its simple calculation. The basic principle is to obtain the weighted sum of the performance scores of each alternative on all criteria (Yeh 2003; Savitha and Chandrasekar 2011).

The algorithm of the SAW method is as follows (Yeh 2003).

1. Normalization of the decision matrix by using the linear normalization method.
2. The total preference values of each alternative are calculated using Eq. 7. The alternative with the highest value is considered as the best alternative.

$$V_i = \sum_{j=1}^{n} w_j r_{ij}; \ \ i = 1, \ldots, m \quad (7)$$

where w_i is the weight of the ith criterion, and r_{ij} is the weighted value of alternatives.

2.4 Weighted Product (WP)

The WP method utilizes multiplication to connect criteria ratings, each of which is raised to the power of the corresponding criteria weight. This multiplication process has the same effect as the normalization process has to control various measurement units (Yeh 2003). The overall preference score of each alternative (Si) is given in Eq. 8 as follows:

$$V_i = \prod_{j=1}^{n} x_{ij}^{wj};\ i = 1, 2, \ldots, m \tag{8}$$

where $\Sigma_{j=1}^{n} w_j = 1$. w_j is a positive power for benefit criteria and a negative power for cost criteria (Yeh 2003).

3 Application of the Model: Maintenance Strategy Evaluation in a Food Company

In this study, one of the most important food production companies in Turkey, which implements the flow type production system, is evaluated to determine the optimal maintenance strategy. When evaluating the MSS problem as an MCDM model (Wang et al. 2007), the following steps are applied:

- A focus group consisting of maintenance managers, maintenance engineers, and maintenance personnel were created.
- Criteria, sub-criteria, and alternatives were determined as a result of the opinions of focus expert group and literature review. A questionnaire was conducted with focus expert group.

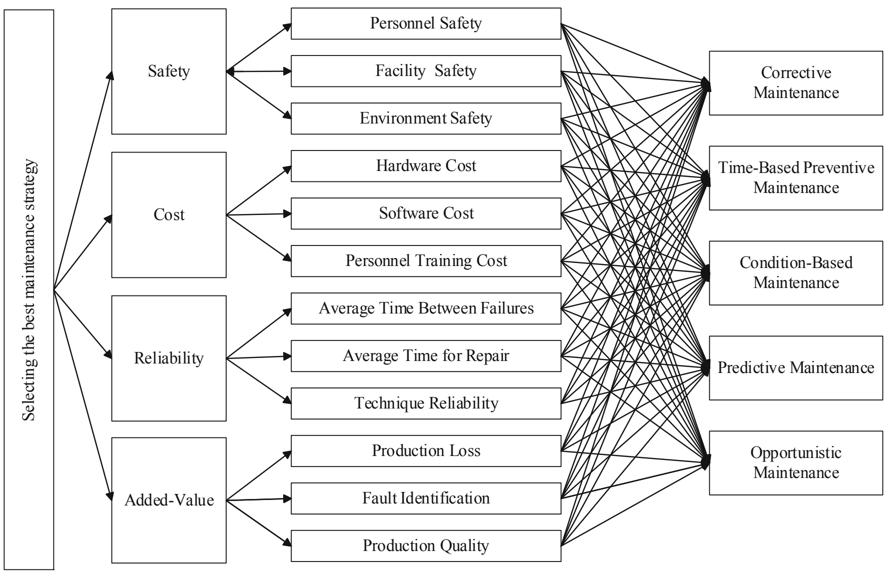

Fig. 1. A hierarchy for selection of the appropriate maintenance strategy

- A hierarchical model was constructed. The hierarchy for the appropriate MSS was illustrated in Fig. 1.
- A questionnaire was conducted to find the weights of the criteria and sub-criteria
- AHP, TOPSIS, SAW, and WP methods were applied.
- The obtained results were compared to each other and decided to optimum one.

3.1 Identifying the Main Criteria and Sub-criteria

It is very important to evaluate the criteria to apply an appropriate and comprehensive MSS problem. The evaluation criteria of the problem defined as follows: (see Table 1)

- Safety: Indicates damage to personnel, facility, and environment in case of mistake, accidents, or other undesirable situations.

  - Personnel Safety: Failure of many machines and equipment can cause serious injury or death to personnel working at the plant.
  - Facility Safety: Failure of any machine or equipment can cause serious damage to the plant and the products produced.
  - Environment Safety: It contains environmental hazards caused by the failure of equipment with toxic liquid or gas.

- Cost: Refers to costs that may arise as a result of selecting a maintenance strategy. Different maintenance strategies result in different costs.

  - Hardware Cost: The cost of hardware required to implement the maintenance strategy.
  - Software Cost: It covers all of the software costs required to implement the maintenance strategy.
  - Personnel Training Cost: It covers all the pieces of training to be given to maintenance personnel to implement the selected maintenance strategy.

- Reliability: It is the ability of equipment to perform its expected functions over a certain time period.

  - The average time between failures: Refers to the average time between failures of machines or equipment (Bevilacqua and Braglia 2000).
  - Average time for repair: Refers to the average repair time of machines or equipment (Bevilacqua and Braglia 2000).
  - Technique Reliability: It expresses the technical and technological infrastructure necessary for the implementation of the maintenance strategy (Wang et al. 2007; Kirubakaran and Ilangkumaran 2016).

- Added-Value: Refers to the benefits of maintenance activities (Ge et al. 2017).

- Production Loss: Failure of highly important machinery and equipment often results in higher production loss costs.
- Fault Identification: When failure can be detected, maintenance time can be reduced, the availability of production systems can be improved, and downtime losses can be reduced (Wang et al. 2007).
- Production Quality: Some machine and equipment failures may affect the quality of the product produced at the plant.

Table 1. Criteria taken into account to select the appropriate maintenance strategy

Main criteria	Sub-criteria	Reference
C1: safety	C11: personnel safety	Wang et al. (2007), Ge et al. (2017)
	C12: facility safety	Wang et al. (2007), Jayaswal et al. (2013)
	C13: environment safety	Xie et al. (2013), Wang et al. (2007)
C2: cost	C21: hardware	Emovon et al. (2018), Wang et al. (2007)
	C22: software	Xie et al. (2013)
	C23: personnel training cost	Emovon et al. (2018)
C3: reliability	C31: average time between failures	Bevilacqua and Braglia (2000), Abdulgader et al. (2018)
	C32: average time for repair	Bevilacqua and Braglia (2000), Jayaswal et al. (2013), Abdulgader et al. (2018)
	C33: technique reliability	Wang et al. (2007), Ge et al. (2017)
C4: added-value	C41: production loss	Mohammed and Saad (2016), Emovon et al. (2018)
	C42: fault identification	Kirubakaran and Ilangkumaran (2016)
	C43: production quality	Jayaswal et al. (2013), Abdulgader et al. (2018)

3.2 Alternative Maintenance Strategies

The five alternative maintenance strategies discussed in the study are described below.

- Corrective Maintenance (CM): The basic feature of CM is that operations are performed only when a machine fails. In this strategy, maintenance is not performed until deterioration occurs (Bevilacqua and Braglia 2000).
- Time-Based Preventive Maintenance (TBPM): TBPM involves the efforts to increase the availability of equipment such as planned and coordinated inspections, adjustments, repairs, and renewal operations of machinery and equipment within a certain

program without the condition of failure. According to the reliability characteristics of the equipment and the machine, maintenance is planned and performed periodically to reduce unexpected failures (Wang et al. 2007).

- Opportunistic Maintenance (OM): OM is the maintenance of a machine or equipment in the system when it fails, and in the meanwhile, it is the maintenance of machinery or equipment maintenance time of which is approaching or which is worn out (Bevilacqua and Braglia 2000).
- Condition-Based Maintenance (CBM): When using a CBM strategy, maintenance decision is made with a series of measurement and data acquisition systems to monitor machine performance in real time (Bevilacqua and Braglia 2000). Continuous review of operating conditions allows maintenance decisions to be made based on historical data and the current state of the equipment. This ensures that the machine runs right before the breakdown, avoiding unnecessary maintenance (Al-Najjar and Alsyouf 2003).
- Predictive Maintenance (PdM): PdM is a maintenance strategy that can predict performance degradation and machine downtime by analyzing the data of monitored parameters (Wang et al. 2007). In contrast to the CBM strategy, the data obtained in PdM are analyzed to find a possible fault trend on the equipment or machines (Bevilacqua and Braglia 2000).

3.3 An Application of AHP

The decision matrices from four decision-maker opinions are aggregated with the geometric mean operator. Pairwise comparisons of the four main criteria are shown in Table 2. The obtained main criteria weights are presented as follows: safety = 0.39, reliability = 0.34, added-value = 0.20, and cost = 0.07. According to these results, weights of safety and reliability criteria are higher than value-added and cost criteria. CR values of the criteria are as shown in Tables 2 and 3. Since the obtained CR values are less than 0.1, they are acceptable.

Table 2. Pairwise comparison of the main criteria

	C1	C2	C3	C4	Weights	CR
C1	1.00	6.30	1.00	1.97	0.39	0.006
C2	0.16	1.00	0.19	0.39	0.07	
C3	1.00	5.21	1.00	1.50	0.34	
C4	0.51	2.59	0.67	1.00	0.20	

Pairwise comparisons of the sub-criteria are shown in Table 3. At first, we obtained the local criteria weights. Then, the local weights were multiplied by the main criterion weights to find the global weights of each sub-criterion. According to the results, the highest global weight has emerged as personnel safety.

Table 3. Pairwise comparison of the sub-criteria

C1	C11	C12	C13	Local weights	Global weights	CR
C11	1.00	5.92	8.45	0.76	0.293	0.054
C12	0.17	1.00	3.00	0.17	0.066	
C13	0.12	0.33	1.00	0.07	0.028	
C2	C21	C22	C23			
C21	1.00	4.40	3.41	0.65	0.045	0.005
C22	0.23	1.00	0.62	0.14	0.009	
C23	0.29	1.61	1.00	0.21	0.014	
C3	C31	C32	C33			
C31	1.00	1.32	1.29	0.39	0.136	0.000
C32	0.76	1.00	1.00	0.30	0.104	
C33	0.77	1.00	1.00	0.30	0.105	
C4	C41	C42	C43			
C41	1.00	3.41	2.24	0.58	0.116	0.008
C42	0.29	1.00	0.88	0.19	0.038	
C43	0.45	1.14	1.00	0.23	0.047	

Table 4. Result of the AHP approach

	CM	TBPM	OM	CBM	PdM	Global weights
C11	0.072	0.184	0.071	0.225	0.449	0.293
C12	0.065	0.168	0.080	0.241	0.446	0.066
C13	0.066	0.174	0.080	0.243	0.437	0.028
C21	0.375	0.109	0.348	0.114	0.053	0.045
C22	0.391	0.096	0.350	0.114	0.050	0.009
C23	0.348	0.170	0.284	0.126	0.072	0.014
C31	0.062	0.222	0.094	0.192	0.430	0.136
C32	0.061	0.236	0.083	0.190	0.431	0.104
C33	0.141	0.257	0.130	0.193	0.280	0.105
C41	0.077	0.284	0.085	0.167	0.386	0.116
C42	0.050	0.179	0.051	0.204	0.517	0.038
C43	0.056	0.207	0.068	0.175	0.494	0.047
Global scores	0.095	0.209	0.101	0.198	0.397	

After determining the criteria weights, five alternatives are also compared regarding sub-criteria. The local scores of alternative maintenance strategies for all sub-criteria are given in Table 4. The CR values of all comparison matrices are less than 0.1. It is concluded from the global scores and alternative scores that the optimal maintenance strategy for the company is PdM. The rank of the other strategies is given, respectively, TBPM, CBM, OM, and CM.

3.4 An Application of TOPSIS

In the TOPSIS method, the obtained data (criteria weights and alternative significance levels) are aggregated using the arithmetic mean operator. The weight of each alternative related to each criterion is shown in Table 5.

The weighted normalized decision matrix is computed using Eq. 1. and shown in Table 6, according to Eqs. 2 and 3, the PIS and NIS are calculated and shown in Table 7, the separation of each alternative from NIS and PIS are calculated using Eqs. 4 and 5 and the relative closeness to the ideal solution is computed using Eq. 6. and given in Table 8.

Table 5. Weights of alternatives and criteria aggregated with arithmetic mean.

Criteria/ Alternatives	CM	TBPM	OM	CBM	PdM	Weights of Criteria
C11	2.25	4.75	2.25	5	6.5	0.105
C12	2	4.5	2.5	4.75	6.25	0.087
C13	2	4.5	2.5	5	6.25	0.073
C21	7	3.25	6.5	3.25	1.5	0.087
C22	7	3	6.5	3.75	1.75	0.058
C23	6.75	5	6.5	5	3	0.073
C31	2.25	5	2.75	4.75	6.25	0.087
C32	2	4.75	2.25	4.75	6.25	0.079
C33	4.25	5.75	4.25	5	5.5	0.085
C41	6.75	3.5	6.5	4.5	2.75	0.099
C42	1.75	4	1.75	4.75	7	0.079
C43	2	5	2.5	4.5	6.25	0.087

Finally, the results obtained by the TOPSIS method are given in Table 8. According to the results, the most appropriate maintenance strategy is PdM. The rank of the other strategies is given, respectively, CBM, TBPM, CM, and OM.

Table 6. The weighted normalized decision matrix

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
CM	0.02	0.02	0.01	0.06	0.04	0.04	0.02	0.02	0.03	0.06	0.01	0.02
TBPM	0.05	0.04	0.03	0.03	0.02	0.03	0.04	0.04	0.04	0.03	0.03	0.04
OM	0.02	0.02	0.02	0.05	0.03	0.04	0.02	0.02	0.03	0.06	0.01	0.02
CBM	0.05	0.04	0.04	0.03	0.02	0.03	0.04	0.04	0.04	0.04	0.04	0.04
PdM	0.07	0.06	0.05	0.01	0.01	0.02	0.05	0.05	0.04	0.02	0.06	0.06

Table 7. PIS and NIS

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
PIS	0.07	0.06	0.05	0.06	0.04	0.04	0.05	0.05	0.04	0.02	0.06	0.06
NIS	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.06	0.01	0.02

Table 8. Results of TOPSIS

Alternatives	D^*	D^-	C	Rank
CM	0.108	0.058	0.349	4
TBPM	0.058	0.071	0.552	3
OM	0.101	0.053	0.346	5
CBM	0.055	0.070	0.560	2
PdM	0.058	0.107	0.651	1

3.5 An Application of SAW

In the SAW method, the obtained data are aggregated with the arithmetic mean and given in Table 5. The matrix calculated by linear normalization shown in Table 9. The total preference values of each alternative (V_i) are computed using Eq. 7 and shown in Table 10.

According to the analysis results, the most appropriate maintenance strategy is PdM, TBPM, CBM, OM, and CM, respectively.

3.6 An Application of WP

The data in Table 5 are also used for the WP method. According to Eq. 8, the overall preference score of each alternative is calculated. The results obtained by the WP method are given in Table 11. According to the results, the most appropriate maintenance strategy is PdM. The rank of the other strategies is given, respectively, TBPM, CBM, OM, and CM.

Table 9. Linear normalized decision matrix

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43
CM	0.35	0.32	0.32	1.00	1.00	1.00	0.36	0.32	0.74	0.41	0.25	0.32
TBP	0.73	0.72	0.72	0.46	0.43	0.74	0.80	0.76	1.00	0.79	0.57	0.80
OM	0.35	0.40	0.40	0.93	0.93	0.96	0.44	0.36	0.74	0.42	0.25	0.40
CBM	0.77	0.76	0.80	0.46	0.54	0.74	0.76	0.76	0.87	0.61	0.68	0.72
PdM	1.00	1.00	1.00	0.21	0.25	0.44	1.00	1.00	0.96	1.00	1.00	1.00

Table 10. Result of SAW

	CM	TBPM	OM	CBM	PdM
V_i	0.514	0.719	0.532	0.708	0.843
Rank	5	2	4	3	1

Table 11. Result of WP

	CM	TBPM	OM	CBM	PdM
V_i	2.186	3.407	2.350	3.386	3.669
Rank	5	2	4	3	1

4 Results and Discussion

It is seen that different alternatives and evaluation criteria are used for each problem when the literature is examined. Therefore, the most appropriate maintenance strategies may be different in each study. However, when we look at the results of the studies in the literature, the most appropriate maintenance strategy is generally obtained as PdM strategy (Bertolini and Bevilacqua 2006; Wang et al. 2007; Odeyale et al. 2013; Kirubakaran and Ilangkumaran 2016). Although different approaches are used to show the order of alternatives in the MSS problem with this study, the optimum strategies obtained are parallel to the literature and verified with this application.

The results of the analysis employing four various MCDM methods are given in Table 12. According to AHP, TOPSIS, SAW, and WP methodologies, PdM is the most appropriate strategy. In the literature, different studies on the MSS problem are discussed, and comparisons are given in Table 13.

Table 12. Comparison of the results

Methods	1	2	3	4	5
AHP	PdM	TBPM	CBM	OM	CM
TOPSIS	PdM	CBM	TBPM	CM	OM
SAW	PdM	TBPM	CBM	OM	CM
WP	PdM	TBPM	CBM	OM	CM

Table 13. The related articles of MSS

References	Strategies	Area	Method	Rank
Bertolini and Bevilacqua (2006)	CM, TBPM, PdM	Oil refinery	AHP and goal programming	PdM
Wang et al. (2007)	CM, TBPM, CBM, PdM	Power generating	Fuzzy AHP	PdM, CBM, TBPM, CM
Aghaee and Fazli (2012)	CM, TBPM, CBM, PdM, TPM, RCM	Automotive	ANP	TPM, RCM, TBPM, PdM, CBM, CM
Odeyale et al. (2013)	CM, TBPM, PdM	Manufacturing	AHP	PdM, TBPM, CM
Kirubakaran and Ilangkumaran (2016)	CM, TBPM, CBM, PdM	Paper industry	Fuzzy AHP with GRA–TOPSIS	PdM, CBM, TBPM, CM
Elseddawy and Kandil (2018)	CM, TBPM, CBM	Medical	AHP	TBPM, CBM, CM
Emovon et al. (2018)	CM, TBPM, CBM	Shipping	Delphi AHP PROMETHEE	CBM, TBPM, CM
Current study	CM, TBPM, OM, CBM PdM	Food	AHP, TOPSIS, SAW, WP	PdM, TBPM, CBM, OM, CM

5 Conclusion

The selection of appropriate MSS is a hot topic investigated by researchers and managers to optimize working conditions with minimal loss. Improper maintenance strategy may adversely affect the availability, efficiency, and reliability levels of company equipment. Therefore, it is aimed to select the most appropriate maintenance strategy utilizing four different decision-making methods to make the results more consistent. After a comparison of the results, PdM has been obtained as the most appropriate strategy. In the future, new models can be developed for other application areas in companies. Future studies can be expanded by adding new evaluation criteria and alternatives. In addition, MCDM methods can be integrated with fuzzy logic applications to select the optimal MSS.

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Engineering and Technology Management

Strategy Proposals for the Preference of SMEs as Workplace

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Abstract. Small and medium-sized enterprises (SMEs) are important drivers of national economies, especially because of their employment-generating characteristics. In spite of this fact, SMEs are facing significant problems related to attracting and retaining a quality workforce, which is critical for organizational performance. This study aims to develop strategies that will attract high-quality employees in choosing SMEs as their workplace. For this purpose, the workplace preferences of employees are examined using conjoint analysis. A sample group was asked how attractive they find the alternative combinations of incentives (benefits) that will be provided by the government. According to the answers given, the impact of each alternative strategy proposed as state incentives were estimated. The results highlight the benefits the government should provide to employees to motivate them work in SMEs.

Keywords: Small · Medium-sized firms · Human resources · Job preferences · Conjoint analysis

1 Introduction

This study aims to develop strategies that will attract high-quality employees in choosing SMEs as their workplace. SMEs have a very important place in both the world economy and Turkish economy. In OECD countries, SMEs constitute 95% of total enterprises (World Trade Organization 2016). The total share among businesses of the SMEs in Turkey is 99% (Science, Industry and Technology Ministry 2015). Although SMEs contribute significantly to the economy, they are facing considerable problems. The first list of these problems is those related to human resources, including attracting and retaining a quality workforce, which plays an important role in improving organizational performance (Tsang et al. 2015; Haşit 2016; Krishnan and Scullion 2017). In this study, to overcome the problems of SMEs about attracting quality staff, alternative strategies and their possible impacts were examined. To do this, the workplace preferences of employees were first determined. Then, it was investigated what benefits the government may provide to employees if they work in SMEs. A conjoint model was developed, and a sample group was asked how attractive they find different firm environments, i.e. alternative combinations of factors covering benefits provided by the government. According to the answers given, the impact of each alternative strategy proposed as state incentives were estimated.

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2 Methodology

Conjoint analysis (Bridges et al. 2011; Green and Krieger 1991) was used in this study to determine the effect of alternative strategies. This method covers the following main steps: (i) determining the relevant factors and their levels, (ii) specifying the data collection approach and designing survey cards (creating profiles), (iii) conducting the survey, and finally (iv) estimating the conjoint model using regression analysis with dummy variables. These steps are explained below.

2.1 Determination of Factors and Levels

Factors to be used in the research were divided into two groups as encouraging factors and incentive factors. The encouraging factors correspond to the characteristics of the firms, while the incentive factors correspond to the applicable strategies by the government. A preliminary survey with a small sample size was conducted to determine the encouraging factors to be used in the study. In this survey, an open-ended questionnaire, including the question "What are the common characteristics of SMEs?" was administered. The result of this survey indicates that low wages, lack of training opportunities and lack of career opportunities are common characteristics of SMEs. SMEs were represented with these characteristics in the conjoint analysis. They constitute the basis of the encouraging type factors (see below) used in the conjoint analysis. Note that in conjoint analysis, a manageable survey should involve seven or less factors in the model. This means less than 16 cards to be directed to respondents if a fractional factorial design is applied.

2.2 Determination of Encouraging Factors

Encouraging factors were determined using results of the preliminary survey, mentioned above, and a comprehensive literature review (i.e. Baum and Kast 2013; Boswell et al 2003; Boswell et al. 2012; Froelich 2005; Jans et al 2001; Judge and Bretz 1991; Arachchige and Robertson 2011; Kim and Yang 2013). These factors, which details are given below, are assumed to reflect the typical differences between large-scale firms and SMEs:

Wages and Fringe Benefits: Direct economic benefits such as salary, premium, and extra-economic benefits such as clothing and family allowances are defined as a factor of wages and fringe benefits. This factor was divided into three levels such as on the industry average, below the industry average, and above the industry average. The level "below the industry average" is assumed to reflect SMEs since SMEs generally pay lower wages and do not provide fringe benefits.

Company Reputation: Company reputation is a factor that shows how well known a company is. In this study, for this factor, two levels were defined as known firm and unknown firm. Since large size firms use employer branding strategies that make firms known by people, and candidates prefer well-known firms to work by considering positive impact of employment in large scale firms on their careers, SMEs have difficulties in influencing candidates (Tumasjan et al. 2011). For that reason, it was assumed in this study that SMEs correspond to the category of "unknown firms."

Training and Career Opportunities: The new generation is sensitive to training opportunities in the workplace. Training that will contribute to career development in firms is an important factor affecting choice of candidates. This factor is divided into two levels as good training and career opportunities and no training and career opportunities. It was assumed that level of "no training and career opportunities" reflects characteristic of SMEs.

2.3 Determination of Incentive Factors

Since this study investigates the effect of incentives that the government could provide to employees if they work in SMEs, the incentives that can be implemented without any burden on both the employee and SMEs were searched. For example, one incentive that can be implemented by the government would be to decrease the income tax rate. This incentive directly affects the wage of an employee. The age of retirement specified by the Social Security Institution (SSI) and the period of work required to earn the right to retirement as well as the compensation of unemployment, the period of granting, and private health insurance can be considered as incentives that can be applied by the government. In addition, employees are considered to be one of the incentives that the government could apply for an extra discount on the income tax rate in the case of graduate or doctoral degrees. Consequently, seven different incentives were determined that are assumed to be applicable by the government.

To limit the number of combinations (profiles) to be used in the conjoint analysis, the incentive factors were reexamined. For this purpose, a questionnaire was designed where incentive factors to be used in conjoint analysis were determined. The respondents were asked to answer the question: "How does the following incentive motivate you to work at a workplace?" A total of 34 respondents participated in the survey. The survey results show that decreasing the income tax rate and providing private health insurance have more influence on motivation than other incentives. Apart from these, the age of retirement and the period of compensation of unemployment are determined as the factors to be used in the research. These four factors chosen as the incentive factors are explained below:

Income Tax Rate: Income tax refers to the amount of money that people have to pay to the state due to the income they earn. This amount is up to a percentage of the payments made to them in the workplace for employees. A reduction in income taxation causes the employee to earn more income. According to the income brackets for 2017, an individual who is newly graduated or has 0–5 years experience and whose position is not a manager is generally known to be in the income bracket above 30,000 TL (Gelir İdaresi Başkanlığı 2017). For that reason, it was accepted that, on average 27% of the income tax in the survey corresponds to the current status. In addition to the current status, two more levels are defined as 5% and 10% less than current status.

Retirement Age: Retirement age indicates the age from which a person will get pension from state without working. Since the retirement age determined by the social security institution varies according to the sex and the age at which the individuals began to work, a specific age is not mentioned in this survey. Three levels were identified for this factor: the current retirement age, 3 years less than the current retirement age, and 5 years less than the current retirement age.

Unemployment Compensation Period: The unemployment compensation period shows how long a person will receive a guaranteed salary from the government agency when he or she is unemployed. Unemployment compensation is given to individuals who work as insured and pay unemployment insurance premiums. The periods are 6 months for the unemployed who worked for 600 days, 8 months for the unemployed who worked as insured for 900 days, and 10 months for the unemployed who worked as insured for 1080 days (iskur.gov.tr). The current status that is valid for the respondent is defined as the first level of the factor. Other levels are 3 months more than the current status and 6 months more than the current status.

Private Health Insurance: Most of the big companies provide private health insurance to their employees. SMEs have difficulty in providing such an opportunity because SMEs do not have sufficient financial resources. This creates a disadvantage for SMEs in the recruitment competition. It is thought that SMEs may come over the difficulty with such an incentive that the government will provide specifically for employees in SMEs. For this factor, two levels have been identified.

All seven factors and their levels that are used in the conjoint analysis are summarized in Table 1.

Table 1. Factors and their levels

Factors	Level 1	Level 2	Level 3
Wages and fringe benefits	Below industry average	Industry average	Above industry average
Firm reputation	Unknown firm	Known firm	–
Training and career opportunities	No	Good	–
Income tax rate	Current status (CS)(App. 27%)	5% less than CS (App. 22%)	10% less than CS (App. 17%)
Retirement age	CS	3 years less than CS	5 years less than CS
Unemployment compensation period	CS (App. 6 months)	3 months more than CS (App. 9 months)	6 months more than CS (App. 12 months)
Private health insurance	Not offered	Offered	–

The main survey question used in the conjoint analysis was designed as “How willing are you to work in a workplace with the following characteristics?” A conjoint card example used in this study is given in Fig. 1.

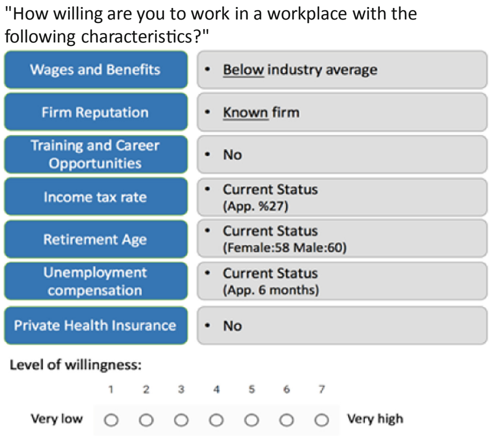

Fig. 1. Conjoint card example

3 Analysis

3.1 Demographic Characteristics

Out of the 163 people who participated in the survey, 104 are women, and 59 are men. It is observed that the participation rate of young people in the survey is high. The age ranges 23–28 and 29–35 constitute 86% of the respondents. When the educational status is examined, it is seen that university graduates, graduate students, and master's degree graduates constitute the majority (90.2%) of the participants. When the occupational groups of the respondents are examined, it is seen that there are about 65% engineers. Age groups, education levels and experiences of the participants are close to each other. In summary, the respondents are mainly composed of newly graduated or less experienced, non-executive or first-tier executive university graduates.

3.2 Conjoint Analysis Results

In Table 2, utility values and standard error values are given for each level of factors. It is seen that utility values increase as the levels of factors is generally improved. Here, it is seen that there are two factors of which utility values do not increase as their levels improve. These are the retirement age and the unemployment compensation period. For retirement age, the utility value of the level of current status is the lowest, the utility value of 3 years below the current status is the highest. Here, the third level, which is 5 years less than the current status, is expected to be the highest, but it results as the second highest. To understand this unexpected result, the conditions to get pension should be analyzed. There are two conditions; one condition is that a person must be at retirement age or more, which is set by the government. The second condition is that a person must work as insured and pay all premiums for a specified period that is also set by the government. Considering these two conditions, people may have thought that since the number of working days is longer than the retirement age, decreasing retirement age is not so meaningful.

For the unemployment compensation period, the current status that is, in average 6 months, has the lowest utility value. The level of 3 months surplus is the highest utility value. In contrast to expectations, the option of giving 6 months more than the current status planned as the best level results in the middle. A reason behind this unexpected result would be that the individuals may have thought of not wanting to remain unemployed for such a long time or not to be unemployed.

Table 2. Factors, levels, and utility values

Factors	Levels	Utility values	Standard error
Wages and fringe benefits	Below industry average	−1.229	0.107
	On industry average	−0.220	0.125
	Above industry average	1.251	0.125
Firm reputation	Known firm	0.297	0.080
	Unknown firm	−0.297	0.080
Training and career opportunities	Good	0.484	0.080
	No	−0.484	0.080
Income tax rate	Current status (CS) (App. 27%)	−0.198	0.107
	5% less than CS (App. 22%)	0.010	0.125
	10% less than CS (App. 17%)	0.188	0.125
Retirement age	CS	−0.178	0.107
	3 years less than CS	0.180	0.125
	5 years less than CS	−0.002	0.125
Unemployment compensation period	CS (App. 6 months)	−0.073	0.107
	3 months more than CS (App. 9 months)	0.076	0.125
	6 months more than CS (App. 12 months)	−0.003	0.125
Private health insurance	Not Offered	0.246	0.080
	Offered	−0.246	0.080
Constant		0.413	0.096

Using the utility values in Table 2, for each of small, medium, and large-sized companies the willingness/attractiveness values for the current situation and incentive situations were calculated (see Table 3). Note that willingness in this paper is used in the same sense as attractiveness. To calculate the attractiveness values of each firm type for the current situation, estimated utility values of the levels of the encouraging factors corresponding to the characteristics of firm type and estimated utility values of the levels of the incentive factors are used. For small firms, the level "below the industry average" for the factor wage and fringe benefits, the level “unknown firm” for company reputation, and the level “no training and career opportunities” are used. For medium-sized firms, the levels considered are “on industry average,” “unknown firm,” and “good training and career opportunities.” It is recognized that large-scale firms provide wages and benefits “above industry averages,” are “well-known firms” and “provide good training career opportunities.” Two incentive policies were defined. In the first policy, for all of the incentive factors, levels with the highest utility value will be in action. In the second incentive policy, the levels of the incentive factors except the one with the highest utility value are set to the current situation. The factor and its level that received the highest attractiveness among the incentive factors is providing private health insurance to employees in SMEs (by the government). For the incentive factors for all types of firms, the same levels of the factors were applied.

For the first incentive policy, 10% less than the current status for the income tax, three years less than the current status for the retirement age, 6 months more for the unemployment benefit period, and providing private health insurance were selected as levels. The attractiveness that comes from the encouraging factors for firm types equals the sum of the utility values of the levels that represent the firm. The attractiveness of encouraging factors is 2.032, −0.033, and −2.01 respectively for large, medium and small scale firms. These findings may indicate that medium and small-sized firms have no attractiveness to employees. Note that the effects of the incentive factors on the attractiveness are independent of the firm types. The effect of these factors varies depending on the current situation and the incentive situations. The total effect of the incentive factors in the current situation is −0.695 whereas the total effect of the incentive factors in the first incentive policy is 0.690. The value of the firm’s current total attractiveness is 5.35, 3.285 and 1.308 for the large, medium and small, respectively. According to these values, the ratio of the attractiveness of medium-sized firms and small-scale firms to the attractiveness of large-scale firms are 0.61 and 0.24, respectively. However, it would be more appropriate to compare the attractiveness of SMEs when incentive policy is implemented with the attractiveness of current situation of large-scale companies to see the effect of the subsidized situation on SMEs. When the first incentive policy is applied, the resulting attractiveness of medium and small-sized ones is 4.71 and 2.71 respectively. In this case, the ratios are 0.88 and 0.51 for medium and small, respectively, which mean that when all of the incentive strategies are applied at the most advanced level, the attractiveness of medium-sized firms reaches 88% of the attractiveness of large-scale firms and the attractiveness of small-scale enterprises reaches only 51%. Attractiveness values will change if the second incentive policy is applied. In this case, the sum of the attractiveness of the incentives is −0.203. If such a strategy is implemented, the attractiveness of medium-sized firms will be 3.81. For small scale firms this value will be 1.80. The ratios are 0.71 and 0.34 for the medium-scale and small-scale firms respectively. The results are summarized in Table 4.

Table 3. Attractiveness values for firm types

Factors	Levels	Utility values	Large firms		Medium scale firms			Small scale firms		
			C	I*	C	I*	I**	C	I*	I**
Wages and benefits	Below industry average	−1,229						X	X	X
	On industry average	−0,220			X	X	X			
	Above industry average	1,251	X	X						
Firm reputation	Known firm	0,297	X	X						
	Unknown firm	−0,297			X	X	X	X	X	X
Training and career opportunities	Good	0,484	X	X	X	X	X			
	No	−0,484						X	X	X
Sum of encouraging factors			**2,032**	**2,032**	**−0,033**	**−0,033**	**−0.033**	**−2,01**	**−2,01**	**−2.01**
Income tax rate	Current status (CS) (App.27%)	−0,198	X		X		X	X		X
	5% less than CS (App. 22%)	0,010								
	10% less than CS (App. 17%)	0,188		X		X			X	
Retirement age	CS	−0,178	X		X		X	X		X
	3 years less than CS	0,180		X		X			X	
	5 years less than CS	−0,002								
Unemployment compensation	CS (App. 6 months)	−0,073	X		X		X	X		X
	3 months more than CS (App. 9 m)	0,076		X		X			X	
	6 months more than CS (App. 12 m)	−0,003								
Private health insurance	Exist	0,246		X		X	X		X	X
	No	−0,246	X		X			X		
Sum of incentive factors			**−0,695**	**0.690**	**−0,695**	**0.690**	**−0.203**	**−0,695**	**0.690**	**−0.203**
Constant		4,013	X	X	X	X	X	X	X	X
Total attractiveness			**5,350**	**6.735**	**3,285**	**4.706**	**3.81**	**1,308**	**2.714**	**1.80**

C: Current, I: Incentive; *First incentive policy, **Second incentive policy

Table 4. Summary of the attractiveness of firm types

Factors	Large size firms	Medium size firms			Small size firms		
	Current	Current	Incentive*	Incentive **	Current	Incentive *	Incentive **
Encouraging	2.032	−0.033	−.033	−.033	−2.01	−2.01	−2.01
Incentive	−0.695	−0.695	0.690	−0.203	−0.695	0.690	−0.203
Coefficient	4.013	4.013	4.013	4.013	4.013	4.013	4.013
Total attractiveness	5.35	3.285	4.706	3.81	1.308	2.714	1.80
Ratio		3.29/5.35 =0,61	4.71/5.35 =0,88	3.81/5.35 =0,71	1.31/5.35 =0,24	2.71/5.35 =0,51	1.80/5.35 =0.34

*First Incentive Policy, **Second Incentive Policy

4 Conclusion

In this study, strategies were developed to motivate high-quality employees in choosing SMEs as their workplace. The four benefits that the government can provide to its employees are considered as a strategy option that can influence the workplace preferences of employees. Effects of these strategies, defined as reducing the income tax rate, reducing the retirement age, increasing the duration of the unemployment compensation, and providing private health insurance to employees in SEMs, on the attractiveness of large scale firms and SMEs were determined by conjoint analysis. According to the results of the conjoint analysis, the ratio of attractiveness of small-scale firms to the attractiveness of large scale firms is 0.24, while that of medium-scale firms is 0.61. These values show that small and medium-sized companies have great disadvantages over large-sized companies. When all incentives for small and medium-sized firms are applied, this ratio is 0.51 for small and 0.88 for medium-sized firms. Only when the incentive factor with the highest attractiveness is applied, these ratios become 0.34 and 0.71. All of these findings indicate that SMEs have significant disadvantages resulting from their structural characteristics. However, it can be concluded that government incentives may help reduce the disadvantages of SMEs in this regard. There are also some limitations to this study. The majority of the respondents are engineers. Therefore, it is not possible to generalize the results to all professions. Moreover, the age range covers mostly young people, which is another restriction to generalize the results. Another limitation concerns the method of gathering respondent evaluations. The method used in conjoint analysis inevitably limits the number of factors and levels. This may cause to exclude factors having significant effect on the results. The results should be interpreted with these limitations in mind. Further analysis can be carried out to overcome these limitations. For example, a more effective evaluation approach can be employed in conjoint analysis to allow considering more factors. In addition, the effects of different environments can be investigated by conducting this study in other countries.

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Ergonomic Review of University Library Furniture: A Case Study of Cyprus International University

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Abstract. As university students spend a considerable part of their daily life studying in the library reading area, ensuring that the furniture dimensions used are agreeable with the principles of anthropometrics has become critical. The compatibility between dimensions of furniture and user anthropometrics is therefore important. This study was carried out to understand the anthropometric dimensions of the library users and juxtapose it with the observed dimensions of the furniture in the library. Two approaches were employed for data collection. Namely, measuring the students' anthropometry and administration of questionnaires to the students using the university library. The questionnaire was focused on the musculoskeletal pain experienced by students. It was discovered that students feel more discomfort in the neck region. Also, shoulders and elbow regions are experiencing a considerable amount of pain. Results of the correlation analysis pointed out that there is a relationship between experienced musculoskeletal pain and variables like gender, age, degree level, and furniture design features. Comparison of furniture dimensions and anthropometric profile of the students highlights that there are mismatches in the paired dimensions. These mismatches are the precursor of the pains felt by the students that affect their well-being.

Keywords: Ergonomics · Anthropometrics · University library furniture · Pain · Students

1 Introduction

The library is one of the main infrastructures in an average university where students are frequently using. It is very notable for its role in supporting academic excellence with a cumulative effect on the goal of the university (Khan et al. 2014). It has remained the undisputable seats of wisdom and the basis for cultural connection and knowledge dissemination (Ugwuanyi et al. 2015). While more emphasis is usually placed on ensuring the safety of the library-building occupiers, the archived materials in the library building, importance needs to be placed on every library to ensure that it provides a comfortable environment for its users.

One of the areas where library users need comfort is the furniture of the library. It is expected that students using the library must sit down on chairs with tables to have

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a hitch-free study. However, poorly designed furniture can create a situation where the users will experience and be restricted to maintain an uncomfortable posture. Since they may spend long hours on a chair, they are prone to experience stress or pains which can affect them in the long run. This boils down to the fact that anthropometric measures are needed while designing the library furniture. There should be a match between the anthropometric profile of the students and the status of the furniture in the library.

In consequence, the need for this research becomes vital as it is of necessity to evaluate the library furniture dimensions and its suitability for the library users by understanding their anthropometric profile in relations to the dimension coupled with its marriage with pains in different regions of the users' body. Pain mostly emanate from musculoskeletal discomfort caused by the library furniture.

In this study, we focus on the perceived health condition and the anthropometric profile of the CIU library users to find out if there is a match or mismatch in their profile and the dimensions of the CIU library furniture (limited to table and chair dimensions).

Anthropometry is the measurement of the human individual to know their variations, which is a vital activity in ergonomics to annex the distribution of different body dimensions in a population (Garba 2010). Anthropometrics cannot be underestimated in industrial design, and garments design for the production of products that are considered fit for use (Pheasant 2014). With the full knowledge of the interaction of humans with objects, ergonomists are equipped with better ways to design products and systems that will enhance comfort while using them. Ergonomic application surely gives birth to an improved working condition, safe environment, better health condition for employees, enhanced employees' performance, and job satisfaction (Lehto and Landry 2012). To have designs of furniture that will be comfortable for sitting, or enhance safety, well-being, and convenience, the basic philosophy of ergonomics is required (Taifa and Desai 2017).

Seating Ergonomics is the science of designing and engineering things to facilitate safe and effective relations between the objects and their users (Biofit.com 2019). (Rogers et al. 2011) state that seats need to be designed in a way that will protect those using it from musculoskeletal discomfort and tedious movement, which should also disallow strains and stresses that clog. While designing seats, the purpose the seat will be used for, the environment the seat will be used, and the activity that is to be performed while using the seat are all factors to be put into consideration (Shneiderman 2010). Also, ergonomic seating can help its users to pay attention to details, boost their performance, and keep them in good shape (Jeong and Yoon 2014). Ergonomic furniture is expected to include a five-legged pedestal base, fully adjustable and cushioned armrests, a seat that allows for even weight distribution, lumbar support, and easy-to-use height adjustment (Biofit.com 2019). Another way to decrease lumbar disc pressure is the utilization of armrests (Van Niekerk et al. 2013). They aid by setting the body weight not completely on the seat and backrest yet directing some of this pressure to the armrests. Armrests are required to be adjustable in height to guarantee that the shoulders are not burdened (Dimberg et al. 2015).

Seating space is an important factor in library design. It is suggested that library users are to have different types of seating arrangements to select from to accommodate their various activities when using any of the three types of seating as reading benches, reading tables and flexible seating (Haapakangas et al. 2011).

Odunaiya et al. (2014) pointed out that furniture plays an imperative role in the environment, coupled with users learning activities. The researchers further noted that wrongly designed furniture, that is, furniture that does not match the features of the users would encourage fatigue, posture out of order, and the formation of neurotic states that is a possible reason for the library user to underperform while using the library to study. Accordingly, it is also a cause of musculoskeletal discomfort, loads, and strain among users of the library, which accounts for their decreased efficiency.

(Pheasant 2014) had made it clear that library seat occupies an important list of facilities needed in the library that is to be considered in equipping the library and compromise must not be made when it comes to the comfort and ease that can be enjoyed while using them. It is expected that library users will use the seats for a considerable length of time for a serious study, while their comfort and satisfaction level are directly related to each other. Frequent or constant contact with hard surfaces, which is known to contact stress, can form pressure that may repress nerve capacity and bloodstream. This kind of stress is associated with a situation when the legs are pressed against a hard surface on a seat or elbows rest on a hard desk surface. Hence, it is not an understatement to say that reading tables or desk and seat dimensions, temperature, lightening, sound are salient ergonomic factors that contribute to a library user's comfort and satisfaction.

Different body sizes and dimensions of human beings sometimes mean mismatch with furniture dimensions and when it occurs, it does mean that there would be some level of discomfort to be experienced by library users (Osquei-Zadeh et al. 2012). When there is a mismatch, it may be because of the level of ignorance of furniture designer about the anthropometric measurements of students expected to use the furniture (Reddy 2015). This ignorance has accounted for the prevalence of discomfort in library users. Although it is very difficult, it has been suggested that library furniture should be designed based on the specific user's anthropometric dimensions. On a general note, the average height of the male library users seems greater than female users in most schools (Pheasant 2014). For elbow height, knee height, shoulder height, upper a safe distance, popliteal height, and buttock-popliteal length, the average height should fall within both genders. According to Straker et al. (2010), height, in terms of students' body dimensions cannot be classed as a significant predictor of furniture fitness.

According to de Macedo Guimarães (2011), low seats cause postural kyphotic among seat users while writing. An appropriate seat aids in achieving a good sitting posture with a resultant positive effect on the lordotic and kyphotic curves of the spine. When the height of seats is too high, it makes students adjust to a kyphotic posture. Castellucci et al. (2010) are not in opposition to this fact, as it was stated that wrong heights could cause pains at the back among students. The seats should not be excessively shallow for library users. According to Khamis (2018), excessively low seats are improper because they increase muscular work at the back while endeavoring to look after balancing. Additionally, fatigue and discomfort are expected to be experienced when seats are excessively low, which is stated by Panagiotopoulou et al. (2004). As indicated by Castellucci et al. (2010), too deep seats are inappropriate for they bring about compression of the popliteal fossa and cause the reception of a flawed posture.

Every section of the library has different furniture such as chairs and tables, and they are to be measured respectively. According to (Panero and Zelnik 2014), mean body measurements of the users helps in knowing the suitability of the furniture. The major standards to determine the suitability should be in the measuring anthropometric mismatches.

Anthropometric mismatches reveal the information of students with a percentage of match and mismatches observed in the body (Odunaiya et al. 2014). A mismatch is defined as the incompatibility between the dimensions of chairs and tables and the dimensions of the body of the students (Mohamed 2013). There are certain rules to be followed to establish mismatch, and they are identified as follows (Khanam et al. 2006):

i. A mismatch is found when the Chair Height (CH) is either 95% or, 80% of the Popliteal Height (PH),
ii. A mismatch is defined when the Seat Pan Length (SPL) is either 95% or, 80% of the Buttock Popliteal Length (BPL),
iii. A mismatch is found when the dimension does not fall in the 95th percentile of Hip Breadth (HB) - sitting, Seat Pan Width (SPW) should be 10% minimum and 30% maximum in length than HB

Saes et al. (2015) point out that the high desk surface is tantamount to head bending. Since students are expected to have their arms rested on the desk, there is an alteration in the position of the pectoral girdle, which normally causes discomfort in the shoulder region. Low table surface means forward-bending, especially when holding books on the table, and it can add up to the possibility of altering the cervical region and thoracic spine.

Reis et al. (2012), in their results, maintained that unsuitable chairs and tables could cause pains in the lumbar spine. Among the eight hundred Brazilian students that were surveyed, back and shoulder are areas where pains are felt most, it was also added that the gluteal region are affected because of the worn-out glutes and this can cause poor balancing in the cervical and dorsal region of the lumbar spine is associated with inadequate school furniture. It is also reported that the height and depth of chairs can cause pains in the cervical spine and lumbar spine.

Ergonomic concerns on furniture would make a major effort in overseeing student discomfort. Generally, students have a preference ergonomically designed furniture to customary ones. Furthermore, little modifications in present states of furniture to standards that have considered ergonomic designs have been made known to increase proper sitting behavior as well as increase students' pleasure and comfortability.

Unfortunately, it is only in office furniture that chairs and tables are adjustable, leaving school furniture to be rigid. This means that the students will be forced to balance the chairs on two legs forming an inclination to derive some level of comfort that is achieved in changing their position on the chair.

2 Method

This study aims to understand the anthropometric dimensions of the library users in Cyprus International University and to investigate musculoskeletal pain of students in some regions of the body part.

Two approaches used in this study to collect data are taking anthropometric measurements of the library users and applying questionnaire to capture experienced musculoskeletal discomfort. The questionnaire was adopted from the study of Farooqui and Shahu (2016) which is sectioned into two; the first section is about demographic information of the respondents, and the second section captures the perceptions of the students on pains in the neck, shoulder, elbow, hip, thigh, knee, and hands.

The anthropometric measurements were collected from October to November 2018 to gather data about current students' anthropometric profile. The nine anthropometric measurements were collected which are Knee height (KH), Popliteal height (PH), Shoulder height (SH), Leg length (LL), Elbow rest height (ERH), Buttock-popliteal length (BPL), Buttock-knee length (BKL), Forearm hand length (FHL) and Hip breadth (HB). In the same time, the questionnaire was filled to gather data from students to investigate the health condition of the students with a focus on pains in different regions of the body.

The research was approved by the Ethics Committee of Cyprus International University. Also, the students who participated in the anthropometric measurement, and the survey were duly informed with a consent letter, and their consent was received with an assurance of adherence to the rule of confidentiality. Safety of the participants was ensured while measurements were taken.

According to the library management, there are 11,392 students that are namely the population of active library users for the period of February 2018 to June 2018. Therefore the sample size was found 380 students (participants) with a 95% confidence level and 5% sampling error.

The questionnaire data were collected in the library hall, and the Anthropometric measurements were taken by the use of Harpenden Anthropometer calibrated in millimeter (mm) as its unit.

A twenty-participant sample was used to check the reliability of questionnaires. Their reliability test result indicated high reliability with a Cronbach's alpha of 0.826 (82.6%).

The collected data were analyzed using SPSS for Windows (version 21.0). Bi-variate correlation analysis was used to investigate the significant relationship between musculoskeletal pains they experience in their body regions and age, gender degree level, and furniture design. In the analyses, Spearman correlation coefficients are utilized.

3 Results

Among the 380 participants, 56.3% were males, and 43.7% were females. The participants of ages between 18 and 35 years old were randomly selected from different academic programs. The participants' age ranges and the level degrees are given in the following figure. As shown in Figure, the participants in the age group 18–21 years are 19% (72), and 70 of them are bachelor students, 22–25 years are 29% (113), and most of them are bachelor students, 26–29 years are 24% and 30 years and above are 28% (106), and 57 of them are master's students (Fig. 1).

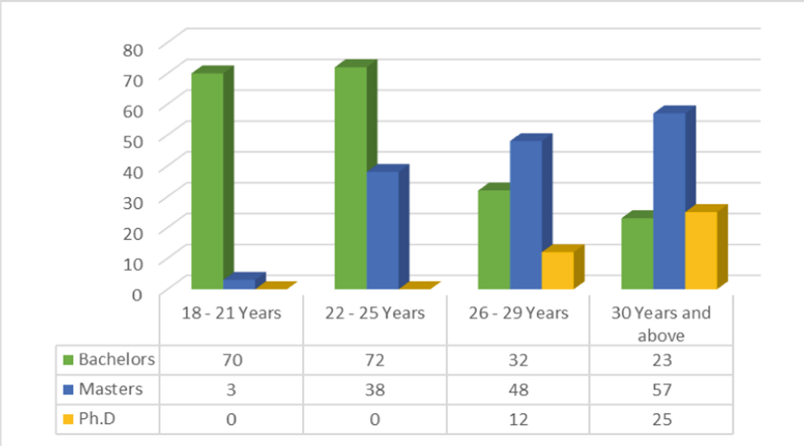

Fig. 1. The age group of students in different Academic levels

By using the questionnaire, musculoskeletal pains experienced by participants were determined. The participants stated that the musculoskeletal discomfort mostly experienced at the neck pain (81.3%) was predominant among all other pains felt by the participants followed by shoulder pain (76.1%) while the least was elbow pain (50.3%). Another important result is that the female students tend to feel more pains than the male students except for pains felt in the elbow (Male = 53.3%, Female = 46.4%). The detail results about body regions where participants feel pains are given in Table 1.

Table 1. Body regions where participants feel pains

	Male (N = 214)		Female (N = 166)		Total	
	Yes(%)	No(%)	Yes(%)	No(%)	Yes(%)	No(%)
Neck pain	79	21	84.3%	15.7	81.3	18.7
Shoulder pain	74.3	25.7	78.3	21.7	76.1	23.9
Elbow pain	53.3	46.7	46.4	53.6	50.3	49.7
Hip pain	54.2	45.8	56.6	43.4	55.3	44.7
Thigh pain	50.5	49.5	61.4	38.6	55.3	44.7
Knee pain	65.4	34.6	74.7	25.3	69.5	30.5
Hands pain	72.0	28.0	74.1	25.9	72.9	27.1

Moreover, 55.5% of participants identified their pains to be because of the design of the library furniture.

Four different correlation analyses were conducted to test if there is a relationship between musculoskeletal pain experienced (for different body regions) and gender, age, degree level, furniture design. It was found that there is a weak but significant relationship between musculoskeletal pain experienced in their body regions and age. The results indicated that the participants who are in 22-26 years old range had felt more pain in their body region compared to other age range. Especially they feel pain/discomfort in their neck and shoulder regions.

The correlation analyses also showed that there is a weak degree of correlation with a significant value between musculoskeletal pains they experience and gender. The results showed that females' feels more pain in your body regions male, especially in neck and shoulder while tests showed that there is no correlation between musculoskeletal pain experienced in their body regions and degree level.

An important result from correlation tests says that although weak, there is a correlation between musculoskeletal pain experienced and furniture design. The correlations and significant values for furniture design and different body regions are shown in Table 2.

Table 2. Summary table of correlation and significant values

	Body region	Spearman's rho correlation
Furniture design	Neck	0.142**
	Shoulder	0.119*
	Hip	0.200**
	Thigh	0.100*

Note: * = p<0,05 ** = p<0,001

According to results, the mean value for KH, PH, SH, LL, ERH, BPL, BKL, and FHL are higher for male participants when compared to the female participants. However, the female participants only had a higher value of mean more than the male participants in the HB.

The anthropometric measurements and furniture dimensions are compared with each other to know if they match, and a chi-square test was done to confirm a relationship between them. The comparison considered 5th percentile for Chair Height versus Popliteal Height, Back Rest Height versus Shoulder Height and Seat Pan Length versus Buttock Popliteal Length. While 95th percentile was used for the comparison between Seat Pan Width versus Hip Breath. This is to allow a larger population with a short person as a subset in the use of the chair. The results showed that there is no statistically significant relationship between the correlated measures. This implies that none of the furniture dimensions checked match corresponding anthropometric measurements of students, which explains why the students might feel some discomfort in their use of the library.

4 Discussion and Conclusion

In addition to the understanding of the anthropometric profile of the library users, this study also examined the musculoskeletal discomfort experienced by the student. According to Azabagic et al. (2016), pains felt in muscles, and skeletal systems of students affect their physical well-being. Perceptions were collected by the use of a structured questionnaire, and eight regions of the body were pointed out as areas where pains are expected to be felt while using the chairs and tables in the library. It was discovered in this study that neck pain was predominant among the library users followed by shoulder pain which is similar to the findings of the studies of Boampong et al. (2015). Among both genders, this pain might have been as a result of a longer sitting, as noted by Azabagic et al. (2016) and Boampong et al. (2015). However, the findings of this study explained a higher prevalence of neck pain among females more than the male. This is confirmed by the studies of Saueressig et al. (2015) but Ruivo et al. (2014) who emphasized that this kind of pain is predominant among females due to forward head posture. However, it can be said that both genders are possibly going to have a forward head posture as well because of the frequency of movements associated with a desire for comfort, which may create a poor alignment of the neck. Nevertheless, having neck pain as a most perceived pain for the library users, it means that most of the library users may experience symptoms like general aches and pains connected with postural fatigue in the neck, shoulders, arms, or constant pain or discomfort in soft tissues surrounding the neck and shoulders (Sabeen et al. 2013). There may be a possibility of having an increase in reported health problems among library users if ergonomic problems in the library furniture are not solved or fixed.

Also, this study considered the mismatch between chair dimensions and the anthropometric profile of the library users. The chi-square test conducted showed a no significant relationship between the dimensions. The mismatch was also observed in the TH and ERH, PH and CH, BPH and SPL, HB and SPW. This meant that the furniture in the library is not suitable for library users, which may cause musculoskeletal disorders in addition to the loss of attention while studying, as stated by Parvez et al. (2018).

In general, the result of this study has shown that library furniture is not suitable for library users in this study. The chairs and tables are of different types, which revealed that they do not vary for ergonomic advantage. Their presence could be as a result of buying the chairs and tables from different suppliers. Nevertheless, it showed that there was no proper consideration of the students while buying the furniture. None of the chairs was adjustable, because they are one-size-fits-all in nature.

In an environment where different students from different nations are gathered, it is important to have the right design that will suit the students for their comfort, which is of vital precursor to their health condition and perhaps academic performance. Even though it is practically difficult to have suitable chairs and tables for all library users in a university library, it is expected that data are collected to support the standard related features that need to be considered in equipping the library of the university. This calls for the need for adjustable library furniture that can be used by the users for their proper sitting positions. A proper sitting position is a sure way to reduce the pains they would feel.

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Digital Twins for Industry 4.0: A Review

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Abstract. Digital twins (DT) are the key enablers for transformation to Industry 4.0 (I4.0), they are required and indispensable to the virtual design and optimization of smart manufacturing systems for I4.0. Recently many researchers have contributed to the development of Digital Twins for smart products processes and manufacturing systems. This paper presents a systematic literature review of recent developments in Digital Twins in I4.0 for Smart manufacturing, by examining the most researches related to DT, and classifying the existing publications according to the applications in various aspects of manufacturing i.e. product design, process design, manufacturing process (such as machining, cutting), additive manufacturing, 3D printing, plant layout design, production planning, ergonomics, maintenance and product lifecycle. This paper classifies, identifies, and analyzes the research on Digital Twin application to smart manufacturing systems for I4.0.

Keywords: Digital Twin · Industry 4.0 · Additive manufacturing · Big Data · Cyber-Physical System · Industrial Internet of Things · Smart Manufacturing

1 Introduction

Industry 4.0 (I4.0) is characterized by a significant evolution in technologies integrating into all areas of smart manufacturing systems and encompassing the complete product lifecycle from the beginning to the end of the product's life, including design, development, manufacturing, sales, and services. I4.0 is envisaged as a consequence of interconnectivity between engineering, production, logistics, services, and marketing. I4.0 is more about intelligent, self-adapting industrial processes and real-time communication that goes beyond automation. I4.0 vision is to define an industrial journey that will facilitate faster, more flexible, more efficient, and with higher quality production. Moreover, it is a new concept of managing the value chain across product lifecycles. This management involves ordering, development, production, and shipping of personalized customer demands. Real-time monitoring availability through the object to object communication in the value chain permits precise predictions of capacity to control value flow.

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The interconnectivity of systems such as objects and people allow real-time optimized systems, self-organization, cross-enterprise value-adding networks, thus reduce the cost, maximize the availability, and optimize the resource consumption (Preiss 2011).

Manufacturing processes are becoming increasingly digital. I4.0 requires a "smart or digital factory." Digitalization is leading to a variety of modifications to all manufacturing processes and systems, increasing the ways of communication, exchange, and cooperation (such as operator to operator, operator and machines, and even between the machines or between the manufacturing and business functions). Future manufacturing invests in new type technologies such as Digital Twin (DT) and Augmented Reality (AR) to improve the process while improving the performance of the operator. Future manufacturing systems called as Smart Factories that have to augment flexibility in production owing to the automation of the production processes, automatic data transmission through the manufacturing chain, consequently leading to increased product variety, reduced manufacturing costs, and reduced carbon emissions. Furthermore, mass customization enables the production of smaller lots due to the capability of quick reconfiguration of the equipment to adapt to stakeholder specifications. The successful transformation to I4.0 is inevitable without the virtual design and optimization of smart manufacturing systems. Zhong et al. (2017) identifies and reviews the major technologies used in smart manufacturing systems that include intelligent manufacturing, IoT-enabled manufacturing, cloud manufacturing, Internet of Things (IoT), Cyber-Physical Systems (CPS)s, cloud computing and Big Data Analytics (BDA). In addition to the technologies above, AI, deep learning, and machine learning are converging to transform data analysis in I4.0. Figure 1 provides a schematic of the digital twin application areas in manufacturing.

2 Digital Twin

DT is a fundamental term associated with I4.0 revolution. DT refers to a virtual duplicate of a physical asset, product, or process, used to understand, predict, and optimize the performance characteristics of the physical counterpart (Herterich 2017). With the advent of IoT, a DT can collect data continuously from sensors and mutually pass information with the physical counterpart throughout the system's life-cycle (Madni et al. 2019). NASA developed an early DT to simulate behaviors and conditions of Apollo 13. However, today, DT is utilized to monitor the entire Space Center (Kemp 2012). Tao et al. (2018b) describes DT as an integrated multi-scale and probabilistic simulation of complex products, that uses advanced physical models, sensors and components to mirror the life of its corresponding twin. DT has three components which are algorithms, set of analytics and a data model.

Digital Twin (DT) was introduced in 2002 as a Product Lifecycle Management (PLM) tool named as "Conceptual Ideal for PLM." Later on, it is called as "Information Mirroring Model" in 2006, the final appellation is named as "Digital Twin" in 2010 (Rajratnakharat et al. 2014). DT concept has evolved from a simple PLM tool to a powerful tool for decision making assistance of digital business (Tao et al. 2018a). With the emergence of I4.0, the focus shifted towards smart manufacturing and smart products, where DT can support ensuring information continuity throughout the entire

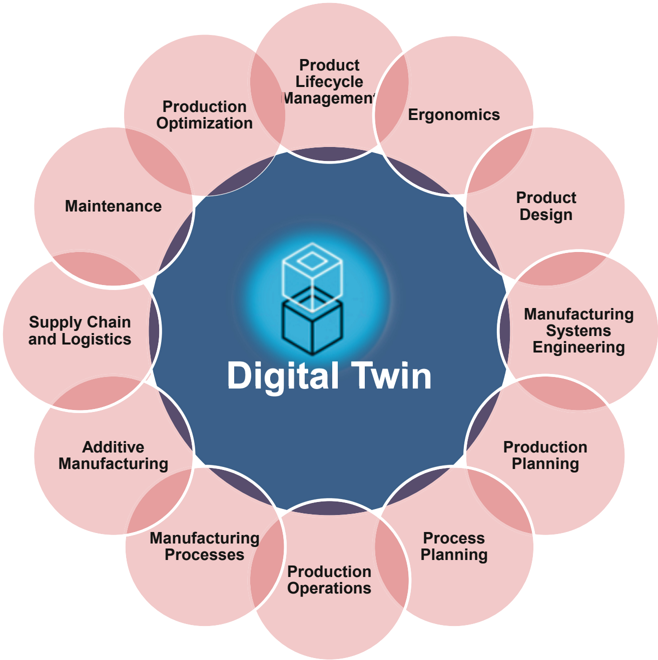

Fig. 1. Digital twin - application areas in smart manufacturing. Adapted from (Rosen et al. 2015)

product lifecycle (Abramovici et al. 2016; Rosen et al. 2015), virtual commissioning of manufacturing systems (Schluse and Rossmann 2016), and support decision making and system behavior predictions in the product development phase (Kraft 2016). DT is a collection of all digital artifacts that are obtained during the product development, and this set of data is generated during product usage.

Furthermore, (Boschert and Rosen 2016) discuss that DT is only a collection of relevant data and models. DT is also a digital representation of an individual product to analyze the properties and behavior of objects through the models. DT allows simulating, developing, characterizing and verifying the behavior of the real equipment inside the manufacturing system, and brings all the simulation technology available for the real system, allowing the self-adaptive behavior of the equipment. With the digital transformation, DT can simulate different environments and also establish the best decision to take in a particular situation of the simulated environment. However, DT replicates the same decision that the real equipment would have taken (without introducing another stochastic event).

Additionally, DT helps to populate relevant Industrial Big Data with the support of the simulation tools. Simulating the different environment in which the real equipment could work, a large set of data could be collected and analyzed (Bottani et al. 2017).

Kritzinger et al. (2018) identify the key technologies required for the implementation of DT, DTs are not restricted to simulation methods (e.g., Discrete Event Simulation, Continuous Simulation, etc.), communication protocols (e.g. OPC-UA, MQTT, etc.) and other technologies commonly described as I4.0 core technologies (Internet of Things, Cloud Computing, Big Data, etc.). GE Digital (2018) provide a hierarchical classification of DT: component, asset, system, and process. The component twin is a major sub-component affecting the performance of the asset to which it belongs, such as a bearing on a rotating piece. Whereas, asset twins can be a collection of component twins such as a motor or pump. Unit twin is known as a collection of asset twins performing a system function such as a production line in the industry. Process twin is usually providing a perspective to a set of operations at the highest level and generally focuses on processes rather than equipment such as a manufacturing process.

Table 1 presents the classification of recent research on DT for smart manufacturing systems.

Table 1. Recent research on the application of DT to smart manufacturing systems in I4.0

Application area	DT hierarchy	Manufacturing	Key findings	I4.0 TECH	References
Product design/virtual prototyping	System	Assembly	• Presents a DT framework to support • Provides a framework for HRC • Carried out a case study for an assembly work station of HRC • Uses Tecnomatix simulation.	Simulation	(Malik and Bilberg 2018)
	Process	SMS	• CPI of manufacturing • The combination of SMS and DT would radically change product manufacturing • Service-oriented architecture may expand the functions of DT • DT has high potential in design & manufacturing and PHM	CPI	(Qi et al. 2018)
	Component	Manufacturing systems and product services	• AutomationML attributes related to DT • Data exchange between systems • An industrial component was modeled and simulated • Provides mechanisms to map the components of an automation system • Uses the object-oriented paradigm to store engineering information	CPS IoT	(Schroeder et al. 2016)

(*continued*)

Table 1. (*continued*)

Application area	DT hierarchy	Manufacturing	Key findings	I4.0 TECH	References
Manufacturing process design	Process	Cutting	• DT of a cutting tool considered • Uses ISO 13399 for data exchange • Developed event-driven LISA with IoT functionality • Effective data exchange and communication requirement discussed • Continuous adjustment	IoT	(Botkina et al. 2018)
	Process	Cutting	• A dynamic model machine tool (Mandelli M5) is developed		(Scaglioni and Ferretti 2018)
	Process	Machining	• Increase in machine uptime • Optimize Tool Life	CPS/CPPS	(Armendia et al. 2019)
	Component	Additive Manufacturing 3D Printing	• DT of 3D printed metallic components • Control and statistical models of 3D printing • Machine learning and Big Data reduce the number of trials and error testing • Defects reduction • Shorter design and production time	Big data Machine Learning	(Mukherjee and DebRoy 2019)
	Process	Maintenance	• Model-based control strategies developed in Twin-Control project • Process monitoring by learning • ARTIS device used in Twin-Control • Improve maintenance actions	CPS/CPPS	(Armendia et al. 2019)
	Process	Maintenance	• Contributed to I4.0 with (Usine4.0) • Defined DT and AR in research areas • Developed DT and AR industrial solution for predictive maintenance framework • Elaborated a proof of concept for the industry • Develop a monitoring method for the detection of forces and failures in rolling bearings	AR	(Rabah et al. 2018)

(*continued*)

Table 1. (*continued*)

Application area	DT hierarchy	Manufacturing	Key findings	I4.0 TECH	References
	Process	–	• Investigated the application methods and frameworks of DT-driven product design. Solved the problems about data in the product lifecycle • Investigated detailed application methods and framework of DT	Big data	(Tao et al. 2018a)
Plant layout	Process	Automobile Assembly line	• DT allows replicating the production line in a virtual environment		(Caputo et al. 2019)
	System	AGV	• Proposed a DT for AGV based on CPS • Implementation of CPS logic on an existing micro-controlled rover • Used DES software for simulation • Combined CPS-DT architecture for optimization of the plant resources in I4.0 • Based on the experimentation, I4.0 is not always the best configuration	CPS and DES	(Bottani et al. 2017)
	Process	Milling Grinding	• A 4% increase in production provided by the conveyor-belt simulation	Simulation	(Damiani et al. 2018)
	Component and process	Instrument making	• Formed principles of DT for CPS in the smart factories of I4.0 • Cloud services are a component of SPS • Interactions between I4.0 and cloud services	CPS and Cloud services	(Gurjanov et al. 2019)
Production planning	System	–	• DT allows for faster product integration • Permits I4.0 concepts	–	(Biesinger et al. 2019)
	Process	–	• Machine learning to enable industrial robots to bypass obstacles • Presented robotic control strategy • Experimental simulation platform (HIRIT) for human-robot interaction	Operator 4.0	(Dröder et al. 2018)

(*continued*)

Table 1. (*continued*)

Application area	DT hierarchy	Manufacturing	Key findings	I4.0 TECH	References
	System	Production	• A MES is developed and applied • MTConnect used for cloud-computing technologies and smart devices	Cloud Computing	(Urbina Coronado et al. 2018)
	System	Drilling	• Forecasts based on the realistic data for simulation	Simulation	(Rosen et al. 2015)
Maintenance	System	Maintenance	• Presents a modular corrective maintenance methodology using DT for I4.0 • DT and associated visual interface provide fault ascription support maintenance • DT applicable for corrective maintenance is developed in OpenModelica	CPS	(Vathoopan et al. 2018)
	–	Maintenance	• Provides an incremental improvement in the vision of the Smart Factory • Developed Service-oriented DT	CPS	(Longo et al. 2019)
Supply chain	System/Process	Order Management process	• The integration of DT into decision making • Conceptual framework and potential applications of decision support systems • Intelligent and self-learning search algorithms • DT of the manufacturing system is associated with a lot of challenges	CPS/CPPS	(Kunath and Winkler 2018)
Ergonomics	Not-defined	Assembly	• Simulation in a virtual environment • Assessing ergonomic index and numerical data	Simulation	(Caputo et al. 2019)

3 Discussion and Conclusion

As manufacturing systems are becoming increasingly digital, the digital twins are now providing a complete digital footprint of products, processes, and systems. Also, it allows producers to detect problems in the early stages and helps to predict outcomes more accurately. Therefore, manufacturing enterprises can build better and smarter products. Digital twins are on their way to revolutionize manufacturing by reducing operating costs and extending the life of equipment and assets. DTs are being applied to manage the performance, effectiveness, and quality of a manufacturer's fixed assets such as manufacturing plants.

This paper reviews the applications of DT to smart products, processes, and smart manufacturing systems for I4.0. It is observed that some of the researchers, (Bottani et al. 2017; Brenner and Hummel 2017; Graessler and Poehler 2018; Kemp 2012; Kousi et al. 2019; Negri et al. 2017; Rabah et al. 2018; Söderberg et al. 2017) applied DT to shop-floor control, assembly production lines and flexible manufacturing systems to optimize robustness, efficiency, autonomous failure detection, and production flow control. However, there is a need for research on Machine Learning, Standards, and Security topics. Only a few researchers, (Dröder et al. 2018; Okita et al. 2019) are focused on those topics, and none of the researchers emphasized the need for DT standards. Digital industrial leaders prefer the application of DT concepts: scientific knowledge over time, leveraging engineering, and machine learning. By this way, advanced analytic applications generate critical business outcomes such as increased reliability and availability, lower maintenance cost, reduced asset downtime, reduced risk, enhanced plant efficiency, fewer cycle times and increased market agility.

Digital Twin concept is still evolving and is yet to reach its zenith. DT has still various applications across the product life cycle and can answer the questions in real time that were not be answered previously. Maintenance is a major contribution area for digital twins. DT integrated into manufacturing and maintenance activities can significantly enhance the predictive maintenance and design. DT can identify equipment faults and troubleshoots equipment remotely, thereby alleviating a key customer concern. In addition to improving virtual system models, a DT can potentially improve physical system operations and sustainment. A DT can also help with product differentiation, product quality, and add-on services. Knowing how customers are using the product post-purchase, can provide useful insights including identifying and eliminating unwanted product functionality and features, as well as unwanted components thereby saving both time and money. The scope of the study is not to include all the available articles about the theme, but to analyze a significant sample scope to provides insight about the recent applications of DT to Smart Manufacturing Systems as well as to assist researchers and practitioners with the simulation and optimization of smart factories for the future studies.

Abbreviations

AR	Augmented Reality
BDA	Big Data Analytics
CBDT	Cloud-Based Digital Twin
CPCM	Cyber-Physical Cloud Manufacturing
CPI	Cyber-Physical Integration
CPPS	Cyber-Physical Production System
CPS	Cyber-Physical System
DES	Discrete Event Simulation
DT	Digital Twin

DM	Digital Model
ERP	Enterprise Resource Planning System
FMU	Functional Mock-up Units
HIRIT	Human Industrial Robot Interaction Tool
HRC	Human Robot Collaboration
ICT	Information and Communication Technology
I4.0	Industry 4.0
IoE	Internet of Everything
IoS	Internet of Services
IIoT	Industrial Internet of Things
IoT	Internet of Things
LISA	Line Information System Architecture
PHM	Prognostic and Health Management
PLM	Product Lifecycle Management
SMS	Smart Manufacturing System
SF	Smart Factory

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Simulation of Factory 4.0: A Review

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Abstract. Computer-based models and simulations are critical to the design, development, and optimization of smart manufacturing systems required for Industry 4.0. Modeling and Simulation technologies are essential to address the challenges in the adoption of Industry 4.0 today, such as the creation of smart manufacturing systems. Recently many researchers have contributed to modeling and simulation of smart factories in Industry 4.0, also known as Factory 4.0. This paper presents a systematic literature review of recent developments in modeling, simulation, and optimization of Smart Factories. It indicates the most frequent contexts, problems, methods, tools, related to simulation and optimization of smart factories. This paper fills this gap by identifying and analyzing research on simulation of smart factories.

Keywords: Factory 4.0 · Industry 4.0 · Cyber-Physical System · Smart manufacturing · Discrete Event Simulation · Petri Nets

1 Introduction

"Industry 4.0", "factory of the future," "factory 4.0" and "smart factory" are some of the terms used to refer this new factory model born of the 4th Industrial Revolution. The successor to the first three major evolutionary phases qualified as revolutions: mechanization, industrialization, and automation. This research is also referred to the Industry 4.0 in terms like "factory 4.0" or "smart factory" (Alcácer and Cruz-Machado 2019; Mourtzis et al. 2014b; Rodič 2017; Wang et al. 2016). (Blanchet et al. 2014) defines "Factory 4.0" as a fully connected way of making things with key manufacturing technologies such as intelligent sensors, 3D printing/additive manufacturing, advanced materials, advanced manufacturing systems [CPS, full interconnected automation], robots, autonomous vehicles, cloud computing, and big data.

For the successful implementation of the Factory 4.0 (Mourtzis et al. 2014a), computer-based simulation models are becoming a trend and powerful technology to

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recognize the dynamics of business systems (Rodič 2017). Challenges faced in manufacturing industries can be overcome by this technology (Zúñiga et al. 2017), dealing with the complex systems that have tons of problems cannot be solved by using typical mathematical modeling methods (Lachenmaier et al. 2017). The importance of simulation method is outstanding on customized product manufacturing environments. Experiments can be simulated for the validation of products, processes, or system designs as well as configurations (Mourtzis et al. 2014a). The advantages of simulation modeling explained as decrease development cycles, increase product quality and cost reduction (Haag and Anderl 2018; Longo et al. 2019; Qi et al. 2018; Rodič 2017; Smart Plants AS 2018; Tao et al. 2018).

Modeling and simulation (M&S) preferably used by manufacturers to examine their operations, to support decision making (Shao et al. 2015). Effectiveness of simulation technologies has been proved in the approach of numerous practical real-world problems in industrial manufacturing companies (Negahban and Smith 2014). Modeling and Simulation (M&S) is the cornerstone of the factory 4.0 and 4th industrial revolution. Therefore, currently, smart factories have been one of the most focused topics in research papers. For instance, (Dunke and Nickel 2015) proposed a simulation and optimization study for industry 4.0 technologies to provide a better understanding of the challenges and provide solutions for information and communication systems. Petri Nets (PN) have also been applied to Industry 4.0 and smart factories. For instance, (Long et al. 2016) highlighted some application examples dealing with the availability of the machine and self-organization. (Zhang et al. 2016) studied a PN model for handling exceptions, whereas (Kahloul et al. 2016) focused on reconfigurable object PNs for designing reconfigurable manufacturing systems. (Mendes et al. 2010) deals with a service-oriented approach in a production plant by PN composition.

Considering (Discrete Event Simulation-Based Optimization) DSBO characteristics, simulation methods can be applied on specific cases associated with the well-defined case and a limited quantity of methods, to assist optimizer in the early phases of optimization processes. The purpose of this work is to apply literature review (SLR) methodology while answering the research questions to highlight the findings as well as to generate a discussion that can assist researchers in accessing the most used DSBO techniques and underwriting with their projects on smart factories.

The structure of the paper is organized as follows: Sect. 2 components and technologies of smart factory, Sect. 3 Existing simulation models and commonly used simulation platforms, Sect. 4 simulation applications to real-world companies and discussion, Sect. 5 conclusion and suggestions.

2 Factory 4.0 and Its Components

The outline of the I4.0 is the development of the Factory 4.0 (Qin et al. 2016; Wagner et al. 2017). In theoretical terms, Smart Factory is the heart of I4.0 (Gilchrist 2016). Cyber-Physical Systems (CPS), Internet of Things (IoT) and Internet of Services (IoS) are the main components of I4.0 (Hofmann and Rüsch 2017). (Qin et al. 2016) defined Factory 4.0 as a system where the manufacturing processes are autonomous and independent with automatic information exchange between resources. Radziwon et al. (2014) defined factory 4.0 as a solution for manufacturing. Those allow flexible production processes that will overcome complex problems occurred on production plants. This special solution can be related to automation, including mechanics, hardware, and software, which lead to the optimization of manufacturing, resulting in a decrease of needless labor and waste of resource. This solution can also be related to collaboration between different industrial and non-industrial associates, where the smartness comes from forming a dynamic organization.

Computer-based simulation techniques have already verified its effectiveness by the application of numerous real-world problems in manufacturing companies (Negahban and Smith 2014). The domain areas of simulation with the focus on simulation methods and tools are presented by (Mourtzis et al. 2014a). Simulation is also defined in their study as an operation imitation of a system or a real-world process concerning time. System's artificial history and its observation over the operational features used to represent the real system. Based on the domain areas of simulation and key components of I4.0, Smart factory layout and its components are proposed in Fig. 1.

3 Simulation Models

There are several definitions of models and simulations. The U.S. Department of Defense (DoD) describes this definition and terms as follows in their online glossary (Defense Modeling and Simulation Coordination Office (DMSCO) 2013): modeling is a physical, mathematical and logical representation of a system or process, Simulation is a method for applying a model and behaviors in a software, and Modeling & Simulation (M&S) is the discipline that contains the development and also uses of the models and simulations.

Table 1 presents the commercial software platforms used by researchers for modeling and simulation of smart factories. Modeling and simulation of the systems provide a better understanding of system efficiency, performance, system maintenance, bottlenecks, process sequences, and process/production times. Furthermore, optimization can be conducted to obtain robust and efficient production systems in smart factories.

3.1 Discrete Event Simulation

Discrete event simulation (DES) is a powerful technique to accurately model complex systems for analysis and also can be used for optimizing processes to make confident and evidence-based decisions. (Creighton and Nahavandi 2003; Dehghanimohammadabadi et al. 2015; Negahban and Smith 2014; Smith et al. 1994).

Trigueiro de Sousa Junior et al. (2019) considers a systematic literature review based on DES integrated to industrial engineering difficulties. Their research designates the most common industrial engineering problems and projected results of DES studies published in the last 25 years. They have determined that 68% of the problems are related to scheduling and processes.

Yesilyurt and Nasser (2013) carried out DES and simulation of an assembly process at GKN Driveline Köping AB in Sweden. DES-based modeling and simulation used in their study to measure productivity, flexibility, and efficiency of the production assembly line. They have used ExtendSim software to visualize the data. Their study provides the

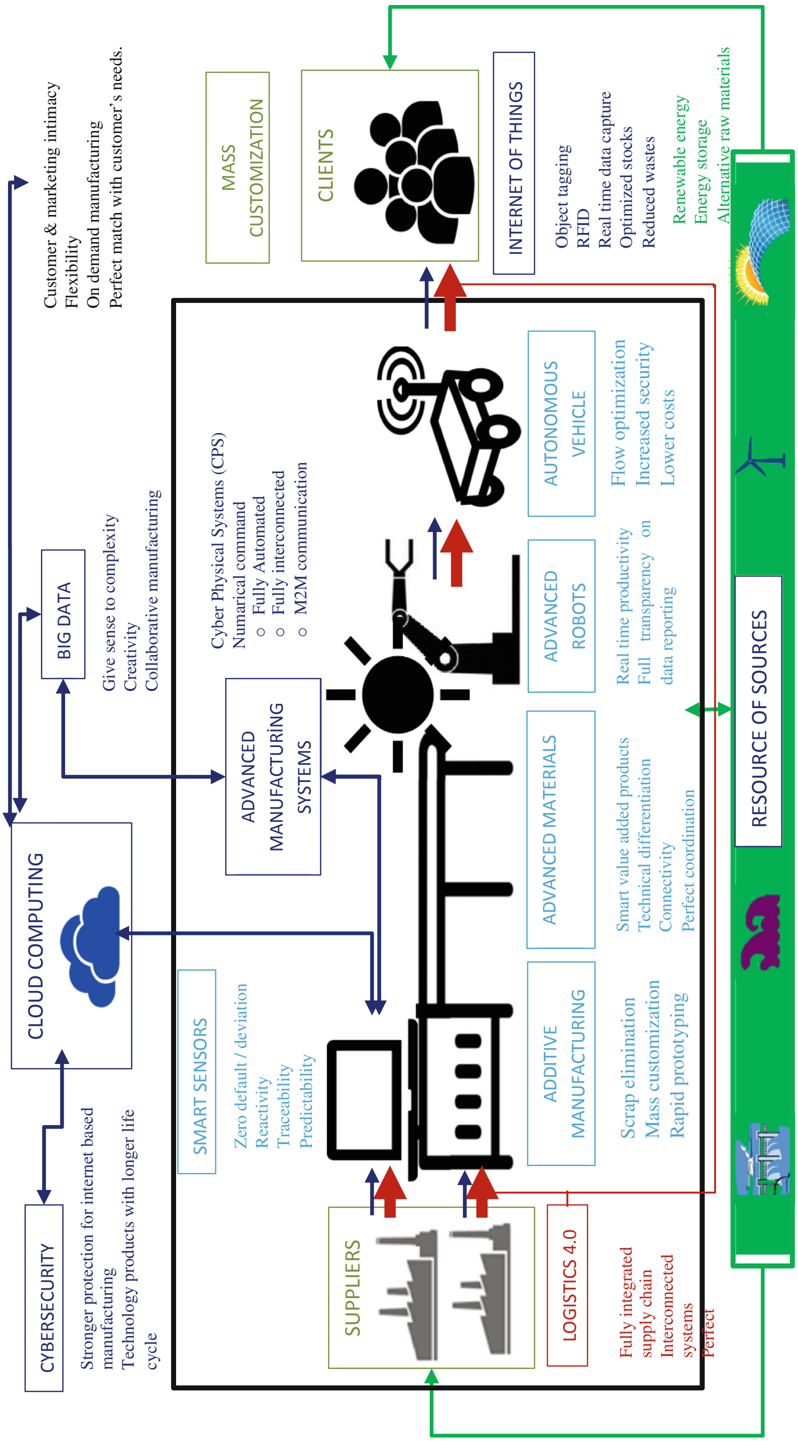

Fig. 1. An overview of Factory 4.0 (Roland Berger 2017).

Table 1. Recent research on Simulation of Factory 4.0

Model	Simulation models	Manufacturing system	Major objectives/key Parameters	References
Discrete Event Simulation	ARENA/SIMAN	Shop-floor control/Penn State CIMLAB	• Performance	(Smith et al. 1994)
	QUEST and MATLAB/SimEvents	Robust system design/Ford Geelong Iron Casting Plant	• Throughput • Maximize work-in-progress Energy consumption	(Creighton and Nahavandi 2003)
	Extendsim8	Assembly Process/GKN Driveline Köping AB	• Waste reduction • Bottleneck finding • Production rate • Cycle time	(Yesilyurt and Nasser 2013)
	MIDAS	Assembly Line/Deere & Company	• Operator efficiency • Work content • Bottleneck finding	(Singh 2016)
	ARENA	PCB Assembly Line/PKC Group plant	• Scheduling policies System performance	(Gebus et al. 2004)
	AnyLogic	Truck access control/BASF	• Performance measurement • Operation efficiency	(Dunke & Nickel 2015)
	Witness	Assembly line/Turk Otomobil Fab. A.S. (TOFAS)	• Performance measurement • Unutilized rates • Throughput	(Kousi et al. 2018)
	MATLAB/SimEvents	Beer production line/Heineken UK	• Repair time • Travel time • System performance	(Edakara 2013)
	AnyLogic	Smart Manufacturing Systems/US manufacturers	• Performance measurement • Number of resources	(Nagadi et al. 2018)
Time Colored Petri Net	MATLAB/Petri Nets	Assembly line/Engine production company CN	• Reel time production • Performance	(Zhang et al. 2016)
	RON Tool and TINA Tool	Multi-stage production line	• Production time • Process configuration • System efficiency	(Kahloul et al. 2016)
	SIMPACK/C Programming	Automated Palletized Conveyor System (APCS)/Flexible Manufacturing Cell	• Job sequencing • Sequence control	(Choi 1994)

(*continued*)

Table 1. (*continued*)

Model	Simulation models	Manufacturing system	Major objectives/key Parameters	References
Extended Colored Scholastic Petri Nets	REALIST	Spare part production line	• Production time • Redesign management • Monitoring and control	(Long et al. 2016)
Labeled Petri Nets	MATLAB/Diagnosis Toolbox	Automated Manufacturing System	• Failure detection • System performance • Equipment cost	(Cabasino et al. 2011)

ability to find bottleneck between stations by analyzing each cycle time as well as the total time required to produce one item.

Singh (2016) defined the term lean manufacturing and presented scenarios for increasing efficiency of the production system. Furthermore, their study deals with an existing assembly line and focusses on making different line segments lean. In this regard, discrete-event simulation applied to their study using MIDAS software to present scenarios, plausible solutions for Deere & Company. Their research provides a solution for finding bottlenecks in the process, least segment length with different operator efficiency factors and length segments for all product variants.

Gebus et al. (2004) carried out a case study of simulation project by using ARENA software based on experimental framework and modeling on Printed Circuit Boards (PCB) assembly line of PKC Group plant. Their study highlighted the effectiveness of discrete-event simulation in comparing production alternatives to improve production processes in electronics manufacturing. Therefore, basic scheduling policies are tested to develop intelligent optimization methods.

Dunke and Nickel (2015) presented a simulation-based approach which allows for the assessment of the optimization potential granted by information transmitting devices. In their paper, real-time problems related to the online optimization paradigm with a look ahead and to discrete event simulation. AnyLogic software used for simulation based on a holistic approach for performance measurement of algorithms. Also, performed a simulation study to highlight how simulation and optimization can be linked to evaluating technological scenarios related to Industry 4.0 for the truck access control at BASF company.

Kousi et al. (2018) studied the implementation of design and prototype of a service-based control system for material supply operations including planning and scheduling in assembly lines in which transportation of the consumables from the warehouse to the production stations carried by autonomous vehicles. In their study, discrete event simulation by using Witness software employed for investigating the production system at Turk Otomobil Fab. A.S. (TOFAS). Finally, their study anticipated architecture that permits the application of multiple and varying characteristics for service technology. Moreover, it provides a solution for well-organized handling of large examples of the material supply problems.

Edakara (2013) proposed a novel simulation model consist of a production line and a maintenance system. The production line model simulates two types of failures in addition to the outages such as breakdowns. The maintenance system model simulates the maintenance actions by considering the repair time, resources availability, and traveling time. Their research validated the proposed simulation model using an industrial case study for a beer production line of Heineken. The proposed model developed on MATLAB/SimEvents software, and this generic model can be easily applied to analyze other industrial production line systems.

Nagadi et al. (2018) studied smart manufacturing systems (SMS) and developed a framework which establishes messaging protocols between system components. Hybrid simulation modeling on AnyLogic software conducted to generate an estimate pre-implementation near optimal manufacturing configurations. An agent-based modeling tool employed to monitor the behavior of the required machines and a DES tool to mimic the process flow.

3.2 Petri Nets

First-time Petri nets were introduced as a modeling method for synchronized discrete systems by Petri in 1962, and Petri nets have four basic elements that are a place, token, arc, and transition (Petri 1962).

CPN and ESPN led to obtaining ECSPN by (Pozsgai 2006; Pozsgai and Bertsche 2004). Some additional features of ESPN developed for properties of queues and several elements specifically prepared for the modeling of state behavior with aging, the inspection strategy, the degree of renovation, and operational cost. The modeling characteristics, which can be considered by ECSPN, are introduced in (Zeiler and Bertsche 2014).

Long et al. (2016) considered three models of high-level Petri nets ECSPN and simulated the proposed model using REALIST software for industry 4.0 and their availability. The model applied to spare part production plant and the models that present interaction and self-organization can be modeled with ECSPN within a certain range.

Kahloul et al. (2016) specified reconfiguration processes as a graph transformation in a model and developed a simulation using the RON-tool, and the analysis exploits the TINA-tool. The proposed model provides a solution for a new requirement in the process and avoids some problems caused by machines failures. The developed model implemented to Multi-stage production line as a case study to increase the efficiency of the system while reducing the global time of the manufacturing process.

4 Simulation Platforms

Recently there are several commercial platforms available for modeling and simulation of smart manufacturing systems.

Table 2 presents the commercial software platforms available for modeling and simulation of smart factories.

Table 2. Commercial software platforms available for simulation of factory 4.0

Simulation Software	Modeling approach	Key features	References to software platforms
MATLAB/Petri Net Toolbox	Discrete Event Simulation and Petri Nets	• Token Game Animation • Fast Simulation • Place Invariants • Structural Analysis • Performance Analysis • Interchangeable File Format	(Cabasino et al. 2011; Choi 1994)
MATLAB/SimEvents	Discrete Event Simulation	• Easy to use. • Block diagram animation • Custom animation creation.	(Creighton and Nahavandi 2003; Edakara 2013)
ARENA	Discrete Event Simulation	• New procedures without disrupting the current system. • High model interface capability. • Create hierarchy resources to reduce time. • "ExcelDatetoBaseTime" function converts the Excel date. • Debugging Variables to identify errors.	(Gebus et al. 2004; Kranz and Zupick 2017; Smith et al. 1994)
Simul8	Discrete Event Simulation	• Advanced objects. • Objects that simulate real-life systems. • Easy to simulate a factory. • Easy to use outing arrows.	–
Virtual Plant Software	Discrete Event Simulation	• Query the database and create data sets. • Easy to compare gene sets. • Anatomy, temporal and Gene ontologies • Functional classification scheme	–
Extendsim8	Discrete Event Simulation	• Interactive, reusable, and visual tool that accelerates model building.	(Yesilyurt and Nasser 2013)
SIMIO	Discrete Event Simulation	• Unique multi-paradigm modeling tool. • A rapid modeling capability. • Without requiring programming. • Allows testing virtually. • Digital Twin to debug. • By the laws of physics.	(Dehghanimohammadabadi et al. 2015; Rodič 2017a)
FlexSim	Discrete Event Simulation	• Object-oriented software environment. • Works with dynamic-flow process systems. • 2–4 times faster than regular software. • Customized features and dynamic options.	(Gebus et al. 2004; Mourtzis et al. 2014a)

(*continued*)

Table 2. (*continued*)

Simulation Software	Modeling approach	Key features	References to software platforms
CONSENSUS	Discrete Event Simulation	• Low data requirements. • System optimization.	(Radziwon et al. 2014)
Witness	Discrete Event Simulation	• Great breadth and depth, direct links and wizards for links to Excel.	(Kousi et al. 2018)
AnyLogic	Discrete Event Simulation	• Combine simulation approaches. • Graphical objects enable quick learning. • Easy to use.	(Dunke and Nickel 2015; Nagadi et al. 2018)
REALIST	Petri Nets	• Modeling the self-organization. • Easy to use.	(Long et al. 2016)
Simulation software	Modeling approach	Key features	References
MIDAS	Discrete Event Simulation	• High-end analyses with unprecedented levels • Easy to use.	(Singh 2016)
Factory 4.0 Maillefer	Discrete Event Systems	• Simulation of raw material flows, cable constructions, production processes. • Architectural design and building tasks are specified. • Expected performance and productivity in the predefined time. • Self-optimizing processes.	–
SIEMENS	Discrete Event Systems	• Plant Simulation and optimization. • The CornerStone of Factory 4.0. • Communication visibility. • Run and the stored data to be synchronized. • Material flow, resource utilization • Work directly with native CAD files.	–
Virtual Factory – ELISA	Discrete Event Systems	• Real-time view of your whole production • Predict anomalies on different levels • Optimize processes • Simulate changes to the processes. • Machine learning capabilities.	–

(*continued*)

Table 2. (*continued*)

Simulation software	Modeling approach	Key features	References
Factory 4.0 Lab	Discrete Event Systems	• Manufacturing development, optimization. • Analyze manufacturing systems. • Specific processes and strategies.	–
Witness	Discrete Event Systems	• Predictive Manufacturing Simulation. • Production, throughput, and risk business change associated with digitalization. • Smart manufacturing can be simulated.	–
Smart Plants	Discrete Event Systems	• Maintain and evolve a one-stop shop. • Extracting, analyzing the existing system. • Optimizing value chain.	–

5 Discussion and Conclusion

This paper reviews the modeling and simulation methods and their corresponding applications in the simulation of smart manufacturing systems. This research resulted that although there are several commercial simulation platforms available for modeling and simulation of smart manufacturing systems, the researchers in academia mostly rely on MATLAB and Simulink for their studies. Most researchers rely on Discrete Event Simulation Modelling; however, recently, some researchers have applied Petri Nets to model a smart manufacturing process.

Most of the papers focused on discrete event simulations for factory 4.0. Creighton and Nahavandi (2003), Dunke and Nickel(2015), Edakara (2013), Gebus et al. (2004), Kousi et al. (2018), Nagadi et al. (2018), Singh (2016), Smith et al. (1994), Yesilyurt and Nasser (2013) performed simulation-based studies by using different simulation platforms such as ARENA, MATLAB, Extendsim8, MIDAS, Anylogic, Witness and SimEvents. However, less considerations given on Petri Nets Simulation models. Cabasino et al. (2011), Choi (1994), Kahloul et al. (2016), Long et al. (2016), Zhang et al. (2016) carried out simulation-based studies including Time Colored Petri Nets, Extended Colored Scholastic Petri Nets and Labeled Petri Nets. Petri Net simulation models mostly simulated on SIMPACK, REALIST, and MATLAB platforms. Simulation-based researches commonly integrated into shop-floor control, assembly production, and flexible manufacturing systems to optimize robustness, efficiency, autonomous failure detection, and production flow control.

Findings from the study show that there is a gap to model all the smart factory constituents like automation, smart sensors, cloud computing, smart supply chain, and unscheduled maintenance. Furthermore, there is a lack of platforms which can model engineering and business functions simultaneously. This is because, there is a strong need for an integrated modeling and simulation platforms which can model all the key components and technologies required for a smart factory, by supporting the design and simulation on virtual manufacturing systems. Manufacturing operations like Additive manufacturing, ERP, MRP, CRP planning and scheduling, Cognitive bots and autonomous robots, Digital twin to digitize an operation; warehouse operations like Augmented reality, and Autonomous robots; Inventory tracking using Sensors; Real-time equipment monitoring and In-line quality testing; augmented reality to assist maintenance personnel; environmental, health, and safety, sensors to geofence hazardous equipment and monitor environmental conditions, to facility layout design and optimization. Encompassing the horizontal and vertical value chain and integrate the engineering and business functions of the factory, modeling the entire product lifecycle on a single platform by integrating the design, process, equipment, workforce, suppliers, product, and customers; thus, enabling the design of efficient factories and leading to the development of novel products for the future.

The scope of the study is not to include all the available articles about the theme, but to analyze a significant sample scope to give understandings about the recent practices on Simulation of Smart Factories, assisting researchers and practitioners with the simulation and optimization of smart factories of the future.

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Operator 4.0 and Cognitive Ergonomics

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Abstract. Industry 4.0 requires a paradigm shift from the traditional manufacturing practices and work environment to a dynamic workplace where humans and machines must work together as a human cyber-physical system for increased productivity and flexibility. It necessitates novel interactions between operators and machines, consequently leading to the transformation of a traditional operator to Operator 4.0 or Smart Operator. Improvement in operators and engineers' cognitive skills is imminent to adapt to Industry 4.0 working environment. Wearable technology, sensors, or virtual reality equipment enhances cognitive capabilities of the Operator 4.0. Thus cognitive skills of the smart operators are required more rather than the physical strength. This paper presents a review of the recent developments in cognitive ergonomics of Smart Operator or Operator 4.0 in the context of Industry 4.0.

Keywords: Industry 4.0 · Operator 4.0 · Cognitive Ergonomics · Human intelligence · Cyber-Physical Systems (CPS) · Human factors · Artificial Intelligence (AI)

1 Introduction

The expression of Industry 4.0 (Fourth Industrial Revolution) is related to the development and improvement of the management of industrial and manufacturing facilities. I4.0 concept was firstly deployed in Germany in 2011, to upgrade German factories for the international industry competition by increasing production amount and efficiency and product quality. According to (Kinzel 2017) a core concept of I4.0 is to integrate various consumers' daily life aspects to the elements of value chain process where this integration leads to one sole system. I4.0 permits new ways of cooperation amongst software systems, machines, and humans and that this phenomenon is called the Industrial Internet of Things, Services and People (IoTSP).

Romero et al. (2017) mentioned improvements such as data analysis, operation optimization, increased productivity and accuracy, and energy conserving that can produce lots of e-services for future factories. They concluded that such improvements could be achieved by the interconnection of things, services, and people with the Internet.

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I4.0 requires the operators to be capable of communicating with machines instead of operating them.

The main elements of industry 4.0 are Artificial Intelligence (AI), Cyber-Physical Systems (CPS), Internet of Things (IoT), Big Data.

Operators and engineers must upgrade their level of cognitive skills to suit the requirements of Industry 4.0 such as being able to deal with and process a considerable amount of information and data to make the right decisions and appropriate actions. This review paper discusses the latest developments in cognitive ergonomics applications in Industry 4.0.

2 Cognitive Ergonomics

Cognitive ergonomics has two concepts merged where cognition is about human brain processes like observing, processing and delivering information. Such processes will require the human ability to preserve, rehearse, remember, and convert information depending on the type of task or job to maintain the work environment (Mehta 2016).

Cognition and Ergonomics together are related to human interactions with machine elements in an industrial unit. Cognitive ergonomics is usually related to the mental processes such as reasoning, perception memory, and response due to the effect of interaction among humans and other components of the system. It is the type of discipline that interacts between human and machines, well-matched with human cognitive capabilities and limitations to ensure proper communication among human needs, works, products, environments, and capabilities (Kim 2016).

Moray et al. (2017) studied the cognitive ergonomics concept that can reduce the worthless mental workload to support operators do their job and duties with better efficiency and fewer faults and misinterpretations only by having a basic awareness of the principles of righteous cognitive design. Also, the author considers that illustrating what kind of human capacities and restrictions of data analysis is considered as a practical aim of this concept in a way such that the work environment and operator's safety and behaviors are developed to make sure that workloads and stress are set aside (Bligård and Osvalder 2014).

3 Human Factors in Industry 4.0

Humans are generally engaged everywhere from designers of systems, workers, operators, and society. In I4.0, the human function is all about mediation to facilitate and support communication needs for everyone involved. Based on the research database, it seems that in I4.0 concept, designers have done a great job on the development of hardware and software technologies. However, according to Bligård and Osvalder (2014), the human role is still not defined clearly in the context of I4.0.

3.1 Operator 4.0

Operator 4.0 must be smart and has the skills to cooperate with robots, and also work aided with machines whenever required, through human cyber-physical systems

(H-CPS), advanced human-machine interaction technologies and adaptive automation. According to Rabelo et al. (2018), the concept of Operator 4.0 has arisen to achieve a balanced interaction between machines and humans.

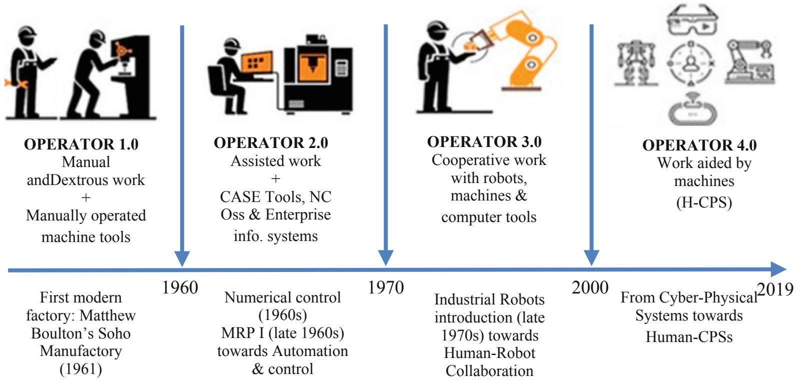

Fig. 1. Evolution of operator tasks and role.

Figure 1 shows the evolution in tasks and role of operators over the last few decades. Table 1 provides the classification of Operator 4.0 (Fig. 2).

Table 1. Classification of Operator 4.0 (Ruppert et al. 2018)

Operator type	Characterization/Duty
Analytical	Examinations and analysis of Big Data information in modern industrial production
Augmented	Augmented reality related improvement of the manufacturing plant condition such as data exchange from the advanced to the physical world
Cooperative	Cooperative automation (CoBots) intended to function in close collaboration with operators to perform routine non-ergonomic jobs
Hygienic	Wearable trackers are intended to measure up performance, pulse and other wellbeing related measurements and different individual information
Intelligent	Intelligent Personal Assistant (IPA) related arrangements which use Artificial Intelligence (AI)
Social	Enterprise Social Networking Services (E-SNS) which centers around the utilization of versatile and social collective strategies to associate intelligent operators in the workplace with keen industrial facility assets
Powerful	Motorized exoskeletons which are wearable, light, and considered as adaptable biomechanical devices
Virtual	Virtual Reality (VR) is a vivid, intelligent computer simulation of reality that can duplicate a digital structure of a layout, assembling or production line and enable the operator test and collaborate the replicated environment

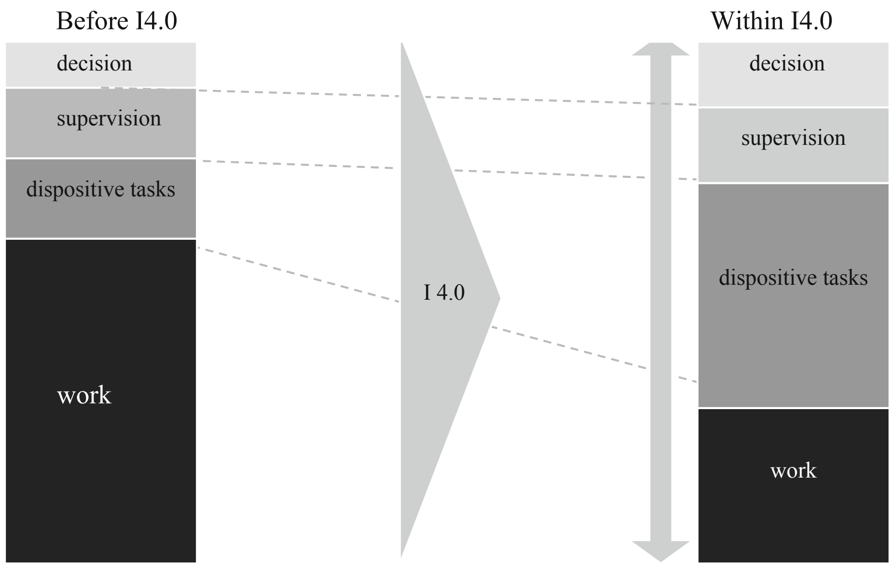

Fig. 2. The change of operator role. Adapted from (Rauch et al. 2019)

3.2 Operator 4.0 and Cognitive Ergonomics

Operator 4.0 must be provided with technologies like smart wearable devices and therefore, facilitate the cooperation with other operators, machines, and software systems (Romero et al. 2017).

Romero et al. (2016) considers various smart wearable devises as part of the Industrial Internet of Things Services and People (IoTSP) model and they are designed for multi-purpose use and can be worn on diverse body parts like head, eyes, wrist, waist, hands, finger and legs which can be embedded in clothes to boost the operator's physical, sensorial and cognitive abilities. Romero et al. (2016) state that powered industrial exoskeletons are a good example of wearable devices, which are lightweight, adaptable, and mobile. A type of biomechanical system is where the human-robotic exoskeleton is powered by a set of motors, aerial, and hydro-mechanical systems operating collaboratively with the operator allowing limb motion with increased strength and endurance. Authors also accept that the concept of wearable devices and exoskeletons existed for decades to empower human operator with more strength and flexibility.

Human-robot collaboration is concerned with the sage movement of the robot due to numerous possible events that can occur in an unstructured environment. Especially, human movements in an unconstructed environment are unpredictable. This is because robot interaction with the human is difficult to represent deterministically (Dröder et al. 2018). The authors also highlighted further developments of human-robot collaboration, such as the use of Artificial Neural Networks (ANN) for industrial robot systems to increase flexibility.

Kim (2016) studied cognitive ergonomic with a major accomplishment to improve security and efficiency within the industry. However, based on their research, ergonomists and security specialists are facing another challenge finding new effective ways for operators having cognitive defects and inabilities like eyesight and hearing defects because like lots of work accidents and injuries are results of human faults due to cognitive failures. It is assured that human faults and errors can have many reasons and causes, and workers' cognitive abilities and limitations have an important role. Kim (2016) agrees that as the rapid development of intelligent sensors is being obtained, the upgrading of operators' workspace is becoming a must. Thereby, making things reasonable and easy to understand plans would fundamentally encourage to reduce errors, boost response times, boost learning and adaptation. Therefore, cognitive ergonomics is a rising section of ergonomics and is related to a deeper level of human role and discipline.

Ruppert et al. (2018) investigated how a new system is being inspired to merge multipurpose and adaptable industrial operations is called Human-Cyber-Physical system or referred to as (H-CPS) where the eventual result of such system is Operator 4.0 model. The model enables the combination of intelligent sensors, manufacturing technologies, and communication methods. Important points are highlighted to conclude on how the shape and design of the new workplace should embrace intelligence. Also, the Internet of Things with it's Indoor Positioning System (IPS) had a critical role in solving the tracking issues of operators with the availability of its equipment to monitor the operator's performance and activities. On the other hand, supporting operators' activities can also be done with IoT systems through visional cooperation systems by giving suitable instructions for different assembly actions. According to authors, this system is only supplying interface of humans with machines for the time being and that the role of IoT makes less costs of both manufacturing and maintenance in a workspace.

Segura et al. (2018) highlighted the importance of centralization and focused on different types of operators to reach industry 4.0 successfully in light of the human factor. However, the implementation of modern tools is a must to empower operators' decision-making procedures. Visual computing systems are great tools and have a big ability to clarify operators' vision at the workspace. Such virtual systems are Virtual reality, Augmented reality and Visual analytics, HMI interfaces, and Media-Social network. It can be easily proven how those technologies enable the enhancement of operator's performances to carry out classic tasks along with new complicated ones. Nonetheless, it is still required to make measurements and tests to have a better understanding of the real effects of these systems on the efficiency and social sides in a manufacturing plant.

Kopka and Żytniewski (2014) studied the concept of cognitive ergonomics that could be used to analyze the effectiveness of software agents in a working place by specifying some measurements to know the amount of support software agents are providing to organizations in general. There has been little research made on this area, and more improvements should be made to upgrade the concept of cognitive ergonomics to upgrade individuals' cognitive capabilities. The writer has also mentioned how agent technologies like anthropomorphic agent system are the key to apply the applications of cognitive ergonomics and that such agents provide fast responses to a huge amount of information available and accomplish the purpose that it was made for. Also, those agents can take independent actions based on the preferences of operators. The essential aspects of ergonomics must be used in the development of software technologies. Measuring the effectiveness, performance, and satisfaction are important to guarantee the effectiveness and efficiency of software agents are also mentioned in their research. The author concluded that not much research had been done in this area, and the vision of ergonomics of those agents is not fully clear yet.

Lödding et al. (2017) presented three Norwegian factories to highlight how digitization has not yet reached to the operator. Their study involved several cases, and some basic subjects were found in them:

The operator's need for production information.

The inadequacy of existing PC frameworks to convey data to operators.

The development of local solutions for getting the required information.

The changes of aspects with Industry 4.0 is presented in Table 2.

Table 2. Change in the working environment with I4.0 concept. Adapted from (Lödding et al. 2017)

Aspect	Present	Future (I4.0)
Operator duty	Operating the machine	Controlling the machine
Task complication	Average	High
Situation Awareness (SA) required level	First level	Second level
Speed	High	Very high
Decision making dependency	Managers	Independent operators and work groups
Operator's job	One machine	Entire manufacturing
Data supply	For managers	Real-time decision assistance to operators

To resolve the problem, it is acknowledged that operators must have access to the information that managers can exclusively see since operators are the future managers of manufacturing companies as managers do not have enough time collect and analyze information. Eventually, with the improvement in the ease of use and dimension reduction of manufacturing processes, the human role will do an undeniably imperative job later on to work, as there are other factors which have significant impacts like age and how its effects on how users manage complicated tasks. I4.0 requirements will pressure the significance of user-friendliness and ergonomics in industrial settings.

Valdeza et al. (2015) discusses different methods to reduce the complexity of multidimensional data through the following:

Reducing measurement: Filtering, factual strategies, collapsing, arrange illustrations, Andrews bends, parallel axes representations.

Pattern recognition: Low pass channel, Entropy discovery.

Interaction strategies: Rotation of information as a third measurement, drill down, suggestion, peruse, instrument tips, gadget turn, diversion-based methodologies

Natural mapping of perception and association strategies.

From the literature, it was found that the methods used to reduce multidimensional data complexity have to match the future worker's field of knowledge and the available data. It is found out that complex mental models have to take shape along with the interaction process, which makes interaction by interrogative methods very useful in shaping an appropriate mental model.

Stadnicka et al. (2019) emphasized innovative techniques like learning by doing, simulation and virtual reality as the path to transfer the sense of smart factory systems as well as to increase the encouragement to make more improvements in the future. Authors compared traditional experiments with the simulation experiments and found that simulations are much economical in cost. Also, simulations made it easier to do wider research since there is an easiness to test different hypothesis. Their study is also included that how learning modes and methods applied depends on what the company/organization has decided to be appropriate for their purpose. Using simulation games for educational purposes is recommended where every simulation game can make a simple study related to the financial side as well as product consumption side. Their study showed how real-time simulations of manufacturing processes and machine configuration must be made with Proper Generalized Decomposition (PGD) based algorithms.

Belkadi et al. (2019) defined a semantic model as a primary enabler for setting the information-based system and found that catching and understanding the situation of the operator at all times is the principal requirement for the improvement of the decision-making assistant system.

Birtel et al. (2018) proposes a concept of condition monitoring for Cyber-Physical manufacturing modules by the use of administration shell approach (AAS). Their study demonstrated how condition monitoring is done using the asset administration shell (AAS) to collect and present the required data. They explained how such a model concentrates on the human role in the production, making it the most important and adaptable element where it is fully connected to manufacturing machines. Authors also suggested that it is possible to add more services, like synchronization, identification, simulation, economical energy consumption, etc. Moreover, edge devices can be integrated with the manufacturing modules to outsource the AAS and accordingly, increase the number of services to it without interfering the manufacturing processes.

Jakobs et al. (2017) explored ergonomic issues of Computer Aided Software Engineering (CASE) frameworks and variables affecting this system as well as Graphic User Interface (GUI). Well-understood from the literature that according to professional workshops working with manufacturing partners like software providers and industrial companies, after the analysis and identification of production planning procedures were made, CASE systems need a big upgrade to as they are not yet ready to adjust to the new manufacturing systems.

A study conducted by Nelles et al. (2016) involved the idea of the use of a tablet computer equipped with an Industry 4.0 suitable app in a manufacturing place. This human-based layout approach supports the operator by providing a suitable quantity of knowledge in a very clear means. Aspects like identification of user situation, the specification of user needs, the innovation of design-based solutions, and the analysis of design-based solutions are all provided by the assistance system of the human-based layout.

Benešová and Tupa (2017) point out that the section of Human Resources in an industrial plant is not just centered around selecting operators, hiring, and expelling them. Moreover, it is also responsible for human asset improvement, like instruction, learning, and preparing workers. They concluded as; it was proved that this outcome in the formation of the modern educational module and improving the current high education module.

Kaasinen et al. (2018) propose a design with an evaluation system for the design, assessment, and effect evaluation exercises for Operator 4.0 solutions along with a positive effect on work environment safety. It is found out to be better to include various points of views in the evaluation procedures as the theoretical part. However, they stated that with practical experiments some difficulties were notable since assessment exercises were extraordinary, complex and a wide variety of tools were needed for the practice which resulted with an inability to involve every point of view. It is still cannot be assured whether the effects of workers' safety can be tested with the current solutions of Operator 4.0.

Badri et al. (2018) determines that if the development of technologies leading to Industry 4.0 continues without considering operators' role then, the risk will multiply, and it will negatively affect the Occupational Health and Safety (OHS) principles, and this is all due to the big modifications and changes that are implemented, which puts all former improvements in precautionary management for the workplace safety and health at risk. Their paper concluded that researchers must work on a smooth movement to I4.0 concept, which means that they should improve OHS course just like how technological progression is going.

Malik and Bilberg (2018) defined a Digital Twin (DT) framework to empower the design and control the human-machine interaction where DT framework is consist of two interdependent environments such as physical environment and the virtual environment

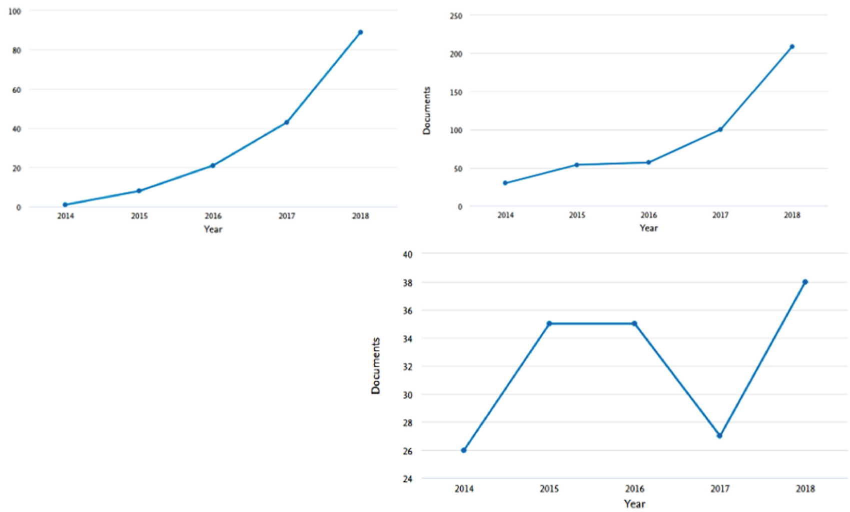

Fig. 3. Statistics from Scopus database (Date: 25.04.2019), **(a)** Documents published about HF in I4.0, **(b)** Documents published about O4.0, **(c)** Documents published about Cognitive Ergonomics.

Table 3. A summary of research on Operator 4.0

Reference	Keyword/s	Method/s applied	Contribution
(Romero et al. 2016)	• Industry 4.0 • Operator 4.0 • Human CPS • Advanced human-machine interaction technologies • Adaptive automation • Human-automation	• Various smart wearable devises for the head, eyes, wrist, waist, hands, fingers, and legs • Powered industrial exoskeletons	• Boosting the operator's physical, sensorial and cognitive abilities
(Kim 2016)	• Operator 4.0 • Industry 4.0	• Upgrading operators' workspace • Making it easy to understand plans	• Reduce errors, boost response times, boost learning and adaptation
(Ruppert et al. 2018)	• Operator 4.0 • Industry 4.0 • Internet of Things (IoT) • Human-Cyber-Physical Systems (H-CPS) • Intelligent workspace	• Combination of intelligent sensors, manufacturing technologies, and communication methods • Indoor positioning system • Visional cooperation systems	• Less costs of both manufacturing and maintenance in a workspace
(Segura et al. 2018)	• Industry 4.0 • Augmented Operator • Visual computing • Digital twin • Operator 4.0	• Visual computing systems • Virtual reality • Augmented reality • Visual analytics	• Clarify operators' vision at the workspace. • Enhancing operator's performances to carry out classic tasks
(Kopka and Żytniewski 2014)	• Ergonomics • Cognitive ergonomics • Software agent • Human-computer interaction	• Visual computing systems • Agent technologies like anthropomorphic agent system	• Facilitating the applications of cognitive ergonomics • Measuring the effectiveness, performance of the software agents
(Lödding et al. 2017)	• Industry 4.0 • Situation awareness • Human-centered manufacturing	• Real-life comparison of present and future (I4.0) operators roles	• Reduction of multidimensional data complexity
(Stadnicka et al. 2019)	• Intelligent manufacturing system • Human factor • Virtual reality • Simulations • Learning by doing	• Learning by doing • Simulation • Virtual reality • Generalized Decomposition	• Methods made testing the manufacturing system much more economical in cost and easier to do wider research
(Belkadi et al. 2019)	• Context-awareness • Decision-aid system • Factory of the future knowledge management	• A semantic model for setting the information-based system	• Understanding the situation of the operator at all times is the main requirement for the improvement of the decision-making assistant system
(Birtel et al. 2018)	• Asset administration shell • RAMI 4.0 • Condition monitoring • CPPM • Modular production	• Condition monitoring for Cyber-Physical manufacturing modules • Administration shell approach (AAS)	• Making the human role in the production the most important and adaptable element
(Jakobs et al. 2017)	• CAx systems • Manufacturing planning systems • GUI design • Industry 4.0 • Human-centered engineering	• Computer Aided Software Engineering (CASE) • Graphics User Interface (GUI)	• CASE and GUI systems need a big upgrade as they are not yet ready to adjust to the new manufacturing systems

(*continued*)

Table 3. (*continued*)

Reference	Keyword/s	Method/s applied	Contribution
(Nelles et al. 2016)	• Human-machine interfaces • Industry 4.0 • Human-centered design • Assistance system • Production planning	• Human-based layout • Tablet computer equipped with an Industry 4.0 suitable app	• Supports the operator by providing a suitable quantity of knowledge in a very clear means
(Benešová and Tupa, 2017)	• Education 4.0 • Industry 4.0 • Human resources management • Smart factory	• Modern educational module for human resources section in a factory	• Human asset improvement like instruction, learning and preparing workers
(Kaasinen et al. 2018)	• Adaptation • Empowerment • Engagement • Factory automation • Training	• An evaluation system for the design, assessment and effect evaluation exercises for Operator 4.0 solutions	• It is still cannot be assured whether the effects of workers' safety can be tested with the current solutions of Operator 4.0
(Badri et al. 2018)	• Industry 4.0 • Occupational health and safety (OHS)	• Considering Human role in Occupational Health and Safety (OHS)	• Must improve OHS principles to reach to I4.0 smoothly
(Malik and Bilberg 2018)	• Digital twins • Human-robot team • Cobot • Lean automation • Simulations • Assembly system	• Digital Twin framework to support the design, build and control of human-machine cooperation • Human-robot collaborative • Ergonomic and biomechanical load analysis	• Less costs and less human-operator injuries for visual production system than real-life production tests

to create DT of human-robot collaborative (HRC) system. In their proposed model, one of the important issues is to update the framework with the changes and modifications made in the physical system.

Commonly manual work is connected to numerous labor performance anxieties. To prevent these anxieties, Microsoft Kinect is used to capture the motion and provide accurate and realistic human motion. One of the advantages of using this device is to be real-time connected to the virtual environment. Therefore, it gives the flexibility to monitor assigned operator tasks by the 3D camera. Additionally, economic and biomechanical load analysis can be performed virtually with the change in production parameters to do not take the risk of any financial loss or human injury in real production. DT technology, such as real-time communication between environments, can increase the usefulness of the system in production (Malik and Bilberg 2018).

The published documents related to HF in I4.0, published documents about O4.0, and published documents about Cognitive Ergonomics are presented in Fig. 3a, b, c, respectively. Based on the data, the significant increase observed, especially in the years 2017 and 2018 (Table 3).

4 Discussion and Conclusion

The increased attention observed by the new industrial paradigm named I4.0 has raised many questions about its concept, developments, and effects to operators. This paper's scope is not to include all the available articles about the theme, but to analyze a substantial sample scope to provide understanding about the recent practices on operator 4.0, assisting researchers and practitioners with the operator 4.0 and cognitive ergonomics of the future. This paper concluded that there are current studies mostly focusing on manufacturing enterprises that are working on improvements to reach I4.0 level considering a different type of operators and their tasks. This concept has several technological and human aspects of developing. Therefore, the paper highlighted the human role in I4.0 to recognize human capacities and restrictions as a practical aim of cognitive ergonomics while considering the working environment, safety, operator behaviors are developed to make sure that all stresses and working loads. However, fewer studies are found in the literature to understand Industry 4.0 standards in the light of operators. Therefore, I4.0 standards considering cognitive ergonomics and operator capabilities & restrictions can be considered as future work.

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A Study on the Adoption of Smart Home Devices: PLS Structural Equation Modeling

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Abstract. In this study, the adoption of smart home devices that offer comfort, security, and energy-saving to users has been examined. The technology acceptance model (TAM) is extended by integrating Domain Specific Innovativeness, Perceived Compatibility, Perceived Data Reliability, Perceived System Reliability, Variety Seeking and Laziness into the model. Different from the existing studies in the literature, the present study introduces the constructs Variety Seeking and Laziness the first time. In addition, Personal Innovativeness is replaced by the construct Domain Specific Innovativeness. Partial least squares structural equation modeling (PLS-SEM) is used to test the proposed model. This statistical technique does not require the data to be normally distributed and is well suited for testing large and complex models including moderating effects. According to the results, the relationship between Domain Specific Innovativeness and Perceived Usefulness is not supported. On the other hand, a positive weak relation is found between Domain Specific Innovativeness and Perceived Ease of Use. Although the analysis also reveals a weak positive relationship between Laziness and Attitude, the moderating effect of Laziness on the relationship between Attitude and Perceived Usefulness as well as Attitude and Perceived Ease of Use is not supported. Finally, a weak positive relationship between Variety Seeking and Attitude is found.

Keywords: Smart home devices · Technology Acceptance Model · PLS structural equation modeling · Moderator analysis

1 Introduction

With the digitalization trend in the world, the importance of smart products is increasing. Companies are creating new business models for the internet of things (IoT) and smart products. Technological developments in this field have begun to change consumer expectations. Consumers are expecting more functional features than ever. Therefore, to survive in this emerging market, companies need to analyze consumer expectations correctly and design products/services accordingly. A business model should consider the substantial factors affecting the acceptance of smart products.

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Smart home devices that can connect to the internet and communicate with each other have recently begun to take place in the houses. However, it has not yet reached widespread use. Research on the adoption of products containing information and communication technologies (ICT) has commonly relied on the technology acceptance model (TAM).

This study aims to model the adoption of smart home devices, and for this purpose, the technology acceptance model (TAM) is extended by integrating Domain Specific Innovativeness, Perceived Compatibility, Perceived Data Reliability, Perceived System Reliability, Variety Seeking and Laziness into the model. Different from the existing studies in the literature, the constructs Variety Seeking and Laziness are introduced the first time. In addition, Personal Innovativeness is replaced by the construct Domain Specific Innovativeness. Partial least squares structural equation modeling (PLS-SEM) is used to test the proposed model.

2 Literature Review

2.1 Smart Home

Smart Home is a house that includes a high technology network with devices that can remotely be monitored, accessed and controlled (Balta-Ozkan et al. 2013). The smart home has hardware and software that can detect and control consumer habits and requirements. For instance, the refrigerator can monitor food consumption, detect expiry or spoiled products, and alert the user. While the house owner is reading at home, room lights can be adjusted appropriately, or his/her favorite music can start playing according to his/her habits. Home temperature can be fixed to the desired degree. The house resident can learn from his television that his dish is cooked.

The main feature of smart technology is to obtain information from the environment and respond to it (Chan et al. 2008). Smart home technology, also called home automation, allows house residents to control their smart devices (television, combi, refrigerator, washing machine, dryer, personal assistant, etc.) from smart home applications on their smartphones or tablets, allowing them to control security, comfort, convenience, and provides energy efficiency.

Revenue in the Smart Home (Home Entertainment, Smart Appliances, Energy Management, Control and Connectivity, Comfort and Lighting, Security) market is expected to be $71,629 million in 2019. The prevalence of smart home in home users is expected to reach 7.7% in 2019 and 18.1% in 2023. The average income per Smart Home is currently $124.63 (Statista 2019).

Smart devices have three basic components. These are, namely; smart, physical, and connectivity components. Physical components include mechanical and electrical components of the product. Microprocessors, sensors, data warehouses, embedded software are smart components of smart home devices. Connection components include ports, antennas, and protocols (Porter and Heppelmann 2015).

2.2 Technology Acceptance Model

Acceptance is a positive decision to use innovation as opposed to the term of rejection (Simon 2001). Technology Acceptance Model (TAM) was formed 20 years ago to modeling consumer acceptance of computers (Davis 1989). TAM can evaluate the intention and acceptance of ICT by consumers.

TAM evolved from the socio-psychological theories Theory of Reasoned Action (TRA) and Theory of Planned Behavior (TPB), which predict human behavior. TRA model was originally developed for sociological and psychological researches (Fishbein and Ajzen 1975). According to the model, human behavior is explained by three main cognitive factors. Namely, attitude (positivity or negativity in a person's feeling of behavior), social norms (social impact), and behavioral intent (decision to make or not to behave). TRA describes the behaviors of the users within their will. Ajzen has developed the Theory of Planned Behavior by expanding Theory of Reasoned Action model. In cases where behaviors are not under the full will and control of individuals, TRA is insufficient (Chang 1998). Consequently, Azjen composed TPB by appending Behavioral Control to the previous model (Ajzen 1991). In both TRA and TPB models, intention affects behavior of the consumer. TPB model can use for actions where the individual has no under volitional control. In TAM, effect of four variables on system use was measured. Latent variables in the TAM are perceived ease of use, perceived usefulness, attitude towards use and behavioral intention. Perceived usefulness is the perception that a consumer using a device would improve his/her efficiency. Perceived Ease of Use is consumer's perception of how minimum effort will make to use a home device. In TAM, attitude determines the consumer's intention to use (Davis et al. 1989).

Smart home devices can connect to the Internet, communicate between them. Recently, devices began to take place in homes. The product is not yet widespread in Turkey. They are classified as high-tech products. The technology acceptance model will be an important tool for understanding the adoption of the product as it is not yet widespread.

2.3 Domain-Specific Innovativeness

Innovation is a very important capability for a firm's success to be sustainable (Pauwels et al. 2004). Despite continuity in R&D and marketing activities, most products or processes do not succeed (Srinivasan et al. 2009). Personal Innovativeness is important for users to adopt the technology. (Yi et al. 2006). When we look at the types of innovativeness: Firm innovativeness is the skill of a firm to quickly design and market novel products. (Hurley and Hult 1998) Product innovativeness is that the product is first and new in market. (Daneels and Kleinsmith 2001) Consumer innovativeness is propensity to purchase more often novel products than another consumer. (Midgley and Dowling 1978).

Innovativeness is divided into three grades (Midgley and Dowling 1978). These are, respectively; innate innovativeness, domain-specific innovativeness, and innovation as actualized behavior. When the articles in the literature are examined, innate innovativeness levels mostly examined, followed by domain-specific innovativeness (Bartels and Reinders 2011).

Innate Innovativeness is the innate propensity to acquiring new information or experimentation (Hirschman 1980). According to research (Bartels and Reinders 2011) innate innovativeness and new product adoption have positive relationships in some researches. Also, the relationship between them can not be proven in some researches. In addition, innate innovation has no significant impact on the number of products purchased.

Domain-specific innovativeness is the propensity of a consumer to obtain/seek information and adoption of new products for specific products of an area of interest (Goldsmith and Hofacker 1991; Roehrich 2004). According to the research (Bartels and Reinders 2011) domain-specific innovativeness is linked to the new product adoption. Unlike innate innovativeness, domain-specific innovativeness has positive and statistically considerable relationship with product adoption behavior. There is a positive relationship between domain-specific innovativeness and intention to use (Agarwal and Karahanna 2000).

The concept of innovative behavior (innovation as actualized behavior) defines the adoption of a person's capability to use a novel product before than other consumers (Midgley and Dowling 1978).

Since the purchasing decision is affected by the factors between the situational and the interpersonal, innovation as actualized behavior is very weak in the explanation of the innovative purchasing behavior in the future (Goldsmith and Hofacker 1991). Innate innovativeness has the highest grade of abstraction among personal innovativeness grades. Structures at high abstraction degree often fail to explain certain behaviors (Hoffmann and Soyez 2010). To understand purchasing behavior, innovativeness must be evaluated within a specific area of interest (Gatignon and Robertson 1985). Smart home devices; Thanks to the technologies it has, it is in a certain product category by differentiating from existing home devices. For the specific features and the reasons mentioned above, this article will be examined innovativeness as domain-specific innovativeness.

2.4 Variety Seeking

Variety seeking is a desire to utilize a product that is different from the product currently used by the consumer or to use another service or product because it was not satisfied before (Hou et al. 2011). Variety seeking is a tendency to discover other products/services instead of using a specific service/product (Chou et al. 2016; Bansal et al. 2005). Variety seeking is a chase of the choice of diversified products or services (Kahn 1995).

Smart home appliances have been sold in the market recently. The diffusiveness rate is not yet high in the market. In most households, there are only a few smart home devices, while in most homes there are no smart home devices. Consumers who are interested in discovering new products will want to try these smart home devices that they didn't have before.

2.5 Perceived Compatibility

One of the five main characteristics of innovation diffusion theory is compatibility. Five characteristics are respectively; relative advantage, compatibility, triability, observability, complexity. A unique innovation is compatible when current and traditional values are consistent with needs (Rogers 2010). Tornatzky and Klein (1982) divide compatibility into two: These are the normative or cognitive compatibility and practical or operational compatibility of people about innovation. Considering the compatibility for smart home devices; preferred home style, existing home routines, previous products, and personal values are important. Perceived compatibility is very important for users' perspectives on systems (Islam 2016).

2.6 Perceived Data Security

Perceived data security is the perspective of the level of protection against possible dangers when using smart home devices (Cheng et al. 2006).

As the world enters the digitalization process, data are collected and processed continuously. In this digitalization process, it is a great threat that the data of residents in the house gets into the hands of undesirable people. When the smart home devices are considered, all the data that the user makes in the house, which is the most special area of the user, is collected and converted into benefits. Users can expect their personal preferences and other information about their private life to be protected.

2.7 Perceived System Reliability

The perceived system reliability is related to how smart home appliances provide reliable services for users (Park et al. 2018). According to another definition; System reliability is the possibility of the system to achieve its goals at certain conditions and times (Saha et al. 2001). Reliable operation of the system is very important for the correct functioning of the process and personal safety. To smart home appliances to perform both their functions and provide personalized service, the system must be able to recognize the person correctly, analyze the person correctly and fulfill its function accordingly. For instance, a home security system that works with voice commands; the owner of the house should not get any problems while entering the house, and the system should not allow foreigners to enter the house.

2.8 User's Laziness

The Lazy User Behavior is that a user chooses the device to meet his needs with minimal effort (Collan 2007). Smart home devices enable users to do their current housework with less effort. Spending less effort into doing housework is important for the user. Smart home devices can offer users both physical energy savings and time savings thanks to their features.

ICT device users receive their decision to continue using technology compared to their initial expectations and experiences (Bhattacherjee 2001). Users' adoption of lazy use is important for the achievement of devices that use information and communication technology (Tsao 2018).

3 Proposed Model and Hypotheses

To model the adoption of smart home devices, first one-to-one interviews were conducted with 37 people. In these interviews, the smart house concept was first explained, and then respondents were asked: "Will you invest smart home devices to your home, why?" The answers were noted in detail. Responses that affect their decisions were summarized as keywords (see Table 1).

Table 1. One-to-one interview results

Responses	Frequency
Facilitating life	11
Time-saving	9
Materiality (Cost)	7
Data security	4
Personal security	3
Laziness	3
Variety Seeking	3
Personalization	2
Control request	2
Health	1
Social status	1

After this survey, a literature review was performed, and 29 articles were reviewed about the subject. Studies based on TAM and containing the constructs listed above were taken into consideration. The relationships between constructs considered in these articles were carefully examined. Figure 1 shows both the hypotheses and the number of hypotheses supported in these 29 articles.

In some of the examined articles, it was seen that some constructs were directly connected to intention. Attitude has not been considered in these articles. However, these constructs should be related to attitude according to the Theory of Reasoned Action. Following the field research and literature review, the proposed model on the adoption of smart home devices is demonstrated in Fig. 2.

(Recommended Hypothesis / Accepted Hypothesis)	*Domain-Specific Innovativeness*	*Variety Seeking*	*Compatibility*	*Data Security*	*System Reliability*	*Usefulness*	*Easy of Use*	*Laziness*	*Attitude*	*Intention to Use*
Domain-Specific Innovativeness		0/0	0/0	0/0	0/0	3/1	3/3	0/0	0/0	4/3
Variety Seeking	0/0		0/0	0/0	0/0	0/0	0/0	0/0	0/0	2/1
Compatibility	0/0	0/0		0/0	0/0	8/7	7/7	0/0	1/1	3/3
Data Security	0/0	0/0	0/0		0/0	8/5	5/3	0/0	4/3	5/4
System Reliability	0/0	0/0	0/0	0/0		3/3	0/0	0/0	1/0	3/2
Usefulness	0/0	0/0	0/0	0/0	0/0		1/1	0/0	8/8	16/13
Easy of Use	0/0	0/0	0/0	0/0	0/0	14/12		0/0	8/7	12/7
Laziness	0/0	0/0	0/0	0/0	0/0	0/0	0/0		0/0	0/0
Attitude	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0		7/7
Intention to Use	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	

Fig. 1. Hypotheses supported in the literature

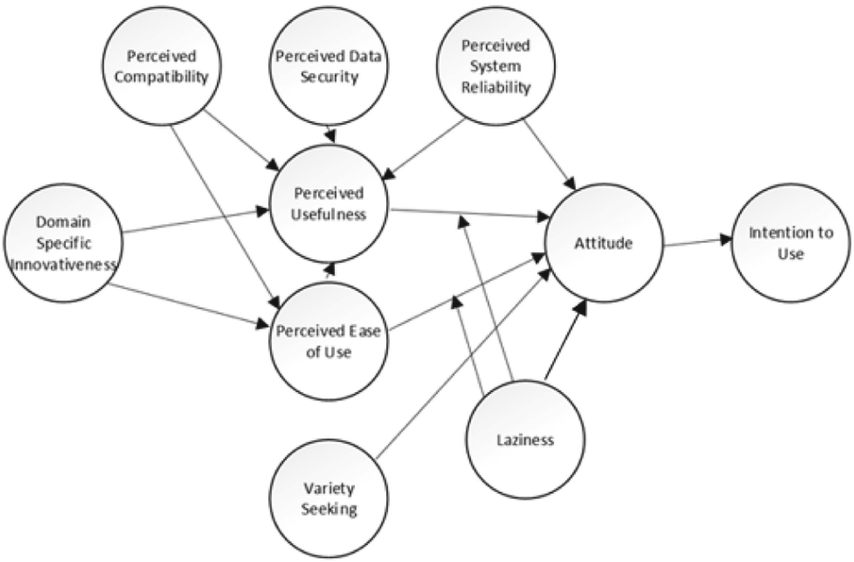

Fig. 2. Proposed model

4 Methodology

Within the scope of this study, a questionnaire consisting of 43 questions was designed. For the measurement of the constructs, common scales developed in the literature were adapted (Jeong et al. 2017; Steenkamp and Baumgartner 1992; Park et al. 2017, 2018; Karahanna et al. 2006; Featherman and Pavlou 2003; Yang et al. 2017; Hubert et al.

2018; Venkatesh et al. 2012; Bhattacherjee 2000; Baudier et al. 2018; Venkatesh and Davis 2000). The suggested questionnaire was prepared with a 5-point Likert Scale. Two hundred seventy-two people participated in the survey. Table 2 shows the demographic characteristics of respondents.

Table 2. Demographic characteristics of respondents

		Sample size (n)	Ratio (%)
Gender	Male	148	54%
	Female	124	46%
Education level	Ph.D.	15	6%
	Master Degree	71	26%
	Bachelor Degree	144	53%
	Associate Degree	15	6%
	High School	27	10%
Age	18–24	64	24%
	25–29	96	35%
	30–34	27	10%
	35–39	29	11%
	40–44	17	6%
	45–49	15	6%
	50+	24	9%

5 Results

Structural Equation Modeling (SEM) was used to test the hypotheses and determine the factors that affect the adoption of smart home devices. In particular, PLS-SEM was preferred since it is less stringent when working with small sample sizes and nonnormal data, which was the case in our study. A total of 276 usable responses were received and analyzed with SmartPLS 3.2.8.

To examine the statistical significance, bootstrapping was performed. The t, p, and f^2 values are shown in Table 3. The t value must be 1.96 or higher to indicate a significant effect at 95% confidence level (Wong 2013). The effect size (f^2) gives us information about the impact of an exogenous latent variable on an endogenous latent variable. In other words, values of 0.02, 0.15, and 0.35 represent small, medium, and large effects, respectively (Hair et al. 2014). The results of the tests of hypothesis are shown in Table 3.

Table 3. Results of hypotheses tests

Hypothesis	t	p	f^2	Decision	Impact
Attitude positively affects Intention to use	13.156	0,000	0.715	**Supported**	High
Domain-Specific Innovativeness positively affects Perc. Ease of Use	3.081	0.002	0.035	**Supported**	Small
Domain Specific Innovativeness positively affects Perceived Usefulness	0.293	0.770	0.000	Not supported	None
Laziness moderates the relationship btw Perc. Ease of Use and Attitude	0.582	0.561	0.003	Not supported	Low
Laziness moderates the relationship btw Perc. Usefulness and Attitude	0.861	0.390	0.007	Not supported	Low
Laziness positively affects Attitude	3.329	0.001	0.075	**Supported**	Low
Perceived Ease of Use positively affects Attitude	5.116	0,000	0.094	**Supported**	Low
Perceived Ease of Use positively affects Perceived Usefulness	4.735	0,000	0.208	**Supported**	Medium
Perceived Usefulness positively affects Attitude	6.298	0,000	0.207	**Supported**	Medium
Perceived Usefulness positively affects Intention to use	4.154	0,000	0.090	**Supported**	Low
Perceived Compatibility positively affects Perceived Ease of Use	6.273	0,000	0.151	**Supported**	Medium
Perceived Compatibility positively affects Perceived Usefulness	3.844	0,000	0.094	**Supported**	Low
Perceived Data Security positively affects Perceived Usefulness	0.239	0.811	0.000	Not supported	None
Perceived System Reliability positively affects Attitude	4.537	0,000	0.093	**Supported**	Low
Perceived System Reliability positively affects Perceived Usefulness	4.109	0,000	0.073	**Supported**	Low
Variety Seeking positively affects Attitude	2.028	0.044	0.014	**Supported**	Low

Convergent Validity and Average Variance Extracted (AVE) values of all factors were examined for reliability and validity. As an example, Factor loadings, Convergent Validity, and AVE values of the latent variable "Variety Seeking" are given in Table 4. Due to space limitations, the details of other constructs are not given here.

Two indicators of the latent variable, "Laziness" (T1 and T4) were excluded from the original model since their factor loadings were less than 0.4. The Composite Reliability (CR) and AVE values of the latent variables are shown in Table 5.

Table 4. Factor loadings, convergent validity and AVE values of Variety Seeking

Latent variable	Indicators	Factor loadings	Convergent validity	AVE
Variety Seeking	DI1	0.869	0.931	0.731
	DI2	0.915		
	DI3	0.910		
	DI4	0.842		
	DI5	0.727		

Table 5. Latent variables and their CR and AVE values

	CR	AVE
Attitude	0.944	0.809
DSI	0.867	0.621
Intention to use	0.952	0.832
Laziness - PEOU to ATT (Moderator1)	1.000	1.000
Laziness - PEU to ATT (Moderator2)	1.000	1.000
Laziness	0.817	0.694
PEOU	0.906	0.709
PEU	0.962	0.834
Per. Compatibility	0.683	0.535
Per. Data Security	0.901	0.697
Per. System Reliability	0.832	0.555
Variety Seeking	0.931	0.731

Each diagonal value in the Fornell and Larcker matrix shown in Table 6 is the square root of the corresponding latent variable's AVE (Hair et al. 2014). The nondiagonal values denote the correlations between the latent variables. Since the square root of the AVE values exceeds the correlations, the discriminant validity of the measurement model is ensured (Wong 2013).

The final path diagram, where two indicators of the latent variable "Laziness" is removed, is given in Fig. 3.

The determination coefficients (i.e., R^2) of the endogenous latent constructs Attitude, Intention to Use, Perceived Ease of Use, and Perceived Usefulness are given in Table 7. The coefficient of determination reflects the level of explained variance of an endogenous latent variable. All R^2 values, except the value of Perceived Ease of Use (0.308) that can be considered as weak, seem to be adequate.

Table 6. Discriminant validity

	Attitude	DSI	IU	Mod1	Mod2	Laziness	PEOU	PEU	C	DS	SR	VR
Attitude	0.9											
DSI	0.513	0.788										
Intention to Use (IU)	0.863	0.605	0.912									
Moderator 1	−0.095	−0.127	−0.129	1								
Moderator 2	−0.198	−0.132	−0.215	0.668	1							
Laziness	0.617	0.327	0.588	0.039	−0.005	0.833						
PEOU	0.691	0.451	0.626	−0.242	−0.078	0.527	0.842					
PEU	0.794	0.451	0.773	−0.075	−0.276	0.559	0.633	0.913				
P. Compatibility (C)	0.622	0.618	0.617	−0.056	−0.18	0.451	0.533	0.592	0.731			
P. Data Security (DS)	0.31	0.102	0.295	0.1	−0.006	0.133	0.128	0.227	0.108	0.835		
P. System Reliability (SR)	0.546	0.352	0.541	−0.009	−0.069	0.285	0.379	0.509	0.379	0.55	0.745	
Variety Seeking (VS)	0.431	0.462	0.396	−0.253	−0.236	0.351	0.434	0.387	0.499	0.01	0.149	0.855

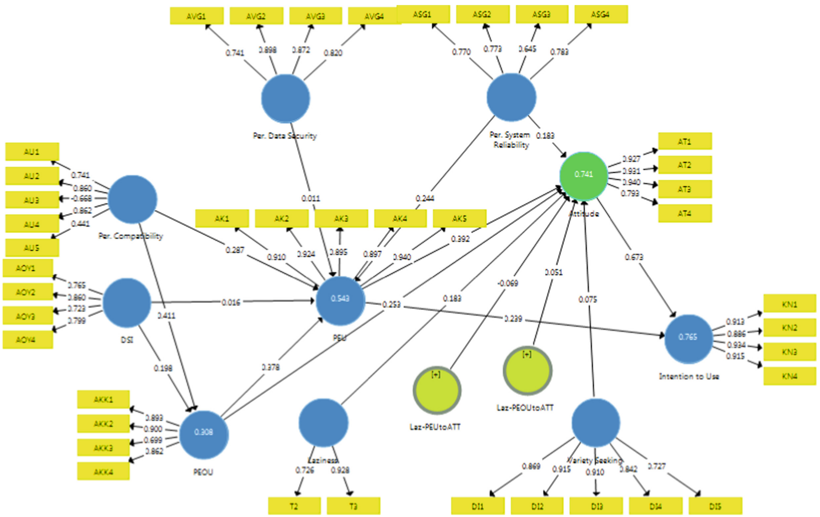

Fig. 3. Final model

Table 7. R^2 values

	R^2	R^2 adjusted
Attitude	0.741	0.734
Intention to use	0.765	0.763
PEOU	0.308	0.303
PEU	0.543	0.535

6 Discussion and Conclusion

This paper intends to analyze the factors influencing the adoption of smart home devices. For this purpose, a model was constructed based on both literature research and field research. Two indicators that failed to pass indicator reliability tests were excluded from the model. According to the final analysis the relationship between to Perceived Data Security and Perceived Usefulness is not supported. Also, the relationship between Domain Specific Innovativeness and Perceived Usefulness is not supported. On the other hand, a positive weak relation between Domain Specific Innovativeness and Perceived Ease of Use is observed. While there is a weak positive relationship between Laziness and Attitude, Laziness does not have a moderating effect on the relationship between Perceived Usefulness and Attitude as well as between Perceived Ease of Use and Attitude. Also, a weak positive relationship between Variety Seeking and Attitude is found. Finally, consistent with the literature, the relations between the constructs of the original technology acceptance model are found significant and positive. For further research, a more comprehensive measurement model for the latent construct Laziness can be developed.

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Segmentation of Social Media Users: A Means-End Chain Approach

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Abstract. The use of social media has risen dramatically over the past few years, and companies are spending more dollars than ever on social media. It has created great opportunities for users in terms of social interaction, knowledge sharing, entertainment, and online shopping. At the same time, social media has generated a new set of capabilities for marketers to collect data, test propositions, understand consumer reactions and communicate more effectively. Therefore, a better understanding of the profiles and preferences of social media users becomes inevitable for developing effective marketing strategies. This requires a detailed analysis of meaningful differences among segments. Only a few studies have attempted to differentiate among users employing either a customer-based or product-based approach. To address this issue, this study applies the means-end approach along with the laddering technique and cluster analysis for data collection and analysis. The proposed approach can provide a deeper understanding of user perceptions and preferences. The constructed model presents the connections between preferred attributes of social media platforms, the benefits obtained from these attributes and the personal values satisfied by those benefits. The study identified four distinct groups that vary according to their motivations for using social media platforms.

Keywords: Social media · Segmentation · Means-end chains · Laddering · Cluster analysis

1 Introduction

According to the research on the usage habits of digital channels published by "We are social" in January 2018, internet users in Turkey spend an average of 7 h per day online, of which 2 h and 48 min on social media platforms. Examining the number of users of common social media platforms shows that there are 51 million users on Facebook, 37 million on Instagram, and 8.8 million on Twitter. When the user rates by population size of countries are examined, Turkey is the second country where Instagram is used at most. Every day a new social media platform launches. The advertising investments on social media in Turkey reached TL 205 million in the first half of 2018, while it was TL 161 million in the first half of 2017 according to IAB Turkey (2018).

The increasing importance and higher level of efficiency of social media have begun to change the way companies do marketing. Companies are spending more dollars than

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ever on digital channels to reach the most attractive customers and develop strong relationships at low costs (Kaplan and Haenlein 2010). All these facts point out that social media is not just used for socializing by users. Therefore, a better understanding of the profiles and preferences of users becomes inevitable for developing effective marketing strategies. However, only a few studies in the literature have attempted to differentiate among social media users (Foster et al. 2011; Lennon et al. 2012; Vinerean et al. 2013; Amaro et al. 2016; Tuten and Solomon 2017). These studies consider only customer-specific or product-specific segmentation bases.

In this study, because of its ability to provide a deeper understanding of social media user perceptions and preferences, an approach based on means-end chain theory (Gutman 1982), along with the laddering technique and cluster analysis, is proposed for data collection and analysis. Market segmentation based on the proposed approach has the distinct advantage of linking attributes (A), consequences (C), and values (V) at the segment level and, thereby, combining product-specific (feature-based) and customer-specific (value-based) segmentations. In other words, the proposed approach reveals the reasons behind the preference and use of social media platforms by associating users' perceptions and preferences with the means (attributes) and ends (consequences and values).

2 The Proposed Means-End Chain Approach

Studies have shown that means-end chain theory is very useful in understanding consumers' consumption-relevant cognitive structures (Audenaert and Steenkamp 1997). "Means" describes objects or activities (such as running, reading) that people are engaged in, while "ends" describe values such as happiness, security, and success. Values are strong forces that shape the behavior of individuals in every aspect of their lives (Rokeach 1968; Yankelovich 1981). To put it all in simple terms, a means-end chain is a model that explains how a choice of product or service leads to the desired results – ultimately to personal values (Gutman 1982; Reynolds and Gutman 1988).

In the Means-End Chain Analysis, a technique called laddering is used to reveal the decision-making structure of the interviewee (Myers 1996). This method is a holistic and one-to-one in-depth interviewing technique designed specifically to understand how users/consumers give meanings to product/service characteristics. The technique follows a special interviewing format repeating the typical question "Why is that important to you?" to clarify the relations between Attributes, Consequences, and Values (Reynolds and Gutman 1988; Reynolds and Olson 2001). This kind of questioning during the interview leads the interviewee moving up to higher levels of abstraction until he/she has reached the level of terminal values or cannot provide any reason for his/her response at the preceding level (Audenaert and Steenkamp 1997).

Laddering begins with eliciting meaningful differences between social media platforms by individual participants. Alternative methods such as free sorting, triadic sorting, direct sorting, picking from a list, and preference ranking have been proposed in the literature for this purpose (see Bech-Larsen and Nielsen 1999; Reynolds and Gutman 1988).

Once the interviews are completed, a coding of laddering data follows. To classify the answers as attributes, consequences, or values, and create summary codes for synonyms, content analysis is used. It should be noted that too much loss of meaning can occur if every answer is coded (Reynolds and Gutman 1988).

In the next step, an implication matrix is generated, which shows how many times each element is connected to other elements, both directly and indirectly (Reynolds and Gutman 1988). Based on this matrix, a hierarchical value map (HVM) is drawn to visualize the relationships between all elements. HVM is a graph in a tree structure showing the cause-and-effect connections that users perceive as fundamental between attributes, consequences, and values (Veludo-de-Oliveira et al. 2006).

Finally, to aggregate individual users with similar associations into homogeneous groups (segments), analytic methods can be employed. In this study, one of the most widely used hierarchical clustering methods, Ward's method, is preferred. The Ward's method usually creates compact, even-sized clusters where the variance within the groups is minimized (Eszergár-Kiss and Caesar 2017). In Comparison to other hierarchical clustering methods, Ward's method offers higher accuracy concerning the results (for more details see Hands and Everitt 1987).

Each resulting segment will have its own specific means-end chains, which will point out to specific product/service development opportunities, rich ideas for advertising and positioning (Vriens and Hofstede 2000). Nevertheless, the means-end chains in several segments can also indicate opportunities for developing standardized services in general, with the help of non-segmented mass communication.

3 Application

The purpose of the application is to determine sets of associations (i.e., A $\rightarrow$ C $\rightarrow$ V), which represent combinations of elements that serve as the basis for distinguishing between social media platforms. To collect data, the laddering technique was employed. The target population was defined as social media users aged between 15 and 30 to make the collected data to be comparable. The social media platforms that have been included in the interviews are Facebook, Instagram, Twitter, YouTube, Snapchat, LinkedIn, Swarm, Myspace, Google+, Wordpress, Goodreads, and Ekşi sözlük.

The social media users interviewed were asked to select four social media platforms out of 12, and sort them according to their preference of use. The interviewee is then asked to say why one certain platform is the most preferred one (or second most preferred etc.). An example interview dialogue with an interviewee who ranked the social media platforms like Instagram, Facebook, YouTube, and Snapchat, according to the frequency of usage is given below.

Interviewer: Why do you prefer Instagram more than Facebook?
Interviewee: I can learn new things. Although I do not always get efficient information, there are things that I can learn.
Interviewer: Why is it important for you to learn new things?
Interviewee: I do not want to miss new things.
Interviewer: Why do you feel like you should not miss new things?
Interviewee: Because seeing new things motivates me. For example, when I see a new place, I make a note of this place for my future vacation plans.

Interviewer: Isn't it more fun to discover new places by yourself?
Interviewee: It is very difficult to find a place, do a research about this place, and to make a plan. I am a lazy person. In my opinion, it is easier to learn from others' experiences. For example, if I try to find a cafe or restaurant abroad that is both good and budget-friendly, I may not find any suitable one and waste a lot of time. Therefore, learning from others' experiences is more risk-free.

As can be seen from the conversation given above, the interviewee uses social media platforms not to socialize or to communicate with his/her friends, but instead to make more risk-free and secure plans. Note that there were situations where no response was received during the interview. Some techniques (such as reviving the situation, assuming the absence of the product or situation, negative laddering) were used to enable the flow of the conversation when the interviewee was unable to tell the reason for the next level (for more details the reader should refer to Reynolds and Gutman 1988).

In the interviews, preferences regarding the social media platforms were compared in a pairwise manner, and different chains were revealed. For example, one participant was interviewed about the ranking of Instagram-Facebook, Facebook-YouTube, and YouTube-Snapchat pairs. In this way, means-end chains were created for each participant. In total, 27 social media users were interviewed. Although the sample size seems small, it is considered sufficient for this kind of a qualitative research method, in which statistical viability is not sought (Baker et al. 2004).

The data originating from 27 interviews were reduced and categorized under summary codes that were identified as "attributes," "consequences," or "values." Consequently, 47 summary codes were identified, 11 of which were categorized as attributes, 21 as consequences and 15 as values. Then each participant's interview was revised by using these summary codes, and individual chains were constructed. Following the construction of these individual chains, an implication matrix was created for each participant by allocating the identified 47 summary codes within the columns and rows of this matrix, resulting in a square matrix of size 47×47. Then according to the value chain of each participant, interactions among the identified summary codes were numerically coded on these individual implication matrices, in which direct relations among the codes were shown as 1.0 and indirect relations as 0.1 (see Table 1 for an example matrix). After this coding step, implication matrices created for each participant were pairwise compared to find the total number of cells that are filled by both participants. As a result, similarities of these implication matrices (i.e., similarities between participants) were determined, and a 27×27 similarity matrix was formed. Then, as a preparatory step to cluster analysis, this similarity matrix was transformed into a dissimilarity matrix by dividing the values in each cell of the similarity matrix by the total number of cells in the implication matrix and subtracting the result from 1 (see Table 2). If any two participants have no commonly filled cells in their implication matrices, the relevant cell indicating the dissimilarity between these two participants is calculated as one. Additionally, the values in the diagonal of this dissimilarity matrix are zero, as they indicate the dissimilarity of each participant with himself/herself.

As mentioned above, the dissimilarity matrix obtained was used as an input for the hierarchical cluster analysis, which was used for the segmentation of social media users, aged 15–30, according to their perceptions and preferences that were categorized as

Table 1. An example implication matrix for an interviewee

			ATTRIBUTES											CONSEQUENCES																					VALUES														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
ATTRIBUTES	1	Easy and fluent																																															
	2	High number of content																																															
	3	Extensive content													1.0										0.1									0.1							0.1								
	4	Up-to-date content																																															
	5	Content in field of interest																																															
	6	Objective content																																															
	7	Being aware about what is going on																1.0						0.1					0.1	1.0												0.1		0.1			0.1		
	8	High number of users																																															
	9	Spending time																																															
	10	Reaching people																																															
	11	Being aware of the agenda																																															
CONSEQUENCES	12	Increasing knowledge																																															
	13	Learning things simply																							1.0									0.1							0.1								
	14	Spending time on favorite things																																															
	15	Satisfying curiosity																																															
	16	Following popularity																											1.0													0.1							
	17	Communicating																																															
	18	Strengthening communication																																															
	19	Being motivated																																															
	20	Discovering new things																																															
	21	Being inspired																																															
	22	Self-improvement																																										1.0			0.1		
	23	Seeing others' experiences																																1.0							0.1								
	24	Creating and declaring own ideas																																															
	25	Learning different opinions																																															
	26	Posting/Sharing																																															
	27	Being involved																																								1.0							
	28	Taking others as a reference/Benchmarking																						1.0																				0.1			0.1		
	29	Facilitating daily life																																															
	30	Being successful at work																																															
	31	Earning money																																															
	32	Not taking risk																																							1.0								
VALUES	33	Socializing																																															
	34	Security																																															
	35	Quality of life / Welfare level																																															
	36	Happiness																																															
	37	Originality																																															
	38	Comparing and interpreting own life																																															
	39	Efficiency																																															
	40	Becoming integrated																																															
	41	Popularity																																															
	42	Success																																													1.0		
	43	Accessibility/Visibility																																															
	44	Productivity																																															
	45	Appreciation																																															
	46	Self-satisfaction																																															
	47	Entertainment																																															

Table 2. Dissimilarity matrix

	Interviewee-1	Interviewee-2	Interviewee-3	Interviewee-4	Interviewee-5	Interviewee-6	Interviewee-7	Interviewee-8	Interviewee-9	Interviewee-10	Interviewee-11	Interviewee-12	Interviewee-13	Interviewee-14	Interviewee-15	Interviewee-16	Interviewee-17	Interviewee-18	Interviewee-19	Interviewee-20	Interviewee-21	Interviewee-22	Interviewee-23	Interviewee-24	Interviewee-25	Interviewee-26	Interviewee-27
Interviewee-1	0	1	0,9986	0,9995	0,9995	1	1	1	1	0,9995	1	1	1	0,9995	0,9991	0,9986	1	1	1	1	1	1	1	1	1	1	1
Interviewee-2	1	0	0,9995	1	1	1	1	0,9995	0,9995	1	1	1	0,9995	0,9986	1	0,9995	1	1	1	1	0,9995	0,9986	0,9995	1	0,9977	0,9986	0,9995
Interviewee-3	0,9986	0,9995	0	0,9995	1	1	1	1	0,9973	0,9995	1	1	1	1	1	0,9986	1	1	1	1	1	1	0,9995	1	1	0,9991	0,9995
Interviewee-4	0,9995	1	0,9995	0	0,9995	1	1	0,9995	0,9995	1	1	1	1	0,9986	0,9995	1	1	1	1	1	1	1	0,9995	1	1	1	1
Interviewee-5	0,9995	1	1	0,9995	0	1	0,9995	0,9986	1	1	1	0,9995	1	1	0,9991	1	0,9986	0,9995	0,9986	0,9995	1	1	0,9995	1	0,9995	1	0,9986
Interviewee-6	1	1	1	1	1	0	0,9995	0,9995	1	1	0,9991	0,9995	0,9995	1	0,9995	1	0,9991	1	0,9991	1	1	0,9991	0,9995	1	0,9991	0,9995	0,9968
Interviewee-7	1	1	1	1	0,9995	0,9995	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Interviewee-8	1	0,9995	1	0,9995	0,9986	0,9995	1	0	0,9995	1	1	0,9986	1	0,9995	0,9995	0,9991	0,9995	1	0,9995	1	1	0,9995	0,9991	1	1	0,9991	0,9973
Interviewee-9	1	0,9995	0,9973	0,9995	1	1	1	0,9995	0	1	1	1	0,9995	1	1	1	1	1	1	1	1	1	1	1	1	1	0,9995
Interviewee-10	0,9995	1	0,9995	1	1	1	1	1	1	0	0,9986	1	0,9995	1	1	0,9995	0,9995	1	1	0,9986	1	0,9995	1	1	1	1	1
Interviewee-11	1	1	1	1	1	0,9991	1	1	1	0,9986	0	1	0,9995	1	1	1	0,9986	0,9995	0,9986	0,9986	1	0,9995	1	1	0,9995	1	0,9991
Interviewee-12	1	1	1	1	0,9995	0,9995	1	0,9986	1	1	1	0	0,9986	0,9995	0,9995	0,9986	1	0,9991	0,9995	0,9995	0,9991	0,9986	0,9991	0,9995	1	0,9991	0,9973
Interviewee-13	1	0,9995	1	1	1	0,9995	1	1	0,9995	0,9995	0,9995	0,9986	0	1	1	1	1	1	0,9995	0,9986	0,9995	0,9986	0,9995	1	0,9991	1	0,9977
Interviewee-14	0,9995	0,9986	1	0,9986	1	1	1	0,9995	1	1	1	0,9995	1	0	1	1	1	0,9995	0,9995	1	0,9986	0,9995	0,9995	0,9995	0,9995	1	1
Interviewee-15	0,9991	1	1	0,9995	0,9991	0,9995	1	0,9995	1	1	1	0,9995	1	1	0	1	1	1	1	0,9995	1	1	0,9982	1	1	0,9986	0,9995
Interviewee-16	0,9986	0,9995	0,9986	1	1	1	1	0,9991	1	0,9995	1	0,9986	1	1	1	0	1	0,9973	0,9995	1	0,9995	0,9995	0,9986	1	0,9995	0,9977	0,9986
Interviewee-17	1	1	1	1	0,9986	0,9991	1	0,9995	1	0,9995	0,9986	1	1	1	1	1	0	1	0,9982	0,9995	1	0,9995	1	1	0,9995	1	0,9995
Interviewee-18	1	1	1	1	0,9995	1	1	1	1	1	0,9995	0,9991	1	0,9995	1	0,9973	1	0	0,9986	1	0,9995	0,9995	1	1	1	1	0,9991
Interviewee-19	1	1	1	1	0,9986	0,9991	1	0,9995	1	1	0,9986	0,9995	0,9995	0,9995	1	0,9995	0,9982	0,9986	0	0,9995	0,9995	1	1	1	0,9986	1	0,9995
Interviewee-20	1	1	1	1	0,9995	1	1	1	1	0,9986	0,9986	0,9995	0,9986	1	0,9995	1	0,9995	1	0,9995	0	1	0,9995	0,9982	1	1	0,9991	1
Interviewee-21	1	0,9995	1	1	1	1	1	1	1	1	1	0,9991	0,9995	0,9986	1	0,9995	1	0,9995	0,9995	1	0	0,9982	1	1	0,9995	0,9995	0,9995
Interviewee-22	1	0,9986	1	1	1	0,9991	1	0,9995	1	0,9995	0,9995	0,9986	0,9986	0,9995	1	0,9995	0,9995	0,9995	1	0,9995	0,9982	0	1	1	0,9982	0,9995	0,9968
Interviewee-23	1	0,9995	0,9995	0,9995	0,9995	0,9995	1	0,9991	1	1	1	0,9991	0,9995	0,9995	0,9982	0,9986	1	1	1	0,9982	1	1	0	0,9995	0,9995	0,9968	0,9995
Interviewee-24	1	1	1	1	1	1	1	1	1	1	1	0,9995	1	0,9995	1	1	1	1	1	1	1	1	0,9995	0	1	1	1
Interviewee-25	1	0,9977	1	1	0,9995	0,9991	1	1	1	1	0,9995	1	0,9991	0,9995	1	0,9995	0,9995	1	0,9986	1	0,9995	0,9982	0,9995	1	0	0,9995	0,9991
Interviewee-26	1	0,9986	0,9991	1	1	0,9995	1	0,9991	1	1	1	0,9991	1	1	0,9986	0,9977	1	1	1	0,9991	0,9995	0,9995	0,9968	1	0,9995	0	0,9986
Interviewee-27	1	0,9995	0,9995	1	0,9986	0,9968	1	0,9973	0,9995	1	0,9991	0,9973	0,9977	1	0,9995	0,9986	0,9995	0,9991	0,9995	1	0,9995	0,9968	0,9995	1	0,9991	0,9986	0

"attributes," "consequences," or "values." Since the dataset contained no outliers, and it was aimed to create groups of similar sizes with high accuracy, Ward's method was preferred. Performed using XLSTAT-Pro (version 2017.3, Addinsoft), Ward's method suggested three clusters. However, when the resulting dendrogram, given in Fig. 1, is examined carefully, it can be observed that two or four clusters also provide distinctive clustering solutions. Therefore, the interviews with 27 participants were reexamined and a profile analysis was performed to compare alternative numbers of clusters, and it was decided that four clusters represent the participant profiles better. According to the results with four clusters, 7 out of 27 participants were found to be in the first, 8 in the second, 7 in the third, and 5 in the fourth cluster.

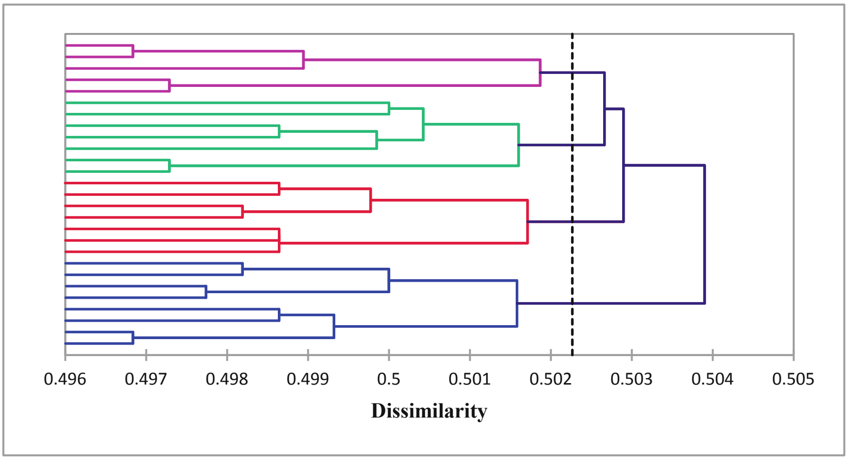

Fig. 1. Dendrogram based on Ward's hierarchical agglomerative clustering method

By combining the individual implication matrices of the relevant participants categorized in each cluster, implication matrices for each cluster were created (see Table 3 for an example combined implication matrix). With these combined implications matrices, the distinct attributes, consequences, and values of each cluster could be seen. HVM of each cluster was then created by using the corresponding cluster implication matrices. When deciding which elements (i.e., summary codes) and relationships should be shown in an HVM, a balance between trying to give enough information about the interviews and creating a simple and sufficiently descriptive map should be tried to be established (Costa et al. 2004). At this point, all relations above several different cutoff levels can be tried to be mapped, and using multiple cutoff levels gives the chance to choose the most informative and most stable set of relations (Reynolds and Gutman 1988). Regarding the relatively small sample size in this study, using cutoff levels could result in a poorer representation of the relevant clusters. Therefore, all identified elements and relationships were decided to be included in the HVMs (see Fig. 2, for example, HVM). The constructed HVMs, visually illustrates the relations between the elements of the relevant participants in a specific cluster, beginning from the product attributes to the personal values (Kangal 2013). The thickness of the arrows in these maps represents the

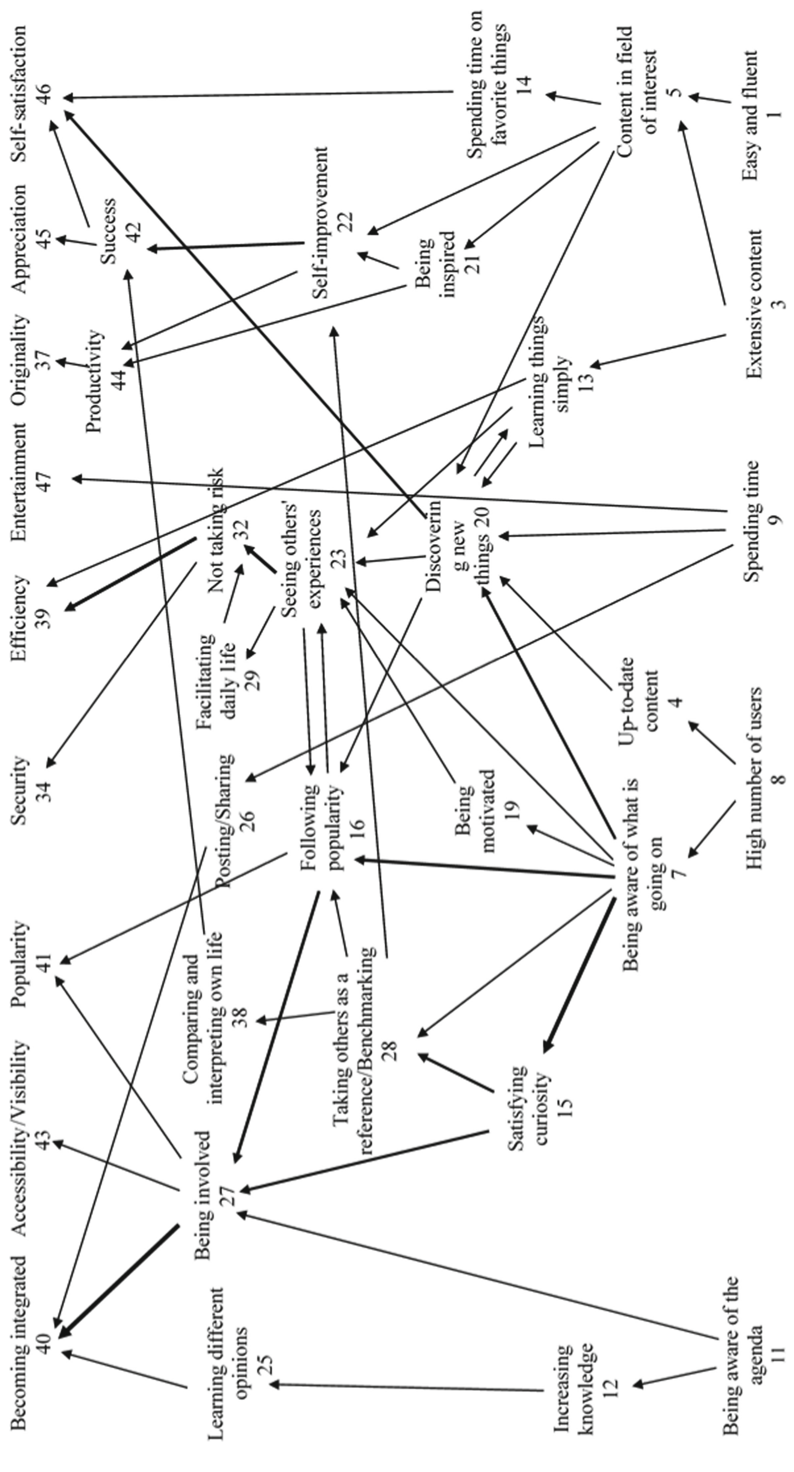

Fig. 2. HVM of the cluster 2

Table 3. An example implication matrix for cluster 2

			ATTRIBUTES											CONSEQUENCES																					VALUES														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
ATTRIBUTES	1	Easy and fluent					1.0																	0.1																							0.1			
	2	High number of content																																																
	3	Extensive content					1.0								1.0	0.1									0.1									0.1							0.1							0.1	
	4	Up-to-date content																				1.0			0.1									0.1															
	5	Content in field of interest														1.0						1.0	1.0	1.1															0.1					0.1		0.2		0.3	
	6	Objective content																																																
	7	Being aware about what is going on													0.1		4.0	3.1			1.0	2.0		0.1	1.2				0.4	1.2	0.1			0.2		0.1				0.2	0.3	0.3	0.2	0.2			0.1	0.1	
	8	High number of users				1.0			1.0								0.1					0.1			0.1				0.1					0.1								0.1							
	9	Spending time																0.1				1.0						1.0	0.1													0.2							1.0
	10	Reaching people																																																
	11	Being aware of the agenda												1.0													0.1		1.0													0.1			0.1				
CONSEQUENCES	12	Increasing knowledge																									1.0															0.1							
	13	Learning things simply																							1.0									0.1							1.1								
	14	Spending time on favorite things																																														1.0	
	15	Satisfying curiosity																											2.0	2.0										0.2		0.2		0.1					
	16	Following popularity																							1.0				3.0					0.1							0.1	0.2	1.1						
	17	Communicating																																																
	18	Strengthening communication																																																
	19	Being motivated																							1.0						0.1			0.1		0.1					0.1								
	20	Discovering new things													1.0			1.0							1.0				0.1					0.1							0.1	0.1						2.0	
	21	Being inspired																						1.0																				0.1		1.0		0.1	
	22	Self-improvement																																										2.0		1.0	0.1	0.1	
	23	Seeing others' experiences																1.0													1.0			3.1		0.1					0.3		0.1						
	24	Creating and declaring own ideas																																																
	25	Learning different opinions																																								1.0							
	26	Posting/Sharing																																								1.0							
	27	Being involved																																								4.0	1.0		1.0				
	28	Taking others as a reference/Benchmarking																						1.0																2.0				0.2			0.1		
	29	Facilitating daily life																																1.0		0.1					0.1								
	30	Being successful at work																																																
	31	Earning money																																																
	32	Not taking risk																																		1.0					3.0								
VALUES	33	Socializing																																																
	34	Security																																																
	35	Quality of life / Welfare level																																																
	36	Happiness																																																
	37	Originality																																																
	38	Comparing and interpreting own life																																										1.0					
	39	Efficiency																																																
	40	Becoming integrated																																																
	41	Popularity																																																
	42	Success																																													1.0	1.0	
	43	Accessibility/Visibility																																																
	44	Productivity																																					1.0										
	45	Appreciation																																																
	46	Self-satisfaction																																																
	47	Entertainment																																																

frequency of the relevant relationship, where thicker lines represent the relations that were repeated more frequently by the participants in that cluster.

Furthermore, the social media platforms that the participants stated at the beginning of the interview were examined for each cluster, and the general tendency of social media platform preferences was determined. While determining the most preferred social media platforms for each cluster, the total weight of a specific platform ($w_{platform}$) was calculated as follows:

$$w_{platform} = \frac{\sum_{i=1}^{4}\left(i \times Number\ of\ participants\ who\ stated\ the\ relevant\ platform\ in\ the\ i^{th}\ rank\right)}{Total\ number\ of\ participants\ who\ use\ that\ platform}$$

Since the lowest weight (i.e., 1) was given to the first place in the ranking, the platform with the lowest total weight indicated the general tendency of the participants in the relevant cluster. Here, it is worth to mention that when calculating the weights of the platforms used by the participants in each cluster, the platforms, which were used only by one or two participants, were not included in the common rankings, as they do not correctly indicate the overall tendency of that cluster.

4 Results

For the first cluster, the social media preferences of the seven participants are affected by the "extensive content." These people use the content on social media platforms to "increase their knowledge" which indicates that this knowledge "facilitates their daily life." "Facilitating daily life" is not directly related to "efficiency," but instead directly related to "security," which denotes being prepared for various unexpected situations and is one of the prominent values for the first cluster. Differently from the participants in the other clusters, this cluster's participants do not use social media platforms for "being aware of what is going on" around them, "posting/sharing" or "being involved." "Being aware of what is going on" attribute is about friends and contacts. One more different characteristic of this cluster is that people in this group do not have a value chain, such as "being motivated" by "spending time on favorite things" and "being productive." YouTube stands out as the most widely used social media platform in this cluster (see Table 4(a)). According to the results of a study, which is carried out by Pew Research Center for one year, politics related content in YouTube constitutes 21% of all content (2010). Although the most commonly used social media platform is Instagram, according to the usage frequencies, only one person out of seven ranked Instagram as their first choice.

When the second cluster is examined, it can be seen that "being aware of what is going on," "satisfying curiosity," "the following popularity," "being involved," and "becoming integrated" are the main elements of the eight participants categorized in this cluster. According to the interviews, these people feel that they are missing something if they are not "aware of what is going on around." The distinctive feature of this cluster is that they do not prefer using social media for "communicating" or for "socializing." Additionally, "happiness" value that is mentioned in all other clusters is not mentioned by anyone in this cluster. Members of this cluster indicate that "seeing others' experiences" on social media "facilitates their daily life," but they do not link it with "security"; instead, they

Table 4. Social media preferences of each cluster

(a) Cluster-1

	Weight	Frequency
YouTube	1.75	4
Instagram	2.16	6
Ekşisözlük	2	3
Twitter	2.5	4

(b) Cluster-2

	Weight	Frequency
Instagram	1.125	8
YouTube	2.42	7
Twitter	2.66	3
Facebook	3	6
LinkedIn	3.2	5

(c) Cluster-3

	Weight	Frequency
Instagram	1.4	5
YouTube	1.83	6
Ekşisözlük	3.2	5
Twitter	3.25	4

(d) Cluster-4

	Weight	Frequency
Instagram	1.8	5
YouTube	2.6	5
Ekşi	2.33	3
Facebook	3.33	3

relate it with "not taking risk" and "efficiency." For example, they make use of the experiences of other people on social media to select the hotel they will stay or the restaurant they will dine when they are making a travel plan. This is also in parallel with "following popularity"; as a very preferred place (i.e., a place "posted/shared" a lot by others) is a good place according to the users. Another value chain, which is seen only in this cluster, is "taking others as a reference" and "comparing and interpreting own life." In this value chain, participants indicate that the way of understanding whether their life is going well or not is to compare their lives with those of others. People in this group do not relate social media with "being successful at work" or "increasing quality of life or welfare level." When the social media preferences of the second cluster are examined, Instagram is in the first rank. (See Table 4(b)). Seven out of eight people in this cluster ranked Instagram as their first choice. The second most used social media platform is YouTube, and this cluster is the group that uses Facebook mostly. The prominent reasons for using Facebook are the requirement of "being aware of what is going on," "being involved," and "becoming integrated."

When the third cluster is examined, it can be seen that the participants in this cluster want to "learn things simply" by using social media platforms, as they think the social media has an "easy and fluent" usage. They want to "develop themselves," be "productive," spend their time "efficiently," and be "happy." Considering interviews with the participants, some of the people in this cluster want to develop themselves by having different hobbies and by producing new things. Some of them indicate that social media platforms increase efficiency, as these platforms contribute a lot in a very short time, and they feel satisfied. They do not have an intention "to be involved" and they are not curious about the "experiences of others." "Popularity" and "entertainment" is not important for these users. When the social media preferences of the seven people in this cluster are examined, Instagram and YouTube are in the first and second ranks, respectively, with close weights (See Table 4(c)). Generally, users that want to see different contents prefer Instagram, and users that want to have hobbies prefer YouTube.

Finally, when the fourth cluster is examined, the relationship between "being aware of the agenda" and "increasing knowledge" becomes prominent. The participant of this cluster use the knowledge they obtain, "to create and declare their ideas," and "to be involved." Prominent values of the cluster are "socializing," "becoming integrated," and "happiness." "Strengthening communication" appears only in this cluster. The difference between "communicating" and "strengthening communication" here is that being informed about the interest areas of other people makes it easier to chat with them and to socialize when communicating. Users in this cluster do not relate social media with "discovering new things," "self-improvement," "inspiration," and "motivation." "Increasing knowledge" is important for them, but they do not want to get knowledge for "self-improvement" or "productivity." Instagram is in the first rank in the social media preferences of this cluster, consisting of five people (See Table 4(d)).

5 Conclusion

This study segments social media users based on their cognitive structures. To do this, an approach based on means-end chain analysis is proposed. According to this approach, the preferred characteristics of social media platforms, which can be considered as the main reasons for their usage, are linked to personal values. Eventually, the values of users addressed by social media platforms are obtained. The results indicate that social media platforms are not used for socialization purposes only, as mentioned at the beginning of the study. The users are categorized under four clusters considering all of the attributes, consequences, and values that were elicited in the interviews. Each cluster is internally homogeneous and contains differentiated aspects compared to other clusters. With the hierarchical value maps generated for each cluster, the dominant elements and chains can be observed. Marketers can use these maps to reach users with specific values and identify which attributes to develop in their products/services for reaching these users. In addition, companies that want to invest in advertising can benefit from the results of this study to reach the users they want to address. Finally, yet importantly, the proposed approach is not restricted to segmentation of social media users and can be applied to brand positioning as well as a wide range of application domains.

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Motivators for the Second-Hand Shopping Through Mobile Commerce

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Abstract. This study aims to reveal the factors affecting the use of second-hand shopping through a mobile application. An extended Technology Acceptance Model (TAM), including economic advantage, natural conservation, sustainable consumption, trust, convenience, and subjective norms is constructed. A total of 318 questionnaires are collected from the users of one of the second-hand shopping application-Letgo. Regression analysis is used to reveal the relationships defined in the model. First, the results of the study confirm the relations defined in TAM in the context of second-hand shopping. Furthermore, behavioral intention to use is affected by perceived usefulness, subjective norms, convenience, and perceived ease of use. Perceived usefulness and subjective norms have a higher impact than others. Another result is that perceived ease of use, economic advantage, sustainable consumption, natural conservation, and subjective norms impact the feeling about the usefulness of second-hand shopping system. Among the factors, perceived ease of use and economic advantage have higher importance on perceived usefulness.

Keywords: M-commerce · Second-hand product · Technology acceptance · Convenience · Environmental factors · Economic issues

1 Introduction

In recent years, the increase in environmental concerns and economic fluctuations causes the second-hand economy to be a multi-billion-dollar sub-industry in the world (url-1). The second-hand economy "includes any transaction of second-hand items, bought, sold, rented, traded, or donated" (url-2). Therefore, second-hand use provides second life to the items instead of useless storage (Parguel et al. 2017). With the advances in e-commerce and mobile commerce, the second-hand economy has moved to online and mobile platforms from second-hand stores.

Just as the internet and web expedite the immense use of e-commerce, a high rate of mobile phone usages also provides preconditions for the proliferation of mobile-commerce (Agrabi and Jallais 2015). According to the transaction value of global m-commerce sales, mobile commerce revenues amounted to 96.3 billion US dollar in 2015, and this value is expected to increase 693 billion US dollars in 2019 (url-3).

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Considering these statistics, mobile commerce is a good enabler for both first and second-hand shopping. Although mobile commerce provides many advantages to users, some potential users do not prefer to use such a system in satisfying their needs.

To understand the motivational factors for using any information system, Davis (1989) develop TAM for individual acceptance of information technology. TAM is one of the robust models that is used to understand the factors affecting the use of information system. The literature on TAM reveals that TAM has been successively used in understanding the use of mobile commerce specifically for shopping (Agrabi and Jallais 2015), real estate transaction (Shih and Chen 2013). Agrabi and Jallais (2015) extend TAM with the satisfaction and perceived enjoyment constructs to understand the critical factors in the decision to use mobile shopping websites. On the other hand, there is a limited number of studies related to second-hand shopping (Liang and Xu 2018; Guiot and Roux 2010). Liang and Xu (2018) aim to understand the second-hand clothing consumption intention by including the variables consumer's perceived hedonic, economic, environmental values, perceived concerns, and descriptive norms. Guiot and Roux (2010) develop a scale to measure second-hand shopping motivations. They propose a research model including three main factors as critical, economic, and hedonic/recreational motivations. All the studies mentioned above are related to the traditional shopping motivators in second-hand shopping items. The current study tries to analyze the motivational factors for second-hand shopping through a mobile application. TAM is used as the base model and extended with the constructs subjective norms, convenience, trust, economic advantage, and environmental concern.

This study contributes to the existing literature in several ways. First, this study is the first study that examines the factors affecting the use of m-commerce for second-hand shopping. Second, an extensive research model including convenience, subjective norms, environmental concerns, economic issues with TAM is developed. Third, this study tries to understand the motivational factors for the use of second-hand shopping system by collecting data from the actual users of the system; only a few studies focus on the actual use of m-commerce.

The remaining part of the study is organized as follows: The research model is explained in the next section. The analyses and results are presented in Sect. 3. In the last part, the results are discussed; the possible studies and managerial implications are provided.

2 Research Model

The research model explaining the factors affecting the use of second-hand product purchase system is shown in Fig. 1. In this model, TAM is integrated with the constructs subjective norms, economic aspect, environmental concerns, convenience, and trust.

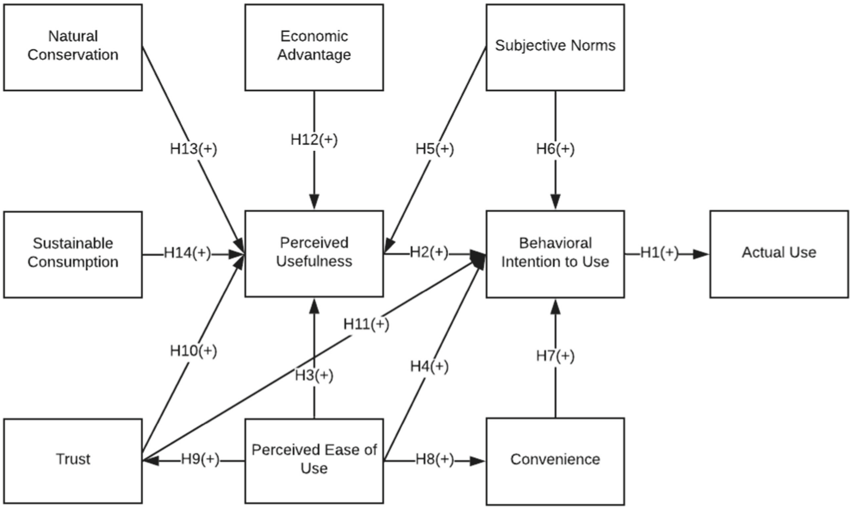

Fig. 1. Research model

2.1 Technology Acceptance Model

TAM is developed by Davis (1989) to understand the important factors affecting the decision to use an information system. According to this model, before the use of an information system, potential users first intend for future uses and then actually use the system. Perceived usefulness and perceived ease of use are the other factors in addition to intention and actual use. Perceived usefulness refers to the "degree to which a person believes that using a particular system would enhance his or her performance" (Davis 1989, p. 320). The users intend to use any system if the system increases the performance of the users. Perceived ease of use can be defined as "the degree to which a person believes that using a particular system would be free of effort" (Davis 1989, p. 195). The easiness of a system may increase the feeling of usefulness and attitude toward the use of a system. The systems are designed to increase the performance of people and users of a system do not want to spend extra time for understanding how to use a system. Otherwise, users may choose alternative ways to conduct their tasks.

TAM has been verified in several studies in explaining the decision to use e-commerce (Kim et al. 2009; Jin 2014) and mobile commerce (Agrabi and Jallais 2015). The hypotheses defined in TAM are as follows:

H1: Behavioral intention to use affects actual use positively.
H2: Perceived usefulness affects behavioral intention to use positively.
H3: Perceived ease of use affects perceived usefulness positively.
H4: Perceived ease of use affects behavioral intention to use positively.

2.2 Subjective Norms

Subjective norms refer to the “person’s perception that most people who are important to him think that he should or should not perform the behavior in question” (Ajzen and Fishbein 1980, p. 73). Theory of Reasoned Action (TRA) is an important theory in explaining human behavior and suggests that subjective norms explain behavior together with the attitude towards the behavior. Especially, the increased usage of social media induces users to get information from several resources. In line with TRA, positive, or negative feelings of others may influence the decision to use a system.

Many studies also confirmed the influence of subjective norms on perceived usefulness (Jin 2014; Kim et al. 2009) and behavioral intention to use (Kim et al. 2009). Jin (2014) finds that subjective norm is the strongest predictor of perceived usefulness in e-book adoption. Kim et al. (2009) find that the feeling about the usefulness of airline e-commerce websites and intention to use is influenced by subjective norms. Therefore, the influence of subjective norms on perceived usefulness and behavioral intention to use is formed as follows:

H5: Subjective norms affects perceived usefulness positively.
H6: Subjective norms affects behavioral intention to use positively.

2.3 Convenience

Convenience is one of the most important factors in online businesses (Jiang et al. 2013). It is defined as the “consumers’ time and effort perceptions related to buying or using a service” (Berry et al. 2002). It is a multifaceted construct, including convenience in access, search, evaluation, and transaction. Access convenience deals with the “speed and ease with which consumers reach a retailer in person, over the phone or through a computer” (Seiders et al. 2000), and be available when it is necessary (Berry et al. 2002). Without accessibility, other forms of convenience may be negligible (Seiders et al. 2000), because if the consumer cannot reach the system, the consumer cannot have an opportunity to search, evaluate and complete transaction (Beauchamp and Ponder 2010). Search convenience is related to the search and selects a product quickly and easily. Evaluation convenience is the ability of the system to provide adequate information about the product to the customers for the evaluation of the products. Transaction convenience is the completion of commerce without difficulty, including payment methods.

Customers’ general belief about convenience is considered as an important reason to make internet purchases (Jayawardhena et al. 2007). The importance of convenience in the decision to use a system has also been verified by several studies (Ozturk et al. 2016; Jiang et al. 2013). Ozturk et al. (2016) reveal the significance of perceived convenience, compatibility, and perceived ease of use on continued intention to use. Jiang et al. (2013) find that search convenience, transaction convenience, and post-purchase convenience are the predictors of behavioral intention to use online shopping. Therefore, the following hypothesis is proposed:

H7: Convenience affects behavioral intention to use positively.

Perceived ease of use is the general perception about how much time and effort required to use a system and may have an impact on the convenience perception of customers (Berry et al. 2002; Okazaki and Mendez 2013; Lai and Chang 2011; Yoon and Kim 2007). Okazaki and Mendez (2013) conclude that perceived ease of use is a strong determinant of simultaneity, speed, and searchability of m-commerce. Lai and Chang (2011) reveal the significant effect of perceived ease of use on convenience and perceived usefulness of e-books. Yoon and Kim (2007) find that perceived ease of use has a positive effect on the convenience of a wireless LAN. Therefore, the following hypothesis is proposed:

H8: Perceived ease of use affects convenience positively.

2.4 Trust

Trust is one of the important factors in many economic transactions (Gefen et al. 2003). Gefen (2002) defined trust as "willingness to depend based on beliefs in ability, benevolence, and integrity." Trust in mobile technology and trust in mobile vendors are important dimensions of trust in m-commerce (Li and Yeh 2010). On the other hand, in the second-hand economy, condition, performance, and durability of second-hand products are also important as other dimensions.

Some studies are investigating the trust factor in online shopping. Gefen et al. (2003) find that the easiness of the system enhances the feeling of trust and positive feelings about trust affect the usefulness perception and future uses. Lee (2009) finds the same significant relationship between trust and perceived ease of use and perceived usefulness as Gefen et al. (2003). Differently, Lee (2009) reveals the significant effect of trust on attitude, perceived behavioral control, and subjective norms. In m-commerce area, Li and Yeh (2010) investigate trust in mobile commerce and find that usefulness, ease of use, design aesthetics, and customization affect trust in mobile commerce (m-trust) positively. Cho et al. (2007) find that structural assurances, calculative-based trust, situational normality, and perceived ease of use are significant factors on trust in online and mobile commerce. They also find that trust affects perceived usefulness positively, but it does not affect the intended use. As seen in these studies, trust is an important aspect of online shopping and mobile commerce. Therefore, the following hypotheses are formed:

H9: Perceived ease of use affects trust positively.
H10: Trust affects perceived usefulness positively.
H11: Trust affects behavioral intention to use positively.

2.5 Economic Advantage

People usually prefer to purchase second-hand products rather than new products because of their economic advantages. Second-hand products are cheaper than new products, and buying second-hand products helps people to save money. People may use their saved money to make an investment, get an education, or go on a vacation. Guiot and Roux (2010) investigate the economic motivation behind second-hand shopping into four categories as wish to pay a less and fair price, feeling satisfaction about the price and unwillingness to bargain. The results of their study show that economic advantage is a motivator behind second-hand shopping and search for a fair price and satisfaction about the price are significant aspects of economic motivation. Therefore, the following hypotheses are formed:

H12: Economic advantage has a positive effect on perceived usefulness.

2.6 Environmental Factors

Many people have unwanted items in their homes. Donating to charity, selling, giving to family or friends, and throwing them in the bin are the possible options to handle these unwanted items. For example, 50% of Australians admit they want to throw their unwanted items in the bin (url-2). If these unwanted items which have good conditions for reusing are thrown in the bin, amount of waste to be handled will grow rapidly. On the other hand, by the help of the second-hand economy, products can be used as long as their life cycle. Therefore, natural resources that will be used to produce new products or to dispose of wastes will be preserved.

In the literature, two studies are investigating the effects of environmental factors on second-hand shopping. Guiot and Roux (2010) discussed environmental concerns in two dimensions as ethics and ecology and recycling behavior. Besides, they investigated the effects of lifestyle traits such as frugality and materialism on second-hand shopping. The results of the study show that frugality has a positive effect, and materialism has a negative effect on critical motivations. Critical motivations positively affect ethics and ecology and recycling behavior. Parguel et al. (2017) find that materialism and environmental awareness impact cognitive inconvenience related to buying behavior, which in turn affects instinct buying. These studies show that environmental factors are one of the important motivators influencing second-hand shopping. Therefore, the following hypotheses are formed:

H13: Natural resources conservation has a positive effect on perceived usefulness.
H14: Sustainable consumption has a positive effect on perceived usefulness.

3 Methodology

A survey methodology is used in the current study. The respondents are the actual users of second-hand shopping system-Letgo. Letgo is a company which has a website and app to buy and sell second-hand products locally. Its application is the largest and fastest growing application, with its tens of million users (Url-3). Letgo offers a wide range of products from electronics, cars, and clothing to furniture, books, DVDs. Also, it allows

Table 1. Demographic characteristics of the participants

Gender (%)	Male		59	
	Female		41	
Age (%)	18–24		15.41	
	25–34		62.26	
	35–44		14.47	
	45–54		4.40	
	55 years or older		3.46	
Annual income (%)	<$20,000		17.92	
	$20,000–$39,999		26.73	
	$40,000–$59,999		25.47	
	$60,000–$79,999		17. 92	
	>$80,000		11.95	
Employment status (%)	Employed for wages		60.06	
	Self-employed		24.53	
	Student		6.29	
	Homemaker		5.66	
	Retired		0.63	
	Unemployed		2.52	
	Unable to work		0.31	
Education level (%)	High school graduate, a college degree		18.24	
	Trade/technical/vocational training		2.52	
	Associate degree		5.03	
	Bachelor's degree		50.94	
	Master's degree		19.18	
	Doctorate degree		0.94	
	Other		3.13	
Online shopping frequency (%)	At least once a week		27.36	
	Once or more per month		41.51	
	7–12 times per year		22.33	
	4–6 times per year		6.60	
	1–3 times per year		1.89	
	Never		0.31	
Preferred product categories for online shopping (%)	Adult clothing	9.35	Household decorative items	5.47
	Bikes	4.67	Jewelry	4.32
	Books	13.40	Knick-knacks	1.85
	Cars	3.53	Mobile phones	7.32
	Children's clothing	6.08	Printers	2.12
	Children's games and toys	4.85	Records, cassettes, CDs, DVDs	2.38
	Collectables	3.35	TV	4.76
	Computers	7.50	Video games	6.35
	Crockery, glassware	2.03	Video game consoles	2.12
	Furniture	6.79	Other	0.26
	Hi-fi	1.50		
Country (%)	United States		71.70	
	Turkey		1.57	
	Canada		5.35	
	Germany		1.26	
	Other		20.13	

customers to chat and bargain with buyers. Therefore, to determine the motivation behind second-hand shopping, our survey is applied to Letgo users.

A total of 318 questionnaires were collected during the period of April-May 2018. The questionnaire is distributed through an online system. The questionnaire has two main parts. In the first part, there are demographic questions such as age, gender, education status, and online shopping habits, etc. The detail of the demographics is given in Table 1. According to the demographic profiles, most of the participants are from USA (71.7%), in the 25–34 age range (62.26%), employed for wages (60%) and most of them have a bachelor degree (50.94%). Besides, according to the results, participants most frequently use online shopping to buy books (13.4%), adult clothing (9.35%) and computers (7.5%).

The second part consisted of questions aiming to measure the factors affecting second-hand shopping application of Letgo. The constructs are adopted from the literature that conforms to the second-hand shopping context (Convenience, Jiang et al. 2013; natural resources conservation, Parguel et al. 2017; Hobbs 2016; Guiot and Roux, 2010; sustainable consumption, Guiot and Roux 2010; trust, Alam 2014; economic advantage, Alam 2014; subjective norms, Kim et al. 2009; perceived usefulness, Gefen et al. 2003; perceived ease of use, Gefen et al. 2003; behavioral intention to use, Moon and Kim 2001; Agarwal and Prasad 1997; Actual use, Agarwal and Prasad 1997). A five-point Likert scale (1: strongly disagree,…, 5: strongly agree) is used to measure the perceptions of users about Letgo while buying a send-hand product.

4 Results

A two-step approach is applied to test the research model with the data. First, the internal reliability of the constructs is tested by calculating Cronbach's alpha values. Second, stepwise regression analyses are applied to reveal the relationship between the constructs

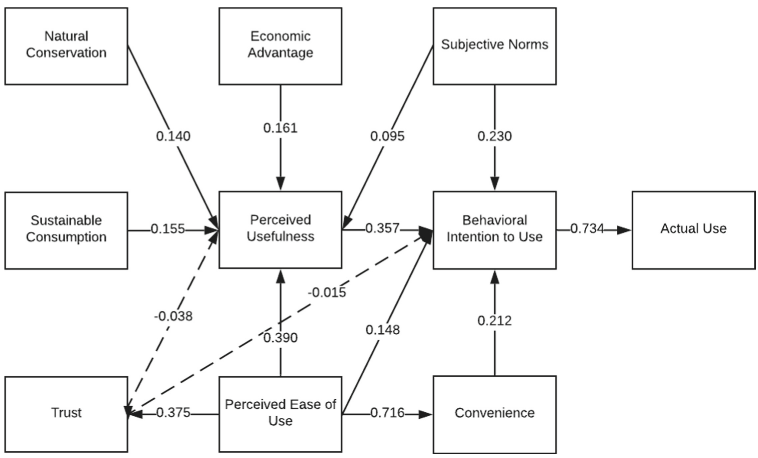

Fig. 2. Results of the proposed research model (--- indicates insignificant relationship)

and to test the hypotheses of the research model. For the analyses, the IBM SPSS Statistics 20 software tool is used.

Cronbach's alpha values are calculated, as shown in Table 2. The results of the reliability analysis show that all Cronbach' alpha values are greater than 0.7. Therefore, all constructs have good internal consistency (Sharma 2016).

The results of stepwise regression analyses are visualized, as shown in Fig. 2. All proposed hypotheses except H10 and H11, which try to explain the relationship between trust and perceived usefulness and behavioral intention to use, are accepted. Furthermore, the significant determinants of perceived usefulness, behavioral intention to use, and actual use are revealed by using the stepwise regression and discussed in detail.

Table 2. Cronbach's alpha values of the constructs

Construct	Number of items	Cronbach's alpha
Convenience	13	0.900
Natural resources conservation	4	0.784
Sustainable consumption	4	0.799
Trust	4	0.750
Economic advantage	3	0.740
Subjective norms	3	0.865
Perceived usefulness	4	0.795
Perceived ease of use	4	0.816
Behavioral intention to use	3	0.766
Actual use	3	0.785

Perceived ease of use explains 51.2% of the total variance of the convenience (F (1; 316) = 331.781, $p < 0.001$). This result show that perceived ease of use ($\beta = 0.716$, $t = 18.215$, $p < 0.001$) is significantly associated with convenience. Perceived ease of use explains 14% of the total variance of trust (F (1; 316) = 51.623, $p < 0.001$) and it is a significant predictor of trust ($\beta = 0.375$, $t = 7.185$, $p < 0.001$).

Perceived ease of use, sustainable consumption, economic advantage, natural conservation and subjective norms explain 57% of the total variance of perceived usefulness (F (5; 312) = 81.295, $p < 0.001$). This result shows that perceived ease of use ($\beta = 0.390$, $t = 7.219$, $p < 0.001$), sustainable consumption ($\beta = 0.155$, $t = 2.863$, $p = 0.004$), economic advantage ($\beta = 0.161$, $t = 3.088$, $p = 0.002$), natural conservation ($\beta = 0.140$, $t = 2.487$, $p = 0.013$) and subjective norms ($\beta = 0.095$, $t = 2.088$, $p = 0.038$) are significant determinants of perceived usefulness. On the contrary, trust ($p = 0.730 > 0.05$) has no significant effect on perceived usefulness.

Perceived usefulness, subjective norms, convenience and perceived ease of use explain 61.3% of the total variance of behavioral intention to use (F (4; 313) = 123.758, $p < 0.001$). The result indicates that behavioral intention to use is positively affected by perceived usefulness ($\beta = 0.357$, $t = 6.560$, $p < 0.001$), subjective norms ($\beta = 0.230$,

$t = 5.705$, $p < 0.001$), convenience ($\beta = 0.212$, $t = 3.643$, $p < 0.001$) and perceived ease of use ($\beta = 0.148$, $t = 2.772$, $p = 0.006 < 0.05$). On the other hand, trust is not a significant factor on behavioral intention to use ($p = 0.711 > 0.05$).

Behavioral intention to use explains 53.9% of the total variance of actual use ($F(1; 316) = 370.078$, $p < 0.001$). Behavioral intention to use ($\beta = 0.734$, $t = 19.237$, $p < 0.001$) has a significant effect on actual use.

5 Conclusion and Discussion

This study aims to understand the factors affecting the decision to use second-hand shopping system by including the factors economic advantage, social impact, environmental concerns, subjective norms, convenience, and trust to the TAM. A survey is conducted to actual users of Letgo app, and a total of 318 surveys are collected.

The results of the study show that actual use is highly influenced by behavioral intention to use and behavioral intention to use is affected by perceived usefulness, subjective norms, convenience, and perceived ease of use. Perceived usefulness is the most significant factor in behavioral intention to use. If users find the application efficient, productive, and faster, they are willing to use more. Furthermore, opinions and suggestions of the other users such as friends or relatives encourage people to use Letgo application to buy or sell second-hand products. Besides, some features of the application, such as easy to access and navigate, easy payment methods, providing detailed information about product and sellers, influence users positively.

Another result of the study indicates that perceived usefulness is affected by perceived ease of use, economic advantage, sustainable consumption, natural conservation, and subjective norms. Perceived ease of use is the most significant factor in perceived usefulness. If the application is easy to learn and use, it also has a clear and flexible interaction, users may find the application more beneficial. Secondly, economic advantages such as an opportunity to buy cheaper products and bargaining about the price increase the user perception of usefulness. Besides, environmental concerns of the users are found as significant factors. In general, these environmental aspects of second-hand shopping are not highlighted. However, the results of the study show that sustainable consumption and natural conservation are almost as important as an economic advantage. Advertising on environmental aspects of second-hand shopping may attract environmentally conscious people.

Another interesting result of the study, trust does not influence perceived usefulness and behavioral intention to use. Second-hand shoppers using Letgo may not concern about the performance and durability of the second-hand product. Also, they find Letgo less risky to purchase second-hand products, and they trust the information provided by the sellers. Letgo already offers verified user profiles with ratings and reviews. The results of the study show that the efforts of Letgo to build a trustful second-hand community are properly working.

Although this study provides some insights about understanding the user behavior, there are still unexplained variances of the constructs. Therefore, additional factors such as recreational motivation, meaning rare or antique products selling through the system may be included for further understanding. Second, the research model may be tested to understand group differences of product types such as cars, housing, technology, fashion, child, etc. by increasing the number of respondents to the questionnaires. Third, potential differences on the use of second-hand shopping apps according to demographic characteristics such as age, gender, education, and employment status or annual income are not discussed in this study and analyses of these factors for future studies may provide a better insight about actual use and intention to use of second hand shopping apps.

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Profit Allocation in the Turkish Electricity Industry Based on Cooperative Game Theory

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Abstract. In this paper, the retail electricity supply to the end-user electricity customers is studied via cooperative game theory. There are two major players in the retail electricity market in Turkey: power plants and retailers. Players with retail licenses, who sell retail electricity directly to the end-user, operate with very low levels of profit margin due to high cost and competition in the market. On the other hand, power plants have a generation capacity, yet they lack sales and marketing know-how compared to retailers. We show that when power plants and retailers cooperate and integrate the market vertically, they can generate more profit compared to stand-alone. Accordingly, we investigate profit-sharing among these players using cooperative game theory. To this end, we choose Nash Bargaining, Kalai-Smorodinsky Bargaining, and weighted Shapley solutions and compare their results.

Keywords: Retail electricity · Cooperative game theory · Nash bargaining · Kalai-Smorodinsky solution · Shapley value

1 Introduction

The Turkish electricity sector is one of the fastest-growing markets in terms of supply and demand, globally. Furthermore, it has been in the process of liberalization within the context of "Energy Sector Reform" since the early 1980s. Since March 2001, the Turkish Government has embarked on a long and comprehensive process to reform and liberalize its energy market to attract private investments, enhance competition, increase efficiency and shift the investment burden from the state to the private sector. And recently there are substantial developments in this regard.

Especially in the retail electricity market, companies have difficulty in competing against each other, although there are separate parties such as power plants, wholesalers, and retailers. All of these players are eligible to obtain retailer license from regulators so that they can supply to the end-users. Because of strict regulatory conditions, in particular, having limited playing field as regulation tariff is too low to compete and general economic situation for Turkish citizens, it became even more difficult for electricity companies to carry on their retail activities.

Within this context, instead of competing with each other, cooperation among players and acting together for retail services became even more relevant for the Turkish electricity retail market. As there are a lot of retailers providing electricity to end-users directly,

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competition becomes more intense and the operational efficiency decreases. Thanks to the economies of scale, excellence in operations by building a significant coalition with two or more players among retailers, wholesalers, and power plants, substantial cost savings can be realized. With the coalition, every part can put the best capability they have so that the new coalition has the margin to fall the end-user price level with the same profit margin levels and increase its electricity volumes.

There are many social science studies analyzed by game theory especially in the field of economics since the seminal work of von Neumann and Morgenstern (1944), which basically builds an abstract mathematical framework to address interactive situations in social science. They develop a comprehensive theory including the normal or extensive games; concepts of stand-alone and mixed strategies, coalitional games, and many others.

The categorization of game theory concepts is a critical milestone for the development of game theory. The first approach is considered as strategic or non-cooperative game theory, and the second approach is called coalitional or cooperative game theory. A non-cooperative game determines all rational and possible actions of each decision-maker in the game. On the other hand cooperative games address the patterns of cooperation.

Aside from introducing the most seminal non-cooperative solution concept, namely Nash equilibrium, John Nash investigated the cooperative games in the context of bargaining. Nash (1953) defines bargaining as a situation in which the mutually beneficial agreement is optional for the parties, and there is a conflict of interests about which agreement to conclude and the agreement may not be imposed on any player without acceptance. The aforementioned two-person bargaining problem has been applied in many important contexts including labor arbitration, duopoly market games, and supply chain contracts where a buyer and a supplier work out a mutually beneficial contract.

Kalai and Smorodinsky (1975) provided an alternative solution for bargaining problems. Instead of Nash's independence of irrelevant alternatives axiom, they use a monotonicity condition, thereby using the best outcomes in the feasible set, which in turn gives another compelling solution for bargaining problems.

Shapley (1953) develops another solution concept, i.e., Shapley value, for cooperative games with transferable utility that ensures a unique allocation for players. The Shapley value is found by the marginal contribution of each player to each coalition, and in the original formulation each player is assumed to be symmetric. However, for some situations there may be some inherent asymmetries in the problem. To address these cases, the weighted Shapley value was introduced. This generalization enables us to assign a weight to each player that is the proportion that they share in unanimity games.

As the service model of energy market includes multi-players and the share of profit/cost for any business agreement, it is a well-suited domain for cooperative game theory. There are in particular few applications with regards to profit/cost-sharing model for energy market. Parsons (1989) develops an application regarding long–term gas supply contracts mainly focusing long-term value of those contracts. More recently, Cobanli (2014), Hubert and Ikonnikova (2003) and Hubert and Suleymanova (2008) investigate a quantitative case of power relations in real-world supply chains using cooperative game theory.

Our purpose is to study whether there is a cooperation possibility between power plants and retailers by using tools of cooperative game theory. In this paper, we use three well-known solution concepts: two-person Nash bargaining solution, Kalai-Smorodinsky bargaining solution, Kalai Smorodinsky bargaining solution, and weighted Shapley solution to analyze a coalition between power plant and retailer in the retail electricity industry. We model the interdependencies in the retail electricity market as a game in the value function form, which is calculated as a net profit value. The solution of each game concept allocates to each player a share from the total profit. Additionally, we compare the three solution concepts mentioned above.

The rest of the paper is organized as follows. Section 2 introduces our setup and the main solution concepts. In Sect. 3, we present a summary of the Turkish electricity market. Section 4 gives our results based on cooperative game theory solutions. Finally, we conclude in Sect. 5.

2 The Model

While the non-cooperative games focus on competition between individual players, cooperative game theory deals with the competition between coalitions of players. The main question is how to allocate revenue and costs in cooperative situations. We restrict our attention to transferable utility games, which ensures the existence of a transferable commodity among the players. Transferable utility games further assume that the utility numbers correspond to the earnings of a coalition. Second, we assume that individuals have risk-averse preferences for money.

Cooperative games are defined by $N = \{1, 2, \ldots, |N|\}$ the set of players. Every subset $S \subseteq N$ of players is called a coalition. N is called the grand coalition, which is the group consisting of all players. The main purpose of cooperative game theory is to study the players' decisions, strategies in this setting and offer compelling solution concepts satisfying desirable normative criteria.

2.1 Nash Bargaining Solution

Bargaining theory addresses the question about how to distribute the surplus among the players. According to Nash (1953), bargaining means that each player has the right to be involved in a game or not. This is totally upon players' decision so that the game should be a mutually beneficial agreement for players.

For a two-person bargaining problem, in the feasible set $P \in \mathbb{R}^2$, Player 1 and Player 2 have utility functions u_1 and u_2, respectively. Disagreement payoffs of Player 1 and Player 2 are denoted by $t = (t_1, t_2) \in P$. This means that if bargaining fails, then Player i receives t_i.

In this bargaining problem, Nash imposes the following axioms: Pareto optimality, Symmetry, Scale Independence, and Independence of Irrelevant Alternatives (IIA). Given these five axioms, Nash provided the characterization of his bargaining solution as $\bar{u} = (\bar{u}_1, \bar{u}_2)$ which is found by the maximization problem below (Fig. 1).

$$(\bar{u}_1 - t_1)(\bar{u}_2 - t_2) = \max_{(u \in P)} [(u_1 - t_1)(u_2 - t_2)]$$

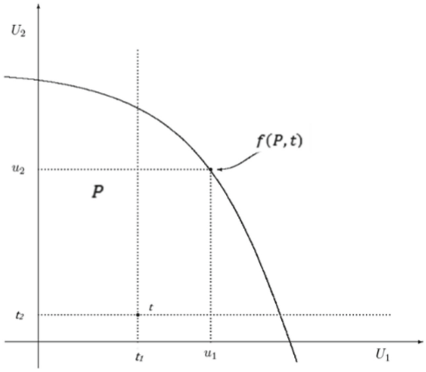

Fig. 1. Bargaining problem and its solution

2.2 Kalai-Smorodinsky Bargaining Solution

Within the scope of the Kalai–Smorodinsky bargaining solution (KSBS in short), the convexity is not a property required for the feasible set. However, we require a feasible set to be comprehensive. Kalai and Smorodinsky (1975) replace Nash's Independence of Irrelevant Alternatives with a monotonicity axiom, and they characterize another unique bargaining outcome. For each feasible set, the utopian point P_{max} is defined as the outcome that ensures the highest possible gains with the agreement. The solution can be found with these following calculation steps. First, disagreement point $t = (t_1, t_2)$ and then the utopian point u_{max} are found. Finally, by connecting $t = (t_1, t_2)$ and u_{max} with a straight line, we find our solution. These calculation steps are illustrated in the figure below (Fig. 2).

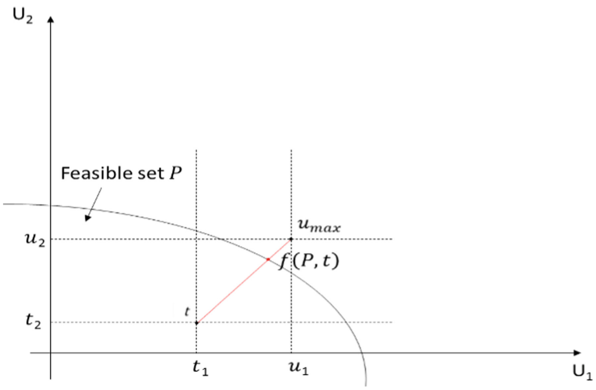

Fig. 2. Kalai–Smorodinsky bargaining problem and its solution

2.3 Weighted-Shapley Bargaining Solution

The Shapley value is a widespread solution concept in cooperative game theory that provides a unique allocation to players. It is considered as the main solution concept for cooperative games with transferable utility. The Shapley value allocates the value among the players according to their marginal contributions for each possible coalition.

One of the main axioms that characterize the Shapley value is symmetry. The underlying motivation for using this axiom is the assumption that except for the parameters of the games, the players are completely symmetric. If the two players cooperate, they can generate an incremental profit, which is to be divided between them. The Shapley value considers this situation as symmetric and allocates the incremental profit uniformly among the players. In some situations, symmetry can be unrealistic. For example, one player's effort may be needed more than another in some cases. Accordingly, Weighted-Shapley solution allocates positive weights for each player that sums up to one. Weights can be given exogenously, such that $w_1 + w_2 = 1$ (Fig. 3). In our study, we assign weights endogenously by the singleton worth of the players.

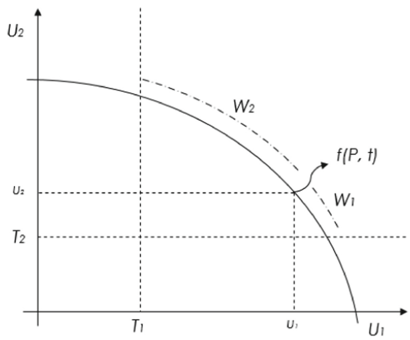

Fig. 3. Weighted-Shapley solution

3 Turkish Retail Electricity Market

Commercially electricity flows through deals or bilateral agreements between players. In the following figure, you can see the flow of the wholesale and retail electric market (Fig. 4).

In this study, we will divide the target customers group into three sub-target segments according to players' marketing and sales planning. In general, players design their sales activities according to customers' profiles and divide total customers into these three sub-segments. Because of the existing market and regulation conditions, high consumption customers are the target customer group for these two players. In this study, our target group is the customers who consume more than 1 million kWh. In the near future, it is predicted that the "Last Resort Tariff" limit will be leveled down to 1 million kWh. The customers consuming 1 million kWh generally consists of corporate customers, so the regulator does not intend to preserve from high electricity billing. For this reason, this

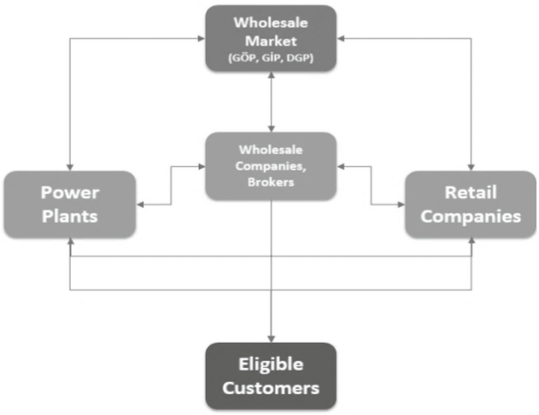

Fig. 4. Wholesale and retail electricity market

target customer group have to find their own retail company to avoid the high price of regulated electricity tariff. In addition to this, players do not have enough sales force to reach a large number of customer groups are not tend to try selling electricity to low consumption customers (Table 1).

Table 1. Target customer subgroups

	Sub target segment	Volume bands	# of customer	%	Volume (TWh)	%
Target customers	1	Over 50 GWh	1.004	0,002%	62.46	26,7%
	2	10 GWh–50 GWh	1.399	0,003%	33.42	14,3%
	3	1 GWh–10 GWh	17.817	0,041%	32.92	14,1%
		0 GWh–1 GWh	43.638.168	100,0%	104.75	44,9%
		Total	**43.658.388**	**100%**	**233.56**	**100%**

4 The Results

We reflect the relationships among the players by a game in value function form (N, v), where N denotes the set of players – Private Power Plant, Retailer – and the value function v: $2^N \to \mathbb{R}$ gives the payoff, which a subset of players $S \subseteq N$ can achieve (Table 2).

$$\text{Value Function: PM} = [\text{SP} - (\text{EC} + \text{FiT} + \text{IC} + \text{MOF} + \text{SF} + \text{DC} + \text{FC} + \text{OPEX})]$$

Sales price to the end customer is generally determined by the discount made on the ceiling price set by the Energy Market Regulatory Authority (EMRA). In this study, we will use the liberal LRT segment sales prices of the player that they implement in 2018

Table 2. Model parameters.

Symbol	Interpretation
PM	Unit Profit Margin (TL/MWh)
SP	Unit Sales Price (TL/MWh)
EC	Unit Energy Cost (TL/MWh)
FiT	Unit Feed-in Tariff Cost (TL/MWh)
IC	Unit Imbalance Cost (TL/MWh)
MOF	Unit Market Operating Fee (TL/MWh)
SF	Unit Spread Fund (TL/MWh)
DC	Unit Doubtful Cost (TL/MWh)
FC	Unit Finance Cost (TL/MWh)
OPEX	Unit Operational Expense (TL/MWh)

and 2019 year to date. We will calculate the sales price as (PTF + FiT) * (1 + X%). X% will change according to the customer segment that we mentioned above.

We will use the actualized monthly cost parameter of the leading examples of the players in Turkey in 2018 to calculate the value functions. Our players are three types of private power plants and retailers. In each game, we will match one type of power plant to the retailer. In this study, we assume the group of generation and retail companies as one sample player for the ease of calculations.

A two-person bargain problem consists of a feasibility set and a disagreement point. In our study, the feasibility set includes all possible payoffs of the coalition of two the players and the disagreement point is the singleton payoff of the players if negotiations break down.

We first define disagreement point t and find the utopian point P_{max} that is equal to the maximum level of profit that the Power Plant and Retailer cooperative can create. Then we determine the feasible set P that includes the points resulting from all different combinations of the coalition of Power Plant and Retailer (Table 3).

Table 3. Players' options

Type	Option A	Option B
Power plant	P_{max}(PP)	t(PP)
Retailer	t(R)	P_{max}(R)

They can also mix these options in arbitrary fractions. That is, they can choose Option A for fraction x of the time, Option B for fraction y, such that: $x + y = 1$. Hence, the set P of feasible agreements is the convex hull of A(P_{max}(PP), t(R)) and B(t(PP), P_{max}(R)).

For both Nash, and Kalai-Smorodinsky solutions, we have to normalize the agents' utilities by subtracting the disagreement values, since we are only interested in the gains that the players can receive above this disagreement point (Table 4).

Table 4. Players' options

Type	Option A	Option B
Power plant	$P_{\max}(\mathrm{PP}) - t(\mathrm{PP})$	0
Retailer	0	$P_{\max}(\mathrm{R}) - t(\mathrm{R})$

The Nash bargaining solution maximizes the product of normalized utilities:

$$\max\left([P_{\max}(\mathrm{PP}) - t(\mathrm{PP})]^{*}\mathrm{X}\right) * \left([P_{\max}(\mathrm{R}) - t(\mathrm{R})]^{*}\mathrm{Y}\right)$$

The Kalai-Smorodinsky bargaining solution equalizes the relative gains - the gain of each player relative to its maximum possible gain - and maximizes this equal value:

$$\max\left([P_{\max}(\mathrm{PP}) - t(\mathrm{PP})]^{*}\mathrm{X}\right)/[P_{\max}(\mathrm{PP}) - t(\mathrm{PP})] = \left([P_{\max}(\mathrm{R}) - t(\mathrm{R})]^{*}\mathrm{Y}\right)/[P_{\max}(\mathrm{R}) - t(\mathrm{R})]$$

The weighted Shapley value splits the value proportional to endogenously given weights of its members where the weights are found by the singleton worth of the players.

$$\begin{aligned}\omega(\mathrm{PP}) &= t(\mathrm{PP})/[t(\mathrm{PP}) + t(\mathrm{R})] \\ \omega(\mathrm{R}) &= t(\mathrm{R})/[t(\mathrm{PP}) + t(\mathrm{R})]\end{aligned}$$

The figures below show the unit in TL/MWh profitability (Figs. 5, 6 and 7).

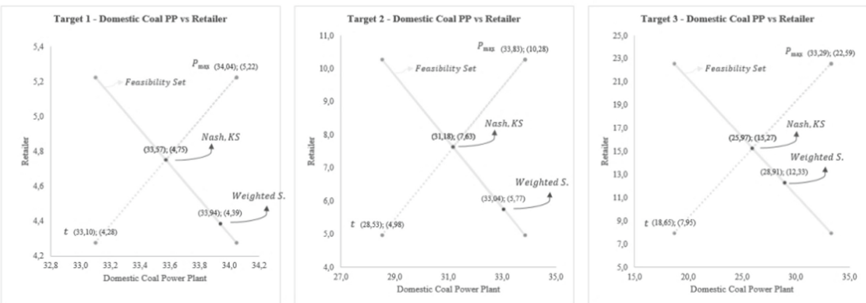

Fig. 5. Domestic coal power plant and retailer solution

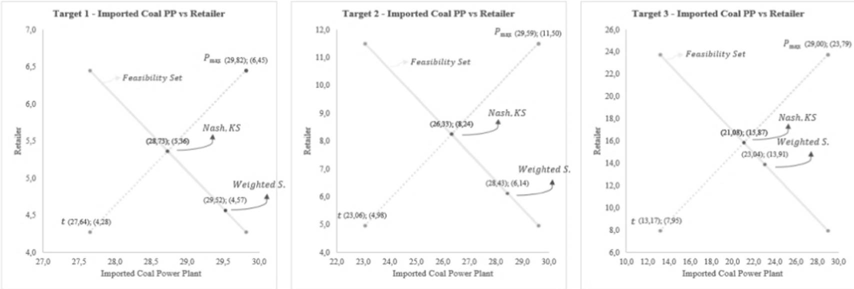

Fig. 6. Imported coal power plant and retailer solution

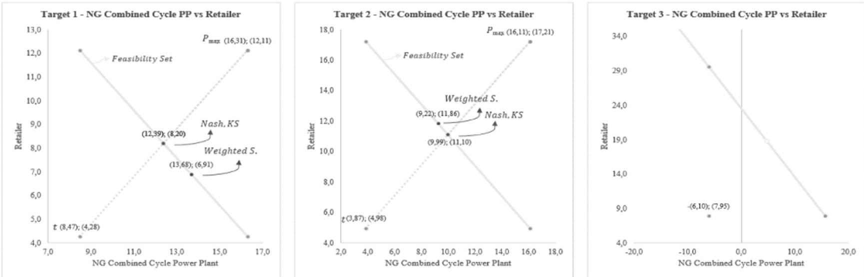

Fig. 7. Natural gas combined cycle power plant and retailer solution

The singleton value of the Natural Gas Cycle Power Plant is negative for the third target customer group. For this reason, it is unreasonable for the power plant to cooperate with the retailer.

Nash and Kalai-Smorodinsky solutions give the same solution for all games. Thus, the utopian point P_{max}, the disagreement point t are the diagonal point of a square. However, the weighted Shapley solution differs from these two solutions.

Given these nine cooperative games, three different subsegments, and three different power plants, we see that retailers have lower profitability than the power plants. Furthermore, the retailer's profitability is increasing when we go down to the bottom according to the consumption subsegment. Nash and Kalai-Smorodinsky solutions give a higher payoff to the retailers compared to the weighted Shapley solution.

5 The Conclusion

In this paper, we studied the profitability of the electricity service delivered to the end-user by using cooperative game theory and how to share the extra profit arising from the cooperation between the players.

First of all, we studied the Turkish retail electricity market by well-known cooperative game theory concepts such as Nash bargaining solution, Kalai-Smorodinsky bargaining solution, and weighted Shapley solution. Next, we analyzed the development of Turkish Retail Electricity Market. EMRA's electricity market tariff regime for the high consumption customers started a mandatory liberalization process which is an essential part of retail electricity development. Then we have identified the problem of the retail electricity market as a commodity business. For the solution of this problem, we suggest the cost-efficient way of a coalition of the player in which both players do what they do best. We consider different value functions to reflect three different types of power plant and retailer game for the three consumption segments. We see an extra profit to be shared between the players. To analyze cooperation opportunities between retailers and power plants, we apply three well-known solution concepts; two-person Nash bargaining solution, Kalai-Smorodinsky bargaining solution and weighted Shapley solution. While Nash and Kalai-Smorodinsky share the extra payoff by the same proportion, the weighted Shapley allocates the surplus non-symmetrically between two players according to their contribution to the coalition. These two different approaches –symmetric or nonsymmetric– can be regarded as two different means of cooperation. For example, if we think that the player cannot bring extra profitability without others, we should share it equally. Otherwise, the size of the singleton value should matter as well.

In terms of functionality, the retail sale of electricity is a financial activity. Electricity is a commodity and supplier, and customer deals on a financial agreement. The quality of the power is the same in wires that reach the customer meters. Suppliers have no chance to improve the quality of power. Thus, low-cost operation and targeted marketing is the only way to improve market share and profitability. Cost-effective energy sale organizations are competitive as they reflect the saving from cost to the price. Cost-effective operations in the retail electricity market can be achieved by the cooperation of the players complementing each other.

In this paper, the retailers step forward by their effective, low-cost sales operation and customer relationship management. On the other side, the power plants have the strength in power cost management. This complementarity generates an extra surplus. In theoretically, bargaining solutions divide the payoffs. We have to keep in mind that the process of the coalition will not be easy for the players. To sustain cooperation, the principle of transparency should be the main shared value for the players.

The applications of the cooperative game theory models in the retail electricity market will provide solutions to the companies that are subject to regulated tariff regime and market risk as well as the thermal power plants, which are challenged by the establishment of renewable power plants and nuclear power plants. While the extra profitability that will arise from the cooperation will benefit these two players in the short term, it will be transferred to the final consumers by increasing the number of bilateral cooperation in the medium-long term.

The decrease in demand for electricity is a possible macro risk for both retailers and power plants. Especially, it is a threat to most of the thermic power plants. If we consider this threat, forming a coalition is the only way for the survival of power plants. In Turkey, most of the power plants are under the credit burden. Therefore, uninterrupted and profitable production is essential for power plants' future financial health.

As an extension of our paper, one can study the effect of the benefits arising from bilateral cooperation on the consumer side. Another interesting direction of research would be incorporating electricity wholesalers, natural gas, and coal suppliers to our existing model.

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Open Data Availability and Suitability for Financial Analyses

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Abstract. The purpose of this study is to explore the benefits of Open Data initiatives for the financial sector. The first approach is to take the financial activities, to consider their data needs (in terms of data kinds and characteristics) and consider if they are available, and in a suitable format for these goals. Even though it has been done for some cases and applied to the case of Luxembourg, we are the first and foremost group to suggest and explain a systematic method, based on an Open Data literature review, to assess the dimensions characterizing the availability (not only the data accessibility, but also the conditions around this accessibility) and the suitability of the data (not only their existence but other dimensions of their accessibility, like licenses). Although the accessibility of financial, economic and commercial information is highly dependent on contextual legal and political frameworks, this framework is adaptable enough to be used for different countries, and even beyond the case of financial data. The last part is showcasing the importance of the title of this study for financial data in Luxembourg. This contribution intends to be useful both for people in charge of the Open Data initiatives in the public and private sectors; for practitioners and researchers aiming at reusing these data; and for Open Data researchers.

Keywords: Financial data assessment · Open Data · Open Government Data

1 Introduction

The increasing size and diversity of available data is the fundamental part of the digital economy, with the notion that data may be the new oil. Although it is excessive in its formulation, yet consistent with the larger and larger production and availability of data and with the emergence of concepts such as Big Data and the progress of computing architectures, allowing to build models based on large amounts of data. It is also essential for academic financial discipline and financial activities. The field is rapidly evolving since the financial crisis of 2007, with the consecutive evolving regulatory framework (for example to protect the general public from harmful financial products), the emergence

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of new business models around data provision, and technological trends such as cloud computing.

At the crossroads of these trends, Open Data may have a central position, as it is aiming to ensure the data availability as well as their publication in a suitable way for different kinds of reusers with different goals.

The main question addressed here is to explore the benefits of adopting the Open Data paradigm for financial data, as well as the conditions required to leverage these benefits and the obstacles to mitigate. This study intends to be useful for financial researchers and practitioners as they need to identify and characterize available data, and to (potential) data handlers aiming at publishing their data following the Open Data principles. If the main audience targeted are the people working with financial data, we are also contributing to the Open Data research through a topic lens, as it has been done for other domains, e.g., on judicial data (Marković and Gostojić 2018).

To address the question of open data availability and suitability for financial analyses, the first part is considering the intersections between Open Data research and financial data or, in other words, how Open Data is leveraged by financial literature and conversely: for which purpose, following which approaches. Consistently with the insights from the Open Data literature review, we propose a method as an evaluation framework, allowing characterization of the data about their availability and their suitability. This method is designed to be useful beyond the sole case of financial data. This framework is then applied to the financial data in Luxembourg, chosen as a case study.

2 Financial Data and Open Data Research

2.1 Financial Data

Finance at large is divided into personal, corporate & public finances, implying the leverage of different disciplinary perspectives and approaches, different regulation, objectives, and data. When this comes to the definition of the object that represents "financial data," there is no single and straightforward definition. It is why, even in textbooks, financial data are more often defined according to their properties ((Koop 2006), (Tsay 2010)), as they are constituting time series or cross-sectional data, or on very generic distinctions: quantitative, qualitative, historical or real time. For example, for corporate finance, financial data consist of pieces or sets of information related to the financial health of a business. The pieces of data are used by internal management to analyze business performance and determine whether tactics and strategies need to be altered. People and organizations outside business will also use financial data reported by the business to judge its creditworthiness, decide whether to invest in the business and determine whether the business in complying with government regulations.

On top of this, some data may be considered as belonging directly to the financial domain; finance is also and more using other types of data like corporate data or economic data at large. Moreover, finance research or practice are fruitfully using unstructured data, e.g., through the use of natural language processing technics. The book on financial information coordinated by Victoria Lemieux is well illustrating these issues (Lemieux 2013). It is leading to a deep heterogeneity of kinds and parameters, requiring relying on a broad definition of financial data to envision them from the lens of Open Data.

2.2 Financial Information Ecosystem and the Case for Open Data

Assessing the potential of the Open Data paradigm firstly requires considering how the financial information is currently accessed, and what kinds of ecosystems do exist around this information.

For a long time, financial information market was dominated by firms like Bloomberg and Reuters. The rise of Internet has led to the emergence of a large number of websites offering financial data more or less for free, but not always providing detailed information on the intellectual property dimension or the limitations opposed to the data reuse. Another issue of these offers is the absence of statements on the long-term access to the data, nor on the technical means offered to access the data. Even big players like Yahoo Finance and Google Finance can choose to discontinue their services and did it with their Application Program Interfaces (APIs). The discontinuation of these APIs, even if the data may remain accessible through other means, is hindering the automation of financial information processing and analysis. The release of the original raw data is a remedy against this issue, ensuring data availability on the long-term, even when the intermediary services disappear or decide to change their policy.

Another purpose of Open Data is also to increase the value creation from the re-use of the data, the business models (Magalhaes et al. 2014) have been explored by the literature, especially those based on data store (Boyd and Crawford 2012) (Pereira et al. 2018). According to these studies, Open Data should enable the emergence of new players on the market, lowering the entry cost and allowing various niche markets. A good illustration of these possibilities is the case of Quandl, which is showing at the same time the opportunity of Open Data to sustain a business model for a new player, and the associated limitations. This platform requires registration, even to access Open Data from third parties, which is allowed by some Open Data licenses not implementing the share-alike condition, the permanence which is not an issue as these data are remaining theoretically accessible from the original source. Another issue is the guarantee of permanence of the access to the data, an important concern for data citation - e.g., the data cited by (Ott 2014) - more for research than industry stakeholders. Open Data platforms, through policy and technical means such as (U.R.I) URIs, tend to better insure the data availability in the long term.

2.3 Open Data

There is a need to explain first what are Open Data and what are Open Data principles. Against a naive approach, Open Data is not equal to any kind of data that may be accessed for free at any moment on the Internet, without considering the potential restrictions. The actual definition is more binding and is based on few but strong pillars.

Even if the sources of Open Data are much older, rooted both in the concept of freedom of information and transparency – required component for a functional market - and in the principles of scientific inquiry (e.g. reproducibility), Open Data itself got some attention and application after the launch of an Open Data initiative by the United States government in 2009. According to the definition suggested by the Open Knowledge Foundation, “Open data is data that can be freely used, re-used and redistributed by anyone - subject only, at most, to the requirement to attribute and share-alike” (Open

Knowledge Foundation 2013). Open corporates (Gkatziaki et al. 2017) and Open Banking (Brodsky and Oakes 2017) may also be considered as subsets or cognates of Open Financial Data. Echoing the common distinction between three kinds of finance, (Davies and Perini 2016) identifies three kinds of data at large: “Data about governments; Data about companies and markets; and Data about citizens.”

The purposes of Open Data are to impact all the sectors for political, social, and economic impacts. For the latter, Open Data is a mean to foster innovation and to ensure a trusted environment leading to risk mitigation where one may re-use the data without any legal concern and so to ensure fair use. One purpose of the Open Data initiatives is also to strengthen the trust (Omole 2017) of the re-users in the data provided on the platforms, on the ways used to deliver these data and in the relationship between the data provider and data re-user;

Open Data, although it is for the moment mainly applied to public bodies, especially governmental ones, is not limited to the public sector: Open Government Data is only one subset. Indeed, there are many other applications: scientific data, data held by private bodies but related to or coming from public interest duties or activities, and private Open Data at large, where (mostly) companies commit to open their data, either to just comply with a legal binding, or to be engaged in an Open Innovation (Chesbrough et al. 2006) strategy.

2.4 Use of Open Data to Get Financial Insights

A large part of the interest brought to Open Data is related to different research topics than the usual ones in financial activities. Because of its roots, Open Data literature also tends to focus on e-government (Pina et al. 2010) and on political and democratic impacts. In this perspective, financial data shall be released as a tool to ensure the transparency (Lemieux et al. 2014) and then the accountability of government (Pina et al. 2010), or its agencies (Tunney and Thomas 2015). To ensure the transparency of governments and their accountability, research focuses on the analysis of data about government contracting (Parkhimovich and Minina 2017) and government spending (Hartog and Mulder 2017) at large. Some portals, especially in the Anglo-Saxon world, are dedicated to accountability, aiming at providing citizens the means to check how their taxes are spent, this is, for example, the case described by (Paige 2017).

This trend is not only aiming at government bodies, but also at other sectors, either they are benefiting from public spending (e.g., non-profit organizations), they are regulatory asked to do so, or following their own will (Gkatziaki et al. 2017). For the case of Non-Profit Organizations (NPOs), (Marshall et al. 2016) are showing the limits of the currently public opened datasets in the UK, which structure is not suitable to get a deep understanding of how this sector is functioning, and also implying interoperability issues.

Another important research stream is related to the Linked Open Data approaches (Vafopoulos et al. 2017), which are at the crossroads of Open Data and semantic technologies, especially to suggest alignment methodologies through the use of ontologies (Najdenov et al. 2014), (Li et al. 2011). These approaches are dealing with the structures and semantics concerns about the available data and the ways to make them interoperable (Gkatziaki et al. 2017). More generally, these studies intend to enable the standardization of financial data (Cavanillas et al. 2016) (Lemieux 2013), especially around the XBRL model, a prerequisite for the emergence of big and comparable datasets.

From the financial standpoint itself, the potential of Open Data has been examined as input for a broad range of topics. At the global scale, financial Open Data have been considered for commodities markets (Giles 2017), to analyze price volatility (Ott 2014), to make stock price prediction (Leung et al. 2014), or to characterize systemic risk (Song 2016) and predict economic crises (Palasca and Jaba 2014).

Open Data is also used to make analyses at the scale of companies' finances, for example, for monitoring companies development (Kapkaev and Sorokin 2018), or assess the credit risk (Mei 2009). A large data availability as well as the development of concepts and tools to use it (Flood et al. 2016) may lead to the emergence of new methodologies, the application of existing concepts at different scales and the development of new questions, similar to what has happened in the Sciences with the Fourth Paradigm (Hey et al. 2009). As an example, it may be illustrated by the increasing importance of the so-called macro-prudential supervision (Flood et al. 2013), and Open Data is one component required to develop this trend: data availability and associated tools are creating "a natural role for a macroprudential supervisor to monitor the evolution of the counterparty network as a whole" beyond the traditional micro-prudential approach. Open financial data have also been used to assess banking performance (Akhisar and Karpak 2010) and bank failures (Canbas et al. 2005). For the latter, the authors use Open Data and show, as it is leading to the provision of more information more conveniently, its contribution to decreasing the data gathering costs – and more generally the cost of banks' monitoring, to increase the number and the quality of the risk analyses, and finally to reinforce trust.

What is showing these insightful albeit limited studies is that Open Data impacts and motivations are not limited to the principles, but that the mere application of these principles can increase the financial analysis efficiency. Still, these insights are somewhat scattered: the purpose of the next part is to design a global framework based on the current Open Data literature with the purpose to analyze the available data relevant for financial analysis.

3 Assessment Framework

The framework below is designed after a literature review of Open Data research. It is based on the works assessing the consistency with Open Data definition and principles (Kučera et al. 2015), on the assessment of data openness, on data quality, especially those synthesized in (Vetrò et al. 2016) and (Máchová et al. 2018), and on data release prioritization, considering academic publications and reports. For most of them, these frameworks are sharing a common focus on the data publisher. What is also need is to adopt a re-user perspective, to assess the suitability of these data for downstream activities. Almost all the points are already covered by merging the insights from literature and the various frameworks already published. The main contribution of this framework is to deeper introduce the needs of the re-users and to take into account the nature and the needs related to financial data and analyses, that is why some indicators are completed and some are added. For each point, a short definition is provided as well as, when there is one, the best reference from the literature.

It may be interesting to apply metrics to get a scoring of each dataset against each criterion, for example, through Likert scales or as percentages of data matching a criterion against the whole data set. However, these metrics depend on the context, they shall have a different weight depending on the perspective of each reuser: a limited license is forbidding by design a commercial reuse; for other needs, a low number of rows or a low temporal coverage availabilities may prevent the use of certain technics, such as neural networks (Table 1).

Table 1. Framework to analyze financial data availability and suitability

1.	Data availability	1.1. Availability; Possibility to access the relevant data; (OpenDataMonitor 2015)
		1.2. High-level usability; Kinds of processing required to use the data; (Oviedo et al. 2015)
		1.3. Cost; Data are provided for free, or at the marginal cost; (Share-PSI 2016)
		1.4. Size; Size of the data, the number of rows and dimensions as well as the is documented and fitting the requirements of a given purpose
		1.5. Raw data; The raw data are accessible
		1.6. Completeness; Data is analyzable without accessing additional information; (Charalabidis et al. 2018)
		1.7. Availability in the long-term; Data provider is ensuring the long-term availability (and accessibility) of the data through policy or technical means
2.	Semantics	2.1. Vocabularies; Data are respecting a vocabulary, especially a standardized one; (W3C 2017)
		2.2. Model; Data are structured following a documented model, preferably a standardized one; (Abella et al. 2014)
		2.3. Semantic coverage; Data semantics are fitting the requirements of a given purpose; (Oviedo et al. 2015)
		2.4. Semantic granularity; Data are provided at the scale convenient for a given purpose; (Oviedo et al. 2015)
		2.5. Temporal coverage; Data are provided at the convenient time-windows for a given purpose; (W3C 2017)
		2.6. Temporal granularity; Data are provided at the convenient granularity for a given purpose; (W3C 2017)
		2.7. Spatial coverage; Data are provided at the convenient geographic area for a given purpose; (Abella et al. 2014)
		2.8. Spatial granularity; Data are provided at the convenient granularity for a given purpose; (Abella et al. 2014)

(*continued*)

Table 1. (*continued*)

3.	Data access and identifiers	3.1. Data discoverability/findability; Data are exposed on a platform a website and indexed (see also data documentation); (Share-PSI 2016)
		3.2. Direct access to the data; Data are provided immediately and without the obligation to register; (Abella et al. 2014)
		3.3. Bulk download; It is possible to download the whole dataset in a request; (Oviedo et al. 2015)
		3.4. Single URLs; Single consistent URL for downloading data; Open Data Institute 2013)
		3.5. URI; Each data set has a unique identifier; (W3C 2017)
		3.6. (Documented) API; Data may be accessed through API; (W3C 2017)
4.	Data documentation/metadata	4.1. Metadata; The data are documented by a consistent and relevant set of information; (Charalabidis et al. 2018)
		4.2. Machine-readable metadata; Metadata are machine-readable; (OpenDataMonitor 2015)
		4.3. Metadata vocabularies and standards; Metadata is respecting a documented vocabulary, preferably a standardized one; (W3C 2017)
		4.4. Data provenance; The processing stages from raw data as well as the relevant stakeholders are documented at least at a high-level; (Oviedo et al. 2015)
		4.5. Data versioning; The versions are documented and remain accessible and referenceable; (W3C 2017)
		4.6. Skills; Statement on the skills (technical or conceptual) required to understand and process the data
		4.7. Feedback mechanism; Data documentation is including a mean to collect feedbacks; (Open Data Institute 2013)
5.	Data formats	5.1. Machine-readable formats; Data formats are machine-readable, e.g., CSV instead of a table in a PDF document; (OpenDataMonitor 2015)
		5.2. Open formats; Data formats are respecting the Open Source principles, and are documented (Abella et al. 2014)
		5.3. Standardized formats; Data format is respecting a standard; (W3C 2017)

(*continued*)

Table 1. (*continued*)

6.	Data quality	6.1. Timeliness; Data are provided at a convenient time for a given purpose (including real-time); (Charalabidis et al. 2018)
		6.2. Accuracy; Data is accurate enough for a given purpose; (Oviedo et al. 2015)
		6.3. Consistency; Data fields and data sets of same kinds are displayed consistently; (Charalabidis et al. 2018)
		6.4. Updates; Data is up-to-date; (Oviedo et al. 2015)
		6.5. Quality documentation; Quality issues are evaluated and documented; (Open Data Institute 2013)
7.	Legal	7.1. Ownership; Owners of the data are clearly identified; (Charalabidis et al. 2018)
		7.2. Legal statements; Clear rights statement are expressed, detailing rights issues; (Open Data Institute 2013)
		7.3. Constraints; The constraints are consistent with Open Data principles, allowing re-use with the lowest barriers; (Charalabidis et al. 2018)
		7.4. Privacy; Privacy issues are clearly expressed, with the ways to overcome them; (Charalabidis et al. 2018)

4 Application to the Financial Data in Luxembourg

The framework has been used for Luxembourg, considering the requirements for different financial activities from the different branches of this discipline. This framework helped to discriminate the strong and weak points for each kind of Data.

Because of the legal commitments, there is good coverage for a large part of public finance. The related data are published on the national Open Data platform, https://data.public.lu, which is providing most government data, that is data collected by the government during its activities, for example, the government budget is published on the national Open Data platform since 2016. However, there are no data concerning the contracts signed by the government, but only aggregated data from the budget perspective.

The legal framework – the European Directive transposed in Luxembourg - and the implementation of the best practices lead to a good quality for the indicators directly related to Open Data: the centralized platform is ensuring a convenient discovery of the data, the metadata are standardized and consistent, the formats are machine-readable and open for most of them, and there are no legal obstacles to the reuse of data. If the data are following a consistent model, they are displayed at a very aggregated level, convenient for the work of government, but not providing detailed and massive data that would be required to use tools such as those based on neural networks.

Personal finance data are showing an intermediate case. Personal finance data are, in essence, very fine-scaled data about individuals or households, and therefore constitute personal data, ruled by the privacy regulation. One of the ways to use these data can be compared to the principles of Open Banking (Brodsky and Oakes 2017), whose objective is both to determine mechanisms that will allow individuals or households to directly benefit from the benefits of Fintechs. It is not clear however how Open Banking, which is at its very early stage in Luxembourg, will match at least partially the requirements of Open Data, or if it will be limited to the banking system stakeholders. Until now, none of these data is currently available. At the statistical scale, following its duties to monitor the economic and social conditions of the country, the national statistical agency, STATEC, is publishing data based on personal finance, but aggregated at the scale of the population. It is leading to figures based at the finest one month, making these data closer to what is considered as economic data. Like public finance data, these data are published suitably from the Open Data principles perspective. However, they are raising an issue concerning their semantic granularity, limiting both the kinds of research questions or financial services that could be built, as well as the applicable tools.

Corporate and market data are the case the least favorable case concerning Open Data. Like personal finance, some data are available at the statistical scale. Excepted these data, the information is highly fragmented, depending on the organizations in charge of their collect. The business registry is providing some amount of data for free, but these data do not fulfill the other criteria, for example, the machine-readability criterion. Stock exchange data are showing the same limitations. The platform is not directly providing high-frequency data, and if the website is displaying data that might be easily scraped, the website owner is forbidding it. It means that for most of the financial analyses in this domain, and even if the data may be accessed under different rules, the approaches may not be implemented nor reproduced while satisfying the conditions of the Open Data paradigm.

5 Conclusion

This study is firstly providing a methodological contribution to analyze financial data based on the Open Data paradigm and taking into account the needs of financial discipline and practice.

The case of Luxembourg is showing that there is a contrast between an industry relying on a large consumption of data and information and making it the basis of its business, and the low uptake of Open Data in this domain. Some issues are more hindering depending on the kind of user: business reusers are more affected by license restrictions than researchers who are benefiting from exceptions, some are affecting all the reusers like a bad semantic granularity. This framework intends to be useful to get a quick statement on the applicability of a methodology or a tool based on the characteristics of the available data.

Available data, by far, are not coinciding with the definition of Open Data. It calls for a better explanation of Open Data outside government, first and foremost to institutions whose duty is to provide these data, but also to companies who would like to engage in an Open Data policy, for example aiming at benefiting from Open Innovation externalities.

Unsurprisingly, the best level of data availability and quality is reached by public finance data. However, even for these data, we showed some limits, some in terms of availability, more in terms of suitability, preventing at least partially their reuse. This may be explained from the semantic and temporal granularity perspectives: data released by the government, mostly because of their statistical nature, are at the scale of the year, whereas a lot of financial questions consider a day or intraday scale. This dissonance is preventing the use of innovative concepts, mostly because the statistical view is providing rare data from the perspective of neural network approaches, hence the need to turn to solutions suitable for this scarcity. This framework may help stakeholders in charge of the data release to better align their publications with the needs of re-users when it is possible. The identified issues are showing the interest of applying an Open Data paradigm to financial data indirectly, that may be a lever to increase the availability of data, their discoverability, and their quality.

The lack of data availability and suitability is preventing a part of the commercial uptake. The current financial ecosystem is nevertheless showing the potential of increased data availability, where the data brokers could continue and develop their business models while the long-term availability of a set of raw data would be guaranteed.

Assessing data availability and suitability is of paramount importance for Open Data re-users, who have to assess the data in a fast and reliable way, and for decision-makers for whom automation is a key concept to lower the costs induced by Open Data policies. Building on state-of-the-art works on automatic data quality assessment, further work will implement a tool allowing to score datasets against this framework, taking into account not only Open Data strictly speaking but Open Data candidates' datasets, considering both metadata and data contents.

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The Moderating Effect of Long-Term Orientation on the Relationship Among Human Capital Research, Business Sophistication, and Knowledge & Technology Outputs

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Abstract. National level innovation is one of the outstanding locomotive factors for both economic and business growth. Global Innovation Index (GII) is one of the most commonly used indices in this context. Furthermore, the innovation level of countries is affected by cultural dynamics. Hofstede's Cultural Dimensions (HCD) is one of the prominent guidelines on cultural dynamics. In this study, human capital & research (HCR), business sophistication (BS) and knowledge & technology outputs (KTO) are addressed to analyze the relationships among them. Moreover, long-term orientation (LTO) factor from HCD is considered as a moderator variable. This study aims at examining the relationships between HCR-BS and BS-KTO and exploring the moderating effect of LTO on these relationships. For this purpose, a conceptual model was proposed to explore these relationships. Structural Equation Modelling (SEM) was performed to conduct path analysis by employing 86 data from official web sites. The results show that hypotheses related to GII factors are supported, and a moderating effect of LTO is observed on the relationship between BS and KTO. These findings pointed out that shortterm oriented countries are more successful in transforming knowledge into outputs. Furthermore, policymakers and innovation managers should consider time-oriented cultural values while planning to gain knowledge and technology outputs.

Keywords: Global Innovation Index · Long term orientation · SEM · Moderating effect

1 Introduction

Country-level innovation has become a salient issue in recent years. To evaluate the innovation level of countries and compare them, many global organizations have created indices. Well-known examples of these indices are the Innovation Union Scoreboard (IUS), the European Innovation Scoreboard (EIS), the World Economic Forum (WEF), and Global Innovation Index. The main aim of these indices is to evaluate and rank the

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innovativeness of countries based on predefined factors. Among them utilizing input and output indicators of innovation during the assessment and including countries from all over the world, GII comes into mind at first sight. The first GII was conceived in 2007 by INSEAD as a tool to sort out how countries cope with the challenge of innovation. Each year, GII adopts a new theme regarding new trends and concepts in innovation and publishes GII yearly report, including evolving indicators since the nature of innovation. This year, there are 102 sub-indicators with 127 countries in the GII 2017 report. The GII consists of two sub-indices: the Innovation Input Sub-Index and the Innovation Output Sub Index. The Input Sub-Index score is the simple average of the first five pillars: institutions (INS), human capital and research, (HCR) infrastructure (INF), market sophistication (MS) and business sophistication (BS). Additionally, the Innovation Output Sub-Index is the simple average of the last two pillars: knowledge & technology outputs (KTO) and creative outputs (CO). Each sub-index score ranges between 0–100, and the final index score is gained by the simple average of sub-index scores (The Global Innovation Index 2017). In this study, two factors from the Innovation Input Sub Index (HCR and BS) and one factor from the Innovation Output Sub Index (KTO) are taken into consideration. Human capital & research include education, tertiary education, and research & development (R&D) sub-factors. Moreover, business sophistication comprised of knowledge workers, innovation linkages, and knowledge absorption. Knowledge & technology output is divided into three sub-factors: knowledge creation, knowledge impact, and knowledge diffusion.

Furthermore, national culture is a significant point that should not be ignored while exploring the innovativeness of countries. Since society is based on behaviors and attitudes of individuals, the culture of societies is expected to moderate innovativeness. Hofstede and colleagues define culture as "the collective programming of the mind that distinguishes the members of one group or category of people from others" and claims that it is the unwritten rules of the social game (Hofstede et al. 2010). Researchers have studies cultural dimensions i.e., Hofstede and Bond (1984) and Hofstede et al. (2010); Schwartz (1994); House et al. (2004); Trompenaars and Hampden-Turner (2011); eventually, Hofstede's framework is adopted more than other studies mentioned above (Beugelsdijk et al. 2015). Hofstede and his colleagues proposed six dimensions of culture: individualism versus collectivism, large versus small power distance, strong versus weak uncertainty avoidance, masculinity versus femininity, long-term orientation versus short-term orientation, and indulgence versus restraint. Additionally, scores of Hofstede's cultural dimension range between 0–120, and preferred to use normalized values between 0–100. Furthermore, each country has its scores for each dimension, and all dimensions are evaluated separately; no integration is needed in HCD. In this study, long-term orientation versus short-term orientation dimension is addressed. Hofstede and his colleagues define long-term orientation as "the fostering of virtues oriented toward future rewards—in particular, perseverance and thrift" and short-term orientation as "fostering of virtues related to the past and present—in particular, respect for tradition, preservation of "face," and fulfilling social obligations" (Hofstede et al. 2010). In other words, long-term orientation represents "future," whereas short-term orientation stands for "now and past" (Hofstede 1991). Since these concepts are evolving, many researchers ultimately have started to use LTO to refer a holistic way of the future and the past rather than valuing the effects of actions here and now (Bearden et al. 2006). Societies scored high in LTO share values are such as giving importance for learning from other countries, having a large saving quote, and appealing of knowledge and education (Hofstede et al. 2010). Moreover, Bearden and his colleagues stated that individuals in LTO societies esteem planning, hard work for future benefit, tradition, and perseverance (Bearden et al. 2006). In this paper, we explored if the human capital & research activities affect business sophistication while business sophistication impact on knowledge & technology outputs. Additionally, another curiosity was if LTO has a moderating effect on the relationships between human capital & research activities and business sophistication; the relationships between business sophistication and knowledge & technology outputs or not. Summarily, the primary purpose of this study is analyzing the relationships among selected factors of GII and examining the moderating effect of long-term orientation on these relationships. This paper contributes to the literature by exploring the relationships among factors chosen of GII and investigating the moderating effect of LTO on these factors. Policymakers of countries and innovation managers of companies could consider these findings while making decisions concerning country-level innovations.

The organization of this paper is as follows. Section 2 presents model development and hypotheses. In Sect. 3, data and methodology are introduced. Analyses and results are mentioned in Sect. 4. Finally, discussion and conclusion are expressed in the last section.

2 Model Development and Hypotheses

Innovation studies at the firm-level based on system approach have been done saturatedly while national-level innovation researches have not been done satisfactorily. Primarily, papers inspired by the relationships among the factors of GII are rarely addressed in the literature. One of the prominent studies regarding this subject is Sohn and his colleagues' work that is proposed a model investigating the relationships among seven main factors of GII (The Global Innovation Index 2017). They introduced a relationship between HCR and BS and found that HCR has a positive effect on BS. Furthermore, although they proposed a relationship between BS and KTO, they could not find a meaningful relationship between them. The motivator of this study is to explore the transformation process from human capital & research activities through business sophistication to knowledge & technology outputs. Additionally, another curiosity was if countries have higher scores in LTO are more successful at transforming innovation input factors into innovation outputs.

Based on Sohn and his colleagues' work (Sohn et al. 2016), we proposed a model as seen Fig. 1 and developed the following hypotheses:

H1a: Human capital & research has a positive effect on business sophistication.

H1b: Long-term orientation has a moderating effect on the relationship between human capital & research and business sophistication.

H2a: The business sophistication has a positive effect on knowledge & technology outputs.

H2b: Long-term orientation has a moderating effect on the relationship between business sophistication and knowledge & technology outputs.

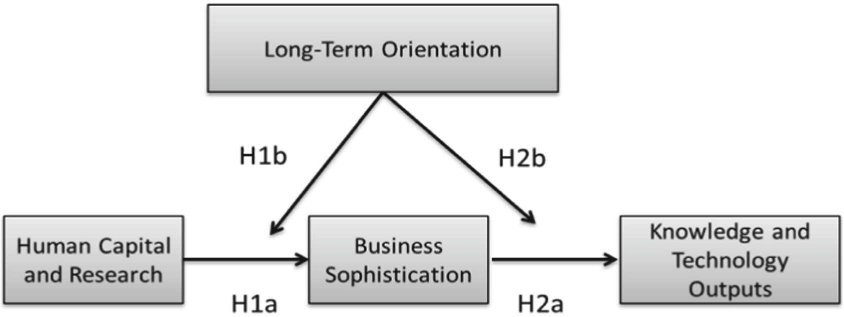

Fig. 1. Research model and hypotheses

3 Data and Methodology

In this study, secondary data gathered from the Global Innovation Index and Hofstede's Cultural Dimensions were used. Furthermore, GII factor scores range between 0–100, and these factor scores are gained by the average of sub-factors. Similarly, the LTO factor of HCD covers the same interval. To analyze the relationships among factors, we used factor scores gained from indices. Moreover, a matching step was conducted by eliminating countries that are included in only GII or HCD since a different number of countries is handled in these indices. Analyses were conducted based on 86 remained countries. To calculate the coefficients, GoF values, and other relevant results, path analysis was conducted by employing SEM methodology via AMOS software. Moreover, the GoF index helps to understand the acceptability of any SEM model, and researchers can report various GoF measures (Hair et al. 2010). Most widely, the GoF indices reported by AMOS users such as $\chi 2$/df, GFI, AGFI, and CFI will be present. Additionally, we made moderator analysis by using "Stats Tools Package" developed by Gaskin (2016).

4 Analyses and Results

We built a path model based on the hypotheses previously mentioned. After employing the model by using AMOS, the coefficients of relationships, and p values in Table 1 were obtained. Our hypotheses regarding relationships (H1a, H2a) are supported. Additionally, positive relationships among factors of GII have been found. Moreover, GoF measures in our analysis are (χ^2/df = 0,396; GFI = 0,997; AGFI = 0,981; CFI = 1,000) greater than cut-off values, and these GoF measures provide sufficient model fit (Hair et al. 2010).

Table 1. Coefficients and p values

Relationships	Estimate	P
BS ← HCR	0,723	***
KTO ← BS	0,919	***

Notes: *** p-value < 0.01

Furthermore, the data was divided into two categories as low level and high level by taking the average value of LTO scores of countries into consideration as a threshold to perform moderation analysis. Group differences were employed to explore the moderating effect of LTO on the relationships among factors mentioned above by using "Stats Tools Package." Table 2 shows that the moderating effect is observed on the relationships between BS and KTO while there is no moderating effect on the relationships between HCR and BS contrary to our expectations.

Table 2. Results of moderating effects

	Low		High		
	Estimate	p	Estimate	p	z-score
BS ← HCR	0,763	0,000	0,763	0,000	−0,955
KTO ← BS	0,737	0,000	0,737	0,000	2,046**

Notes: *** p-value < 0.01; ** p-value < 0.05

5 Discussion and Conclusion

The primary purpose of this study is to investigate the relationships between HCR-BS and BS-KTO and explore the moderating effect of LTO on these relationships. Few researchers have studied the relationships among GII factors, yet cultural dimensions' moderating effect on these relationships has been missed in the literature. To fill the gap, this paper contributes to the literature by validating a conceptual model, including a moderating effect of LTO. The results indicate that our hypotheses are supported, which means HCR has a positive effect on BS, and KTO is also positively affected by BS. In other words, the countries that pay more attention to education and R&D activities are more successful in absorbing knowledge and setting up innovation linkages by knowledge workers. At the same time, this success conveys countries to create knowledge and technology outputs. Moreover, Moderating effects of LTO on the relationships between BS and KTO indicate that the countries with low LTO scores transform knowledge into outputs. On the other hand, there is no moderating effect between level of LTO on the relationships between HCR and BS. It refers that countries' approaches, whether long term or short term oriented, do not make any differentiation on transforming human capital into knowledge. These findings give a strategic viewpoint to policymakers to evaluate their national innovation system. They should be aware of the importance of cultural dynamics during the transformation process of knowledge to outputs.

Even though this study contributes to the literature by proposing a validated model, including one dimension of culture as a moderator, it has several limitations. First of all, only data from 86 countries are used due to available data on both GII and LTO dimension of HCD. Secondly, employed data of GII factors is from 2017. Therefore the results are from only one cross-section since each year countries have different scores. Although there are some limitations, research findings offer a base for future research. For example, the whole factors of GII can be analyzed together. Moreover, each Hofstede's Cultural Dimensions can be added to the model as moderator. Furthermore, the model may be generalized by utilizing data of each accessible year.

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Analysis of the Relationship Between Strategic Management Application and Innovation Level

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Abstract. The purpose of this study is to question whether the level and dimensions of strategic management implementation affect the innovation level of the enterprise. Some situations created by strategic management (such as abundance, institutionalism) provide a healthy development environment in terms of innovation. Environmental scanning has been shown to support service innovation positively and powerfully. In this study, the level of strategic management applications not only impact on the type of innovation but also impact on all types of innovation were investigated. For this purpose, data obtained from 88 managers from various sectors were analyzed and interpreted by using survey method. As a result, a positive relationship was found between the strategic management level and innovation. It was found that the most important strategic management application level indicator affecting all types of innovation is environmental scanning intensity, planning horizon, and strategic control. Other indicators of the level of strategic management implementation, the flexibility of the strategic plan, and the level of participation in the preparation of strategic plans and innovation level of the enterprise could not be determined.

Keywords: Strategic management · Innovation

1 Introduction

Strategic management, which has always existed in the second half of the 20th century, but has not been scientifically studied, helps companies draw their routes in a professional sense (Güçlü 2003). One of the most important concepts today is innovation. Innovation refers to the fact that enterprises implement new applications in factors such as product, service, process, marketing, and organizational structure, thus maintaining their existence and making a profit above the average (Balzat 2002). When it is first heard, ‘innovation’ brings to mind the differentiation strategy by evoking the idea of developing new products, but companies that follow a cost leadership strategy can also reduce their costs and increase their profits by innovating in their processes, organizational structures, and marketing techniques. Therefore, innovation is essential for every enterprise to strengthen its position in the competition and it is a sine qua non for consumers because it provides advantages such as buying new products and services and getting existing ones cheaper.

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2 Strategic Management

According to Güçlü (2003), strategic management emerged in the second half of the 20th century. It means distributing resources for purposes such as regulating relations with the environment and competing with competitors. The main task of strategic management is to think through the mission of a business from start to finish and say, 'What is our job, what should it be?' by asking the questions, in line with the determined objectives, to ensure that the decisions given tomorrow results (Güçlü 2003). According to Ülgen and Mirze (2014), strategic management is not the management of the daily and ordinary business of an enterprise, but the management of the business that will keep the business alive by bringing competitive advantage and profit in the long run.

According to Akgemci (2015), the definition of vision, mission, and values in a business is the first step of the strategic planning process, and the concepts that will guide the business are these concepts. Vision can be defined as the 'situation in which businesses wish to be in the future.' The vision expresses the future situation but does not tell us how to achieve this, what tools to use. When determining the vision of businesses, sometimes a single vision, they can create different visions according to the region or country. When determining the vision statement, attention should be paid to being comprehensive, not as clear or as impossible as imagination. The mission is 'a document that contains the principles and common values necessary for the achievement of the vision of the cause of the organization' (Akgemci 2015). In short, the reason for the existence of the institution can be called.

According to Ülgen and Mirze (2014), the objectives and targets should be determined to ensure the assessment and evaluation of the enterprises by guiding their strategies after determining their vision and mission. The objectives will be able to identify the 'why' and 'how much' the business can do and enable performance evaluation. The goals and objectives are precise and measurable and are the quantitative form of vision within a certain time. Business objectives should be 'realistic, clear, and measurable.' The objectives of the enterprise can be divided into economic and non-economic. Economic objectives are quantitative measures such as profitability, growth, and continuity; non-economic objectives are measured by social and cultural values.

3 Innovation

Innovation is one of the most frequently encountered concepts in the business world of the 20th century. According to Elçi (2006), innovation is the process of continually changing, differentiating, and renewing companies' products, services, and business methods to keep pace with the rapid change in the competitive environment. Innovation can be defined as new products, production techniques, organizational structures, and services (quoted from Schumpeter (Balzat 2002)).

Innovation can be applied to companies in various aspects and can be divided into classes. Innovations can be made in products, services, distribution channels, processes, design, and marketing methods. Another classification of innovation is revealed by questioning whether technology is involved: 'technological innovation' or 'non-technological innovation.' Also, considering the magnitude of the change brought about by innovation, innovation can be divided into 'radical' or 'incremental' (Elçi 2006).

Without innovation, differentiation capacities of firms in the target market will be insufficient, and their chances of adding premium over price to their products and services will decrease (Mazzarol and Rebound 2009). Therefore, innovation is essential for an enterprise to gain a competitive advantage and maintain its competitive position. Businesses can pursue two strategies in competition: cost leadership and differentiation strategies (quoted from Porter (Mazzarol and Rebound 2009)). Small businesses use a focus strategy that can be considered as a sub-section of these two main strategies and gain a place in the market for themselves. Innovation plays an important role in protecting these places. For example, process innovation is the method that cost-competitive firms will use to outperform their competitors. The companies that pursue a differentiation strategy try to produce new products or develop existing ones through product innovation.

Product innovation refers to a significant change in the new product/service or futures or usages of the product/service (Mortensen and Bloch 2005). The success of this innovation is that new product-service is demanded by customers, marketable, sellable, and applicable (Yavuz 2010). Product innovation is the building block of value creation (Visnjic et al. 2014). When nurtured by technological change, this 'creative destruction,' combined with risk-taking and ambition to act under uncertainty, destroys existing value, replacing it with new and superior value. It is only necessary to involve the product itself in innovation, but it is not enough (reports from Chesbrough and Rosenbloom (Visnjic et al. 2014)). It should, therefore, be supported by appropriate business models. Product innovation is of vital importance for companies in dynamic environmental conditions where product life cycles are increasingly shortened (Slater et al. 2013).

Process innovation is the use of a new production or delivery system or the implementation of greatly improved production or delivery methods. These innovations consist of significant changes in techniques, technology, equipment, or software (Mortensen and Bloch 2005). As Yörükoğlu (2000) mentions, while product innovation is related to new products, process innovation helps to produce outputs with less input. Process innovation also referred to as developing a new production method, is an important factor affecting the firm's competitiveness. Because process innovation not only increases productivity in production but also improves quality (Un and Asakawa 2015).

Marketing innovation is the implementation of a new marketing method that involves significant changes in product design or packaging, product placement applications, product promotion, or pricing. Marketing innovations are aimed at better meeting customer needs, opening new markets, or repositioning the product in the market to increase sales (Mortensen and Bloch 2005). An example of marketing innovation is the first time product placement in television programs (Supporting Innovation in SMEs 2015).

Organizational innovation is the introduction of new organizational methods in business applications, workplace organizations, or external relations. As a result of organizational innovations, it is aimed to reduce direct or indirect costs, increase productivity by increasing employee satisfaction, and access to non-commercial assets. As with other types of innovation, the difference between organizational change and organizational innovation lies in the implementation of methods that have not previously been implemented (Mortensen and Bloch 2005). Organizational innovation is very important for companies that want to respond to strategic challenges as they provide improvements in the management of the organization (Ganzer et al. 2017).

4 Relationship Between Strategic Management and Innovation

In most of the studies conducted to date, it has been concluded that strategic management and innovation affect each other indirectly or both affect the organization and lead to each other's existence or absence. Businesses often need idle resources or redundancy to innovate. It is widely seen that companies generally tend to strategic planning only when they have financial difficulties. In most cases, strategic management is preferred during times of shortage, while innovation requires abundance and even waste (Berry 1994). Another finding of Berry (1994) is that large-scale enterprises are more distant than small-scale enterprises prone to innovation. Big business usually brings the presence of redundancy. Moreover, as the business grows, the need for experts increases, relationships become more complex, and strategic management is needed. Therefore, the size of firms is directly proportional to both innovation and the implementation of strategic management (Berry 1994).

Innovation and technological leadership, one of the strategic goals of companies, requires early detection of opportunities and risks. The presence of the company depends on its ability to conduct environmental surveys and analyzes on short, medium- and long-term horizons. Ruff (2015) showed that strategic management and innovation in the automotive sector should work together, and that success will come from here. In the future of international automotive companies, strategic decisions regarding innovation and technological developments are very important (Ruff 2015).

Sołoducho-Pelc (2015) stated that while strategic management enhances corporate governance, it creates business networks and partnerships. These relationships should be established based on uncertainty and risk reduction. This base will increase the chances of using innovations and opportunities in the long run. Sołoducho-Pelc (2015) states that there is an indirect relationship between strategic management and innovation and that strategic management creates the necessary environmental conditions for the emergence of innovation. In recent years, innovation studies have been one of the main factors in determining competition (Sołoducho-Pelc 2015). Innovation is based on the discovery of opportunities and possibilities for inventing new products, services, and technologies. The innovative approach is the ability to use opportunities in the strategic planning process through planning flexibility. Searching for opportunities as part of the strategic management process can also be associated with the flexibility of the strategic plan. As a result, it can be said that innovation paves the way for strategic management tools such as scanning opportunities and flexibility (Sołoducho-Pelc 2015).

According to Tang's (2016) research in the hospitality industry, environmental scanning not only allows hotel managers to plan and keep their plans up-to-date but also creates new services as customer needs are better observed. Environmental scanning, which is a part of strategic management, directly supports service innovation in the hospitality sector as it initiates a new service creation process. Environmental scanning has been shown to support service innovation positively and powerfully (Tang 2016).

Organizational innovation increases as environmental changes increase. A positive and strong relationship was found between the two variables. Considering that the high level of environmental change supports organizational innovation, such organizations should give importance to environmental scanning studies. Therefore, it can be said that there is a relationship between environmental scanning intensity and organizational innovation (Tsuja and Mariño 2013).

As can be seen, there is no direct relationship between strategic management and innovation in the studies, but some indirect conclusions have been reached. In this study, it is aimed to show whether there is a direct relationship between strategic management and innovation, and if so, the type of relationship.

5 Measurement of Strategic Management Application Level

In the study of Barringer and Bluedorn (1999), a measurement method was developed regarding the level of implementation of strategic management in an organization. According to Barringer and Bluedorn (1999), three variables are important for enterprises to behave in an entrepreneurial manner. These are opportunities to see organizational flexibility and innovation. In the study of Barringer and Bluedorn (1999), the level of strategic management application was determined, and the stages with the potential to affect entrepreneurial attitude were selected at the enterprise level.

- Scanning intensity: Environmental scanning covers all activities of the enterprise management to realize all kinds of events and trends occurring in the vicinity of the enterprise.
- Planning flexibility: Planning flexibility is the capacity of the firm's strategic plan to change responsibly to changes in the environment.
- Planning horizon: The planning horizon is the length of time the managers have in their plans. For most companies, this term is the time it takes to implement the company's routine strategies.
- Level of involvement: The level of involvement is the depth of employee involvement in the strategic planning process. Participation in planning, down to the lower hierarchical levels.
- Strategic control: The purpose of strategic control systems is to achieve the predetermined objectives.

6 Measurement of Innovation

The study of Lin et al. (2010) is based on the measurement of innovation levels of enterprises. Lin et al. defined innovation as product innovation, process innovation, marketing innovation, service innovation, and organizational innovation. Product innovation refers to the development and introduction of a new product, or improvements in the function, quality, durability, or appearance of an existing product. Process innovation refers to the creation or development of production methods and the incorporation of new input material, information flow, and equipment into the production processes of the enterprise. Marketing innovation includes market research, pricing strategies, market segmentation, advertising promotions, retail channels, and market information systems. Service innovation is defined as all innovations undertaken by the manufacturer to increase customer satisfaction. Organizational innovation refers to changes that occur in organizational structure or administrative processes (Lin et al. 2010).

7 Model and Hypothesis

As mentioned in the previous chapters, no studies have been conducted to find a direct relationship between the level of strategic management implementation and innovation. The model of this study is given in Fig. 1.

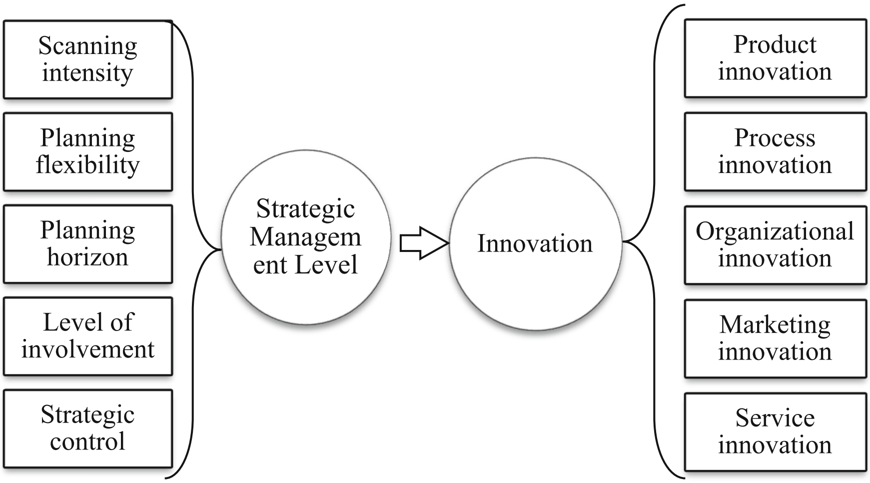

Fig. 1. The model of the study

H1: There is a relationship between the level of strategic management application and innovation.
H1a: There is a relationship between environmental scanning intensity and innovation.
H1b: There is a relationship between planning flexibility and innovation.
H1c: There is a relationship between the planning horizon and innovation.
H1d: There is a relationship between the level of participation and innovation.
H1e: There is a relationship between strategic control and innovation.
H2a: There is a relationship between environmental scanning density and product innovation.
H2b: There is a relationship between planning flexibility and product innovation.
H2c: There is a relationship between the planning horizon and product innovation.
H2d: There is a correlation between the level of participation and product innovation.
H2e: There is a relationship between strategic control and product innovation.
H3a: There is a relationship between environmental scanning intensity and process innovation.

H3b: There is a relationship between planning flexibility and process innovation.
H3c: There is a relationship between the planning horizon and process innovation.
H3d: There is a relationship between participation level and process innovation.
H3e: There is a relationship between strategic control and process innovation.
H4a: There is a relationship between environmental scanning intensity and organizational innovation.
H4b: There is a relationship between planning flexibility and organizational innovation.
H4c: There is a relationship between the planning horizon and organizational innovation.
H4d: There is a relationship between participation level and organizational innovation.
H4e: There is a relationship between strategic control and organizational innovation.
H5a: There is a relationship between environmental scanning intensity and marketing innovation.
H5b: There is a relationship between planning flexibility and marketing innovation.
H5c: There is a relationship between the planning horizon and marketing innovation.
H5d: There is a relationship between the level of participation and marketing innovation.
H5e: There is a relationship between strategic control and marketing innovation.
H6a: There is a relationship between environmental scanning intensity and service innovation.
H6b: There is a relationship between planning flexibility and service innovation.
H6c: There is a relationship between the planning horizon and service innovation.
H6d: There is a relationship between participation level and service innovation.
H6e: There is a relationship between strategic control and service innovation

8 Methodology

The data collection method was used to measure the strategic management level and innovation levels. The questionnaire was first created on 'Google Forms' and then sent to the participants by e-mail to complete it. A total of 88 managers from 11 cities and 18 sectors participated in the survey.

8.1 Data Collection Tools

The questionnaire used to measure the level of strategic management implementation was adapted from Barringer and Bluedorn's 1999 study 'The Relationship between Corporate Entrepreneurship and Strategic Management.' The strategic management level survey consists of 22 questions under 6 subheadings. The questionnaire used to measure innovation was adapted from Lin, Chen, and Chiu's 2010 study 'Customer relationship management and innovation capability: an empirical study.' The innovation questionnaire consists of 24 questions under 6 subheadings. Demographic characteristics section includes sector, age of the company, and city. 7-point Likert scale was used for the application of the questionnaires (1: strongly disagree; 7: strongly agree).

9 Analysis and Findings

Data were analyzed using IBM SPSS Statistics 22 program. Skewness values of the data are between −1,173 and 0,244, kurtosis values are between 1,335 and −1,240. According to Hair et al. (1995), the values should be within the range of ±1.96 of the critical value in the confidence interval of 0.05 to fit the normal distribution. The critical value is calculated by $z = \text{skew}/\sqrt{(6/N)}$. Therefore, if skewness values vary between $\pm 1.96 * \sqrt{(6/88)} = \pm 7.50$, normality is achieved. There is no calculation for kurtosis. When the kurtosis and skewness values are taken into consideration, the data corresponds to the normal distribution within the 0.05 confidence interval.

The data were collected under 12 headings used in the survey, and reliability analysis was performed. Most of the Cronbach's alpha values of the data were found to be 0,700 and above. Cronbach's alpha values are given in Table 1 below. According to Coulter et al. (1994), if Cronbach's alpha value is over 0.5, it is acceptable. Our data is also above the limit.

Table 1. Results of the factor analysis

Factors	Cronbach's alpha	KMO	% Variance
Strategic management application level	0,869	0,823	68,276
Strategic management environmental scanning intensity	0,792	0,753	61,827
Strategic management planning flexibility	0,894	0,825	76,066
Strategic management planning horizon	0,887	0,624	81,796
Level of participation in strategic management	0,889	0,803	75,142
Strategic management strategic control	0,715	0,600	77,797
Innovation level	0,875	0,837	66,978
Product innovation	0,872	0,806	72,314
Process innovation	0,874	0,817	68,382
Organizational innovation	0,879	0,665	80,725
Marketing innovation	0,879	0,812	73,636
Service innovation	0,932	0,748	88,096

For factor analysis, the sample size should not be less than 50, preferably greater than 100, according to Hair et al. (1995). Although the sample size in this study was below the preference limits, it was above the acceptable limit, and factor analysis could be performed. The data were subjected to factor analysis. Correlation matrix values were higher than 0.3, anti-image matrix values were higher than 0.5, and KMO values were higher than 0.5 for all factors. According to Hair et al., The correlation matrix values should be greater than 0.3 (Multivariate Data Analysis, 1995, p. 374). According to Field (2009), the axis (diagonal) values of the anti-image matrix should be greater than 0.5, and KMO values should be greater than 0.5. Factor analysis results were accepted since the values were above the required limit. Statistical results are summarized in Table 1.

As a result of factor analysis, double tail Pearson-Correlation test was applied to 12 factors formed from all data. Correlation (r) values were in the range of 0.5–0.6, and moderate positive relations were observed at the end of the test, and Regression analysis was performed for detailed examination.

In the regression analysis, while the level of innovation was the dependent variable, strategic management related factors were taken as independent variables. Durbin-Watson coefficient should be between 1 and 3, according to Field, which quotes from the original study of Durbin and Watson (Field 2009). All of our regression test results have a Durbin-Watson coefficient in the designated range.

As a result of the regression analysis between innovation and strategic management application level, R^2 value was found to be 0.377. There is not enough evidence to reject the H1 hypothesis. There is a relationship between the level of strategic management application and innovation.

In the regression analysis between innovation and environmental scanning intensity, planning flexibility, planning horizon, level of participation and strategic control, planning flexibility, planning horizon and level of participation (as it does not explain innovation) were excluded from the test. There was not enough evidence to accept H1b, H1c, and H1d. As a result of the regression analysis between innovation and environmental scanning density and strategic control, the R^2 value was found to be 0.516. There is not enough evidence to reject H1a and H1e hypotheses. There is a strong relationship between environmental scanning intensity and innovation. There is a weak relationship between strategic control and innovation.

As a result of the regression analysis between product innovation and environmental scanning intensity, planning flexibility, planning horizon, participation level, and strategic control, R^2 value between product innovation and environmental scanning intensity and planning horizon was found to be 0.463. Not enough evidence to accept H2b, H2d and H2e H1d were rejected. There is not enough evidence to reject the H2a and H2c hypotheses. There is a strong relationship between product innovation and environmental scanning intensity. There is a weak relationship between product innovation and planning horizon.

As a result of the regression analysis between a process innovation and environmental scanning intensity, planning flexibility, planning horizon, participation level, and strategic control, R^2 value between a process innovation and environmental scanning intensity and planning horizon was found to be 0.380. There is not enough evidence to reject H3a and H3c hypotheses. There is a strong relationship between a process innovation and environmental scanning intensity. There is a weak relationship between a process innovation and planning horizon. There was not enough evidence to accept H3b, H3d, and H3e.

As a result of the regression analysis between organizational innovation and environmental scanning intensity, planning flexibility, planning horizon, participation level, and strategic control, R^2 value between organizational innovation and strategic control and environmental scanning intensity was found to be 0.525. There is not enough evidence to reject H4a and H4e hypotheses. There is a strong relationship between organizational innovation and strategic control. There is a weak relationship between organizational innovation and environmental scanning intensity. Since there was not enough evidence to accept H4b, H4c, and H4d, they were rejected.

As a result of the regression analysis between marketing innovation and environmental scanning intensity, planning flexibility, planning horizon, level of participation and strategic control, R^2 value between marketing innovation and strategic control and environmental scanning intensity was found to be 0.478. There is not enough evidence to reject the H5a and H5e hypotheses. There is a strong relationship between marketing

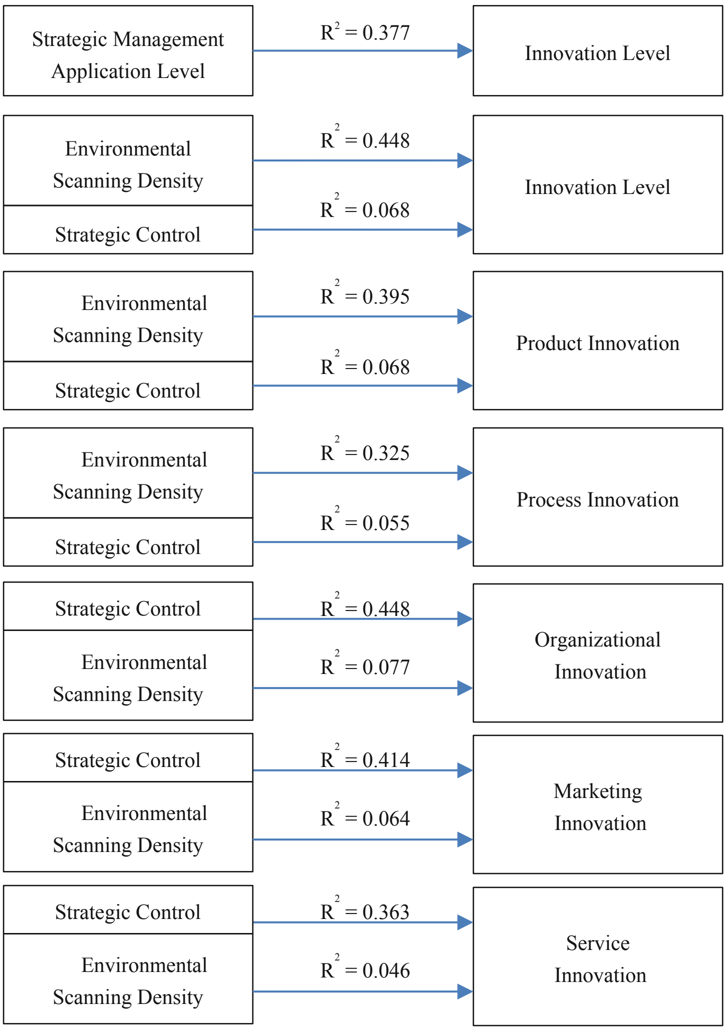

Fig. 2. Regression analysis results

innovation and strategic control. There is a weak relationship between marketing innovation and environmental scanning intensity. Since there was not enough evidence to accept H5b, H5c, and H5d, they were rejected.

As a result of regression analysis between service innovation and environmental scanning intensity, planning flexibility, planning horizon, participation level, and strategic control, R^2 value between service innovation and strategic control and environmental scanning intensity was found to be 0.410. There is not enough evidence to reject H6a and H6e hypotheses. There is a strong relationship between service innovation and strategic control. There is a weak relationship between service innovation and environmental scanning intensity. Since there was not enough evidence to accept H6b, H6c, and H6d, they were rejected. All relationships are shown in Fig. 2.

10 Discussion and Conclusion

Ruff (2015) and Berry (1994) found that size and abundance of resources increase innovation. In this study, a positive relationship was found between the level of strategic management implementation and the level of innovation, even if the same sub-dimensions were not present. Implementation of vision, mission, target, and strategy determination activities applied in companies increases the innovation of companies.

As Sołoducho-Pelc (2015) noted, a positive relationship was found between innovation and environmental scanning intensity, one of the sub-dimensions of strategic management. It is seen that if firms follow environmental elements like competitors, customers, and suppliers more closely, their innovation increases. Again, if political developments, economic developments, and social developments are followed from environmental elements, opportunities, or threats are recognized early, so that enterprises can develop innovative solutions to evaluate opportunities or avoid threats. Environmental scanning was the main factor affecting all types of innovation. In this context, companies should conduct environmental scanning while developing new products, developing new processes, making organizational innovations, using new marketing techniques, and providing new services.

A positive correlation was found between environmental scanning intensity and planning horizon and product innovation. Businesses develop new products systematically with long-term plans. They also have to follow their competitors' products, observe customer behavior, and ensure that suppliers are ready for developments. They also need market research, customer feedback, i.e., environmental scanning, to produce specialized products for specific market groups.

A positive correlation was found between environmental scanning intensity and planning innovation and process innovation. Companies that use automated or programmable advanced hardware to manage their processes or use advanced software such as ERP programs also make long-term plans, because once these technologies are integrated into the process, it is very difficult and costly to change them. Also, when companies use these processes, they sometimes establish integrated systems with their suppliers or customers. This possibility can even differentiate them from their competitors. Therefore, enterprises that are considering process innovation need environmental scanning processes to monitor their suppliers, customers, and competitors to identify such technologies.

As Tsuja and Marino (2013) stated in their study, organizational innovation is positively related to both environmental scanning intensity and strategic control. Companies restructuring their structures and business processes can see their configuration needs through financial control tools such as ROI, ROE, ROA. The results obtained through strategic control encourage enterprises to make organizational innovations. The state of competition in the sector provides enterprises with reasons for innovation in their organizational structures. The remaining firms in the competition are turning to radical innovation applications such as change engineering. Companies that are lagging behind customer expectations are also changing to different organizational structures to respond to the environment faster.

Environmental scanning intensity and strategic control have a positive impact on marketing innovation. Finding new pricing and new promotional techniques are the ones that do good environmental scanning. Because even if innovation is made in marketing channels before the customer is fully understood, if the profit is low, a bad example of innovation will arise. Innovation is also observed in customer relationship management (CRM) applications of these enterprises. Since marketing innovations have a great place in terms of firm strategies, strategic control also supports marketing innovation.

Environmental scanning intensity and strategic control have a positive impact on service innovation. Similar to product innovation, service innovation firms can create new services, as Tang (2016) says, thanks to environmental scanning, as customers' needs are better observed. Developments in competition and customer expectations encourage companies to provide new services, as well as pre-sales and after-sales services.

In general, the relationship between the level of strategic management implementation and innovation was found. Environmental scanning intensity, planning horizon, and strategic control dimensions, which are the sub-factors of strategic management, support various types of innovation at different rates. What companies need to do is to give importance to environmental scanning in line with these factors, to develop strategies that keep planning horizons long and not to leave strategic control.

When planning flexibility and participation level is not related to any innovation, we can conclude that the enterprises in the sample do not act participant in determining their strategies and do not revise their strategies according to environmental scanning results. This can be considered as an indication that the enterprises in the sample did not fully implement their strategic planning studies. Although they do not fully implement their strategic planning activities, they monitor their environment, determine strategies even if they are not a participant, and monitor whether they can achieve these strategies.

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Healthcare Systems Engineering and Management

Research on the Interaction Between Patient Satisfaction, Service Quality, Organizational Image and Trust in a Training and Research Hospital

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Abstract. Today, the satisfaction of people who benefit from health systems and health systems are gaining importance. In this context, analyzing the basic concepts affecting customer satisfaction and analyzing the interactions of these concepts became essential for an accurate health system management. It is inevitable that the priorities of the customers are determined, and action is taken in line with these priorities. The concepts of Perceived Service Quality, Trust, and Organizational Image are the subjects of this study. The number of studies analyzing these four concepts together is deficient. The study was carried out in the district of Bakırköy. Sadi Konuk Research Hospital, Bakırköy. Sadi Konuk Hospital has 20 polyclinics, 359 beds and 800–1500 people in a day and it is the largest hospital in the region. The data of the study were collected from patients in these outpatient clinics. By using a convenience sampling method, polyclinic patients with at least two hospital visits responded to the questionnaire. Various demographic data were collected under the name of Age, Gender, Marital Status, Education Level, and Number of Arrival to Hospital. The questions were asked objectively, and the patients were asked to answer each question. According to the results obtained from the study, Perceived Service Quality is positively affected by Patient Satisfaction, Organizational Image, and Trust. Trust, Patient Satisfaction, and Organizational Image adversely affect Trust. Organizational Image also positively affects Patient Satisfaction.

Keywords: Perceived Service Quality · Patient Satisfaction · Organizational Image · Trust · Healthcare

1 Introduction

In recent years, health care providers have become one of the main issues of health managers to know and better understand their priorities. The dissatisfaction and negativity experienced in health services have led to the innovative action plans, investment and managerial decisions of the healthcare providers, and in this research, internal and external factors have been directed to increase the satisfaction level of the patients (Silvestro 2005).

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Better levels of health services depend on knowing the priorities of patients. In this context, evaluating perceived patient satisfaction levels and knowing the factors related to these satisfaction levels and taking appropriate actions were the focus of health service managers. At another point, the high level of satisfaction that the patient perceives from the health care institution prevents the consequences of their future treatment, complaints and judicial processes caused by these complaints, and negative judgments of the patient in the community. In the opinion of the American College of Healthcare Executives, if patients are satisfied with a wide range of services, a large part of the hospital mission is achieved (Raposo et al. 2009). In this context, the perceived patient satisfaction level, which is the outcome of health services, is about many factors, and there are various links between these factors. Primarily, the first factor is the perceived service quality.

As known, quality of service, it is the difference between expected service and perceived service (Parasuraman et al. 1985). In line with this definition, it is necessary to keep the perceived level of service quality in health services as well, and the results show that patients' views are the most critical point in measuring and improving the quality of health services (Baltussen et al. 2002). Another factor examined is trust in the hospital. The confidence of patients in health institutions affects the relationship between the doctor and the patient from a medical point of view and, consequently, the effective management of the treatment and the organizational effectiveness and efficiency of the organization. A high level of trust provides a better estimate of customer behavior, lower customer attrition rate, and high customer value creation (Chang and Chang 2013). Because trust creates value for the customer, it provides a cost advantage in increasing customer satisfaction (Chang et al. 2013). Researchers have stated that trust is positive on satisfaction. Therefore, trust, customer satisfaction, and service quality are the concepts that should not be ignored in their research. Another factor that is essential for patient satisfaction is the organizational image. From a conceptual point of view, the image symbolizes reputation, trust, dignity, and credibility; The corporate reputation refers to the emotional reactions of customers, investors, employees and the society - good or bad, strong or weak (Çinaroglu and Sahin 2013; Burke and Martin 2016). There are also shortcomings in the proof of the relationship between these concepts in a small number of article studies examining the relationship between service quality, trust and service quality described above (Chang et al. 2013). In this study, unlike other studies, organizational image, service quality, trust, and customer satisfaction were investigated together with hospital-based, and the effect of Organizational Image on customer satisfaction was investigated together with other variables defined in the study.

The concept of service in scientific studies to the present day has been changing because of the privatization of the service, due to the importance of the ideas of the service buyers and the fact that the service is based on mutual communication. In today's works, it is essential to evaluate the thoughts of the people who benefit from the service through interactive methods and to take action in this direction. Many studies conducted in this way are reported in the literature (Brady et al. 2002; Wongrukmit and Thawesaengskulthai 2014; Özer et al. 2017). Customer-oriented professions (doctors, lawyers, tailors), they are in close contact with the customer, and they can rapidly improve the solutions that will increase the service quality by evaluating the customer's expectations (Chang et al. 2013). This study aims to develop solutions for health care and find factors that affect patient satisfaction by making measurements to increase the quality of health service and customer satisfaction by taking the evaluations of those who receive services. Thus, recommendations can be developed on what needs to be done to optimize patient satisfaction.

2 Methodology

2.1 Research Model and Hypotheses

According to Oliver (1980), satisfaction is a function of expectations and perceived product performance. In this context, satisfaction can also arise when the patient's expectations from the service exceed their expectations. Based on these, according to Linder-Pelz (1982), patient satisfaction can be considered as a result of many health care factors. Koenig and Bazant (2009), said that many factors of quality of service also affect patient satisfaction. Many studies have been conducted on factors affecting the Quality of Service and Patient Satisfaction (Senic and Marinkovic 2013; Raposo et al. 2009; Hawthorne et al. 2014; Otani et al. 2012; Chang and Chang 2013; Lee et al. 2004). Although this phenomenon of trust is more important especially in service systems, many studies have revealed that the trust of customers is an essential factor in evaluating the service process and there is a positive relationship between satisfaction levels (Namasivayam and Guchait 2013; Fauzi and Suryani 2019; Musa-Juroš et al. 2018). According to Özata and Sevinç (2007), there is a very close and mutual relationship between service quality and corporate image. While the factors and variables of the organizational image are used in determining the quality of service, the factors and variables of service quality can also affect the organizational image. If a health care provider has a successful image, patients may see this as a preference. A good image is related to the dimensions of the quality of the services offered by this health institution (Faria and Mendes 2013). In these studies, the relationship between perceived quality of service, organizational image, trust to the hospital, and patient satisfaction was investigated. However, the research models developed did not examine these four concepts together. The difference between this study and other studies is that the relationship between perceived service quality, organizational image, trust to the hospital and patient satisfaction is examined in a model and hypotheses are formed to cover four dimensions. In particular, the effects of organizational image and trust in the hospital were investigated to determine the effect on patient satisfaction. Also, in this study, perceived service quality was examined in four different dimensions. These dimensions are Process, Infrastructure, Physician, Diagnosis.

After all these explanations, the hypotheses of the research will be as follows (Fig. 1):

H1: Perceived Service Quality positively affects patient satisfaction.
H2: Perceived Service Quality affects the organizational image positively.
H3: Perceived Quality of Service positively affects the Trust.
H4: Trust to Hospital, Positive Affect of Patient Satisfaction.
H5: Organizational Image positively affects trust.
H6: Organizational Image positively affects patient satisfaction.

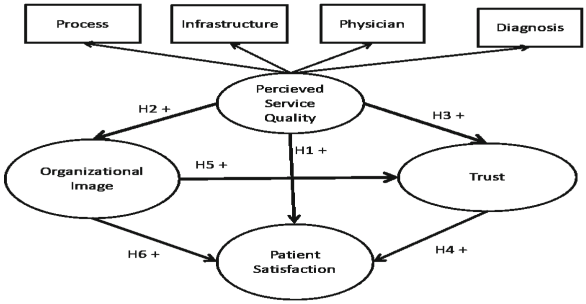

Fig. 1. Research model and theoretical relationships

2.2 Research Design

The data collection was carried out in the public hospital, Dr. Sadi Konuk Training and Research Hospital in the district of Bakırköy, Istanbul. Bakirkoy Sadi Konuk Training and Research Hospital was opened in 1969. In this context, there are ten similar health institutions in the Bakırköy district of Istanbul and one of the largest hospital where the study was conducted. The data of the study were collected from patients in these outpatient clinics. By using a convenience sampling method, polyclinic patients with at least two hospital visits responded to the questionnaire.

Various demographic data were collected under the name of Age, Gender, Marital Status, Education Level, and Number of Arrival to Hospital. At the same time, the survey that has 51 items was asked patient face to face. The questions were asked objectively, and the patients were asked to answer each question.

Hair and the other. As he pointed out, there is a need to observe at least five times the number of expected (estimated) variables. Also, a suitable sample volume for Maximum Likelihood estimation is 100. Between April 2016 and June 2016, 355 surveys were conducted by one-to-one interviews, and 301 of these questionnaires were used in the study. Our survey rate is 84.7%. (Israel 2003), when the main mass is over 100,000, the theoretical sample volume should be between 200 (95% confidence level and ±7% precision level) to 400 (95% confidence level and ±5% precision level). The number of questionaries' collected in this study provides a theoretical sample volume condition.

2.3 Instruments

The questions for measuring the variables defined in the study were firstly obtained from the literature review. Questionnaires obtained from the literature review were reviewed and revised in consultation with hospital managers and physicians who were associated with the study. As given in Table 1, all variables defined by Cronbach Alpha value greater than 0,6 (Hair et al. 1998). Factor names and descriptions are also given in Table 2. Likert scale was used as a scale, and one, strongly disagreed and five, heartily agreed.

Questionnaires were examined for reliability and validity using reliability analysis, construct convergent validity, and construct discriminant validity. In the reliability analysis, Principle Factor Analysis was used to determine the main factors, and other factors on common factors with varimax rotation were determined with the factor scores. Also, Cronbach alpha values were examined, and all of these values exceeded 0.60 (Hair et al. 1998). The results of all these analyses are given in Table 2.

Table 1. Factor naming and reliability analysis results

Construct/variable	Definition	Cronbach's α (>0,60)	References
Perceived Service Quality	*Process* The satisfaction of the patient in the process of registration and other procedures	0,945	(Faria and Mendes 2013; Chang et al. 2013; Chang and Chang 2013)
	Infrastructure Satisfaction from all kinds of subsystems that provide operation in the hospital (hygiene, lighting, room sizes, etc.)	0,944	
	Physician Satisfaction with the doctor's inspection service	0,948	
	Diagnosis The satisfaction of the patient from examination areas	0,930	
Trust	The patient's confidence in the decisions taken by the doctor, the treatment process applied and the results of Laboratory and Imaging (MR, X-ray, Ultrasound)	**0,940**	(Pearson and Raeke 2000)
Organizational Image	A measure of whether the hospital left a positive, disciplined and adequate impression in the patient	0,946	(Özata and Sevinç 2007; Izci and Saydan 2013; Faria and Mendes 2013)
Patient Satisfaction	General satisfaction with the service in the hospital	0,945	(Mache et al. 2012; Schoenfelder et al. 2011)

Table 2. Summary of model fit indices for CFA model

Construct	Variable/question item	Standard loading	Composite Reliability > 0.6	AVE > 0.5
Perceived Service Quality	*Process*		0,93	0,72
	1. I could quickly get my appointment to be examined	0,89*		
	2. I made the registration process easily and quickly	0,93*		
	3. The staff at the registration desk were able to do the operations fluently and quickly	0,95*		
	4. The person at the registration desk was able to direct me where I wanted	0,92*		
	Infrastructure		0,96	0,81
	1. The instruments used during the examination were quite clean	0,89*		
	2. The examination rooms were bright enough	0,92*		
	3. The doctor rooms were large and spacious	0,90*		
	4. The doctor's examination room was clean	0,89*		
	Physician		0,95	0,75
	1. My doctor was very keen to examine	0,90*		
	2. My doctor explained my condition in a language that I could understand	0,92*		

(*continued*)

Table 2. (*continued*)

Construct	Variable/question item	Standard loading	Composite Reliability > 0.6	AVE > 0.5
	3. My doctor told me about the use, dose, and effects of the drug treatment that will be applied to me in understandable language	0,87*		
	4. I am delighted with the kindness and kindness of my doctor	0,92*		
	Diagnosis		0,95	0,72
	1. Those who work in blood, X-rays, etc. were kind to me	0,95*		
	2. Persons who helped me with blood donation, x-ray extraction, were eager to help	0,87*		
	3. Providing my comfort with blood, X-rays, etc	0,91*		
Goodness of fit: χ^2/d.f. = 2.332, CFI = 0,979, TLI = 0,973, SRMR = 0,024, RMSEA = 0,067 (Sharma et al. 2005)				
Trust	1. I believe that my blood test/imaging results reflect the truth	0,91	0,97	0,79
	2. I think my blood test/imaging results belong to me	0,88		
	3. I think that the shooting/analysis of my disease is done	0,90		
	4. I think the devices are working correctly and sufficiently	0,86		

(*continued*)

Table 2. (*continued*)

Construct	Variable/question item	Standard loading	Composite Reliability > 0.6	AVE > 0.5
Goodness of fit: χ^2/d.f. = 3.606, CFI = 0,998, TLI = 0,987, SRMR = 0,0049, RMSEA = 0,095 (Sharma et al. 2005)				
Organizational Image	1. I think this hospital is a reliable health center	0,909	0,96	1,11
	2. I think this hospital is an experienced health center	0,887		
	3. This hospital is a hospital that deals with patients	0,881		
	4. This hospital is an innovative Health Center with advanced technology	0,934		
Goodness of fit: χ^2/d.f. = 0,542, CFI = 1, TLI = 1, SRMR = 0,0473, RMSEA = 0,0023 (Sharma et al. 2005)				
Patient Satisfaction	1. The service I received from this hospital made me happy	0,923	0,94	0,82
	2. The general procedure at the hospital was satisfactory	0,943		
	3. My overall impression of this hospital is quite good	0,97		
	4. I prefer this hospital again when I need it	0,773		
Goodness of fit: χ^2/d.f. = 1,022, CFI = 1, TLI = 1, SRMR = 0,0053, RMSEA = 0,009 (Sharma et al. 2005)				

* $p < .05$. AVE = Average variance extracted. χ^2/df. = Ratio of Chi-square. CFI = Comparative Fit Index. TLI = Tucker Lewis index. SRMR = Standardized Root Mean Square Residual. RMSEA = Root Mean Square Error of Approximation.

The factor loading, Composite Reliability (CR) and Average Variance Extracted (AVE) were used to test the measurement model's construct convergent validity. The item had a factor loading of higher than 0.50 that there exist some common points of convergence (Hair et al. 1998). The CR shows results which are higher than 0.70, which means that the variables did converge at some point (Hair et al. 1998). The Average Variable Extracted (AVE) values for the variables are above 0.50 that the latent variables also had high convergent validity (Fornell and Larcker 1981).

We used the chi-square difference test on constructs that had items which were suspected of producing confusion among respondents. In this study, the method proposed by Bagozzi and Yi (1988) was used. To test for discriminant validity, we followed (Segars 1997) recommendations and performed a chi-square variance test for limited and unlimited measurement patterns. The chi-square values of limited patterns do not exceed those of unlimited patterns and reach a level of significance (as shown in Table 3), indicating discriminant validities among all dimensions are accepted (Chang et al. 2013).

Table 3. Discriminant validity analysis results of all the constructs

Pattern	χ^2	d. f.	$\triangle\chi^2$
Perceived Service Quality			
Unlimited Measurement Pattern	192,933	82	–
Process and Infrastructure	395,609	83	202,68**
Process and Physician	382,146	83	189,21**
Process and Diagnosis	365,801	83	172,87**
Infrastructure and Physician	452,323	83	259,39**
Infrastructure and Diagnosis	418,909	83	225,98**
Physician and Diagnosis	458,335	83	265,40**
Pattern	χ^2	d. f.	$\triangle\chi^2$
Trust			
Unlimited Measurement Pattern	90,565	23	–
Trust Physician and Trust Diagnosis Results	301,753	24	211,10**

** $p < 0.01$

2.4 Data Analysis Methods

Data were analyzed using SPSS 20 and AMOS 22 (Structural Equation Modeling) statistical package programs. Structural Equation Modeling (SEM) was used in the analysis of relations. SEM is used to define relationships between variables, taking into account the interaction of each other

SEM is used to study the theoretical structures of latent factors. Makes the relationship analysis by defining the regression and path coefficients among the factors in the theoretical structures. For this reason, SEM was used in the tests of hypotheses. In this study, Average variance extracted (AVE > 0,5), Ratio of Chi-square (χ^2/df < 5), Comparative Fit Index (CFI > 0,80), Tucker-Lewis index (TLI > 0,90), Standardized Root Mean Square Residual (SRMR < 0.10), Root Mean Square Error of Approximation (RMSEA < 0,10), SRMR value less than 0.10 and of 0.08 (in a more conservative version view; see Lt and Bentler (1999), were used for overall model fitness.

3 Results

3.1 Characteristic of Samples

Characteristic of Samples can be seen in Table 4, and the most critical point is since 37.2% of the respondents visited the hospital 8 or more times, they have the experience to evaluate the services they receive.

Table 4. Characteristics of samples (N = 301)

Description	Frequency	Percentage (%)
Age		
12–30 years	62	20,6
30–45 years	89	29,6
45–60 years	89	29,6
60 years and above	61	20,2
Gender		
Female	203	67,4
Male	98	32,6
Education level		
Elementary school and below	129	42,8
Junior high school	114	37,9
Senior high school	15	5
University/college	43	14,3
Postgraduate	–	
Marital status		
Married	212	70,4
Single	89	29,6
Visit number		
2–4 times	143	47,5
5–7 times	46	15,3
8 times and more	112	37,2

3.2 Results of Model

As can be seen in Table 5, Perceived Service Quality is positively affected by Patient Satisfaction (0.76), Organizational Image (0.54), and Trust (0.94). In this case, hypotheses one, two, and three are validated. The Trust adversely affects Patient Satisfaction (−0.14) and Organizational Image, Trust (−0.23). Organizational Image also positively affects Patient Satisfaction (0.37). In this case, hypotheses 4 and five are not supported, but hypothesis 6 is supported. Also, Table 5, SEM Model and conformity test (the model of the goodness of fit) results can be seen. As a result, the research model and data are appropriate.

Table 5. Results of a structural equation modeling

Path	Path coefficient	t Value	Hypothesis
Perceived Service Quality –> Patient Satisfaction	0,82	1,537**	H1
Perceived Service Quality –> Organizational Image	0,54	1,050**	H2
Perceived Service Quality –> Trust	0,98	1,217**	H3
Trust –> Patient Satisfaction	−0,2	−0,302*	H4
Organizational Image –> Trust	−0,23	−0,149**	H5
Organizational Image –> Patient Satisfaction	0,36	0,343**	H6
Goodness of fit: χ^2/d.f. = 3,703, CFI = 0,914, TLI = 0,903 SRMR = 0,1017, RMSEA = 0,097 (Sharma et al. 2005)			

* p < .05. ** p < 0,01

Table 6 summarizes the direct and indirect effects of variables affecting patient satisfaction. According to the standardized path coefficients, Patient Satisfaction makes the highest direct impact on Perceived Service Quality. The minimum direct effect is Organizational image. Perceived Service Quality makes the highest impact in terms of the total effect.

Table 6. Direct, indirect, and total effects of Patient Satisfaction

Variable	Total effect			Direct effect			Indirect effect		
	OI	T	PS	OI	T	PS	OI	T	PS
SQ	0,545	0,821	0,846	0,545	0,944	0,759		−0,123	0,087
OI		−0,225	0,398		−0,225	0,367			0,031
T			−0,138			−0,138			

OI, Organizational Image, T, Trust, PS, Patient Satisfaction, SQ, Perceived Service Quality.

4 Discussion and Conclusion

The main results obtained from this study are as follows. As the Perceived Service Quality increases, the Patient Satisfaction increases, the Organizational Image increases as the Perceived Service Quality increases, the Trust increases as the Perceived Service Quality increases, and finally, the rise in Perceived Service Quality increases the organization image, and this increases patient satisfaction. Evaluation of these results is made in the following paragraphs.

Chang et al. (2013) stated that Perceived Service Quality and Trust had a positive impact on Patient Satisfaction and Perceived Service Quality had positively affected the Trust (Faria and Mendes 2013). In their study of patient satisfaction, perceived service quality is a function of, i.e., perceived service quality as a result of satisfaction was revealed. Besides, another hypothesis suggested by (Özata and Sevinç 2007) is that Organizational Image is affected by Perceived Service Quality. They also emphasized that previous studies (Wong and Sohal 2003) were one of the most critical determinants of the service quality is trust, and Josep and Velilla (2003) and Singh and Sirdeshmukh (2000) said that, trust directly affected real satisfaction.

The two concepts that have the most significant impact on Patient Satisfaction are Perceived Service Quality and Trust. It is common for patients to have high Quality of Service and to increase patient satisfaction as a result. In the services provided by the patient, the competence of the doctor, the accuracy and the quickness of the laboratory and imaging systems, the effectiveness of the process followed by the patient and the suitability of the hospital infrastructure determine the quality of service. Therefore, as the service quality increases, the treatment process of the patient increases more positively, and the satisfaction increases. In addition to this natural result, it was found that the result of the study had a considerable effect on customer satisfaction in Hospital Trust. These results are similar to Chang et al. (2013) study. Only by improving the quality of service, it may not be possible to provide patient satisfaction at the desired level. Also, the patient's confidence in the hospital should increase. To increase the patient's confidence in the hospital, the patient must prove that the correct examinations are performed and the correct results are obtained in all the examinations performed and thus the patient should be assured to trust the patient in the hospital. This result is similar to the results found by Özata and Sevinç (2007).

Also, the patient should not have any doubts that the examinations required by the doctor are the correct examinations. Another critical point for applications is the relationship between Hospital Image and Perceived Quality of Service. As Perceived Service Quality increases, patients' view of the hospital is more positive. When they compare the hospital with other hospitals, they see it more successful and generally evaluate the hospital positively. However, the increase in Hospital Image has a positive effect on patient satisfaction. As the patient's perception of working in the hospital is better than other hospitals, the satisfaction of the patient is positively affected.

After all these explanations, the main thing is to achieve success in health services by meeting the expectations of the patient and increasing the number of satisfied patients. Priorities for achieving this goal are described below.

- Improving service quality is essential. To improve the quality of the service, the patient should be able to proceed quickly in all other processes starting from the registration process. The doctor and other areas should be clean and big enough. The communication with the doctor should be complete; the correct diagnosis and treatment method should be applied and be said to the patient. Laboratory analysis and other imaging results should be reliable.
- Confidence in the hospital should be increased. For this purpose, it should be understood by the patient that the correct results are obtained in the hospital, and the related analyses are performed.
- To be the best hospital image in the perception of patients, the hospital should be promoted well.
- Hospital and hospital employees should achieve correct results in all of the procedures they do and should not make mistakes in matters that are directly related to the patient.
- One of the results of the study is that the Hospital Image is also important to increase patient satisfaction. However, the positive image should be supported by increased confidence in the hospital, which should not decrease patient satisfaction.

The results obtained from this study were collected by considering them under certain constraints. The service quality title should be further elaborated. The most effective topics were taken into consideration. However, The service quality can be analyzed other criteria such as physical conditions, waiting times, management, monetary costs.

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Gamification of Upper Limb Tangible-Wearable Rehabilitation Devices

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Abstract. The researchers have focused on device-aided rehabilitation systems for many years. Wearable, tangible devices, and virtual reality technologies have been used to rehabilitate impaired patients in rehabilitation centers since repetitive exercises induce neuroplasticity. Neuroplasticity is the capability of a neural network system to new situations or environmental and behavioral changes. During this adaptation stage, the brain forms new neural connections that cut off old injured ones, and it reorganizes itself. This lifelong process continues throughout a person's life. The brain reshapes and rewires itself by synaptic pruning, deleting the neural connections that are no longer necessary and make the useful connections stronger. Some research studies have proved that intensive therapy sessions at hospital and rehabilitation centers improve the motor skills of patients. However, device-aided therapies applied in centers have expensive, time, and labor consuming issues. Additionally, some patients find repetitive exercises hard and boring. For this reason, home-based and gamified rehabilitation tools, devices, and robots have been becoming more attractive. Starting to use upper limb partially or completely is one of the most important issues makes the daily and business life of patients more comfortable. Games integrated to home-based, tangible-wearable rehabilitation devices designed for upper limb impairments, especially after stroke have been started to be used for motivating the patients to continue rehabilitation exercises. The design and manufacturing of wearable and tangible, game-based equipment is a subject of a multidisciplinary study and requires mainly engineering, medical, and education sciences. The purpose of this study is conducting a literature review to provide foundation knowledge on the topic and a picture about the research problem being studied clarifying what has been done until now and what is needed to be done.

Keywords: Gamification · Rehabilitation · Tangible · Wearable · Upper limb · Device · Home-based rehabilitation

1 Introduction

Stroke is a massive global health issue, and it is estimated that one in six people worldwide will have a stroke during their lifetime (Yassi and Campbell 2016). It is one of the most common causes of long-term disability, significantly reducing the quality of life through impairing motor functions and cognitive abilities (Kytö et al. 2019, May 4–9). Every two

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seconds, someone in the world will have a stroke. Almost two-thirds of stroke survivors leave the hospital with a disability.

People of working age are two to three times more likely to be unemployed eight years after their stroke (Stroke Association 2018). Due to the aging population, the demand for technology support in stroke recovery has rapidly increased in the last decade (Yang 2019).

Rehabilitation is a long term treatment program to cure an impaired patient for getting back keeping or improving his/her abilities needed for daily life. It is usually applied by repetitive exercises induce neuroplasticity. Neuroplasticity is the ability of neural network systems to new situations or environmental and behavioral changes. During this adaptation stage, the brain forms new neural connections, cuts off old injured ones, and it reorganizes itself. This lifelong process continues throughout a person's life. The brain reshapes and rewires itself by synaptic pruning, deleting the neural connections which are no longer necessary and make the useful connections stronger.

Stroke is a significant cause of long-term disability, impairing over 10 million people motor function, primarily on one side of the body every year. While effective rehabilitation exercises can help recover and maintain some affected motor function, stroke survivors often do not carry out enough of these. Relying on their 'good' side to carry out tasks leads to poor recovery limiting the ability to carry out everyday bimanual tasks (such as dressing or cooking) (Kytö et al. 2018).

To regain motor control, stroke patients should do various exercises that target specific body functions. During daily exercising, they need assistance from either therapists or caregivers in setting tasks, providing feedback and other activities (Yang et al. 2019).

Some research studies have proven that intensive therapy sessions at hospital and rehabilitation centers improve the motor skills of patients. Rehabilitation aims to ameliorate deficits in motor control via intensive practice with the affected limb (Guneysu Ozgur et al. 2018). However, device-aided therapies applied in centers have expensive, time, and labor consuming issues. Additionally, some of the patients find repetitive exercises hard and boring.

Then, home-based and gamified rehabilitation tools, devices, video games, virtual reality systems, augmented technologies, and robots have been becoming more attractive. Starting to use the upper limb partially or completely is one of the most important issues makes the daily and business life of patients more comfortable. Additionally, developing these kinds of digital systems are not only good at for repetitive exercises, but also they may be very successful to record the data and to use artificial machine learning methods to track the movements and improvement level of patients and adapt and plan the rehabilitation program accordingly.

2 Methodology

In this study, scholar.google.com.tr and ResearchGate.net were searched with the main keywords gamification OR gamified AND rehabilitation AND upper limb AND robotics, wearable OR tangible and AND stroke. More than 60 articles are reviewed manually, and 27 of them were selected to be used.

Then new database resources including Scopus, Web of Science, PubMed and Wiley were used, and new 50 articles were reviewed. They were mainly used for strokes and serious games related information and not included in statistics. Nineteen of them were selected to be evaluated. Finally, over 110 articles were scanned, and 46 of them were evaluated.

3 Results

Some statistical analysis of the review study is given in Figs. 1 and 2, and Tables 1 and 2. The oldest article is a review (Riener et al. 2005) and it provides an overview of existing devices that can support movement therapy of the upper extremities in subjects with neurological pathologies. The devices are critically compared concerning technical functions, clinical applicability, and, if they exist, clinical outcomes, and their commercialization possibilities. It does not mention gamification. Although the number of articles mentioning gamification has been started to increase from the 2010s. The interest of researchers on gamification not only for rehabilitation but also for the other areas of life, such as education and military. Game design is a rapidly growing area of research, due in part to the number and variety of application areas that 'serious games' are now identified with. They have identified two principles of game design which have particular relevance to rehabilitation: meaningful play and challenge (Burke et al. 2009). Serious games are the games which are not designed for entertainment.

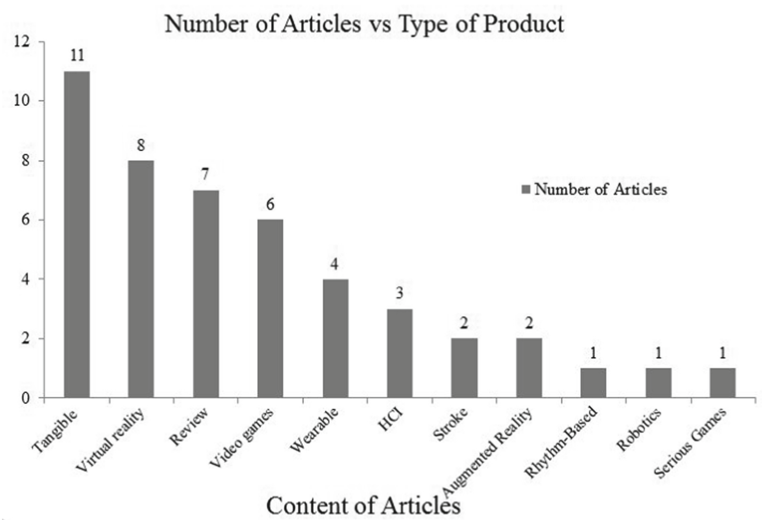

Fig. 1. The distribution of articles according to content

One of the newest articles (Yang et al. 2019) presents a portable and interactive prototype designed to facilitate arm reaching exercise. It consists of a tabletop device and a game map that serves as visual guidance on arm movements. This device also provides light and sound feedback while patients can choose different game modes. Preliminary user trials support the implementation of tangible interactive training in rehab centers and further inspire us on building a tabletop training system.

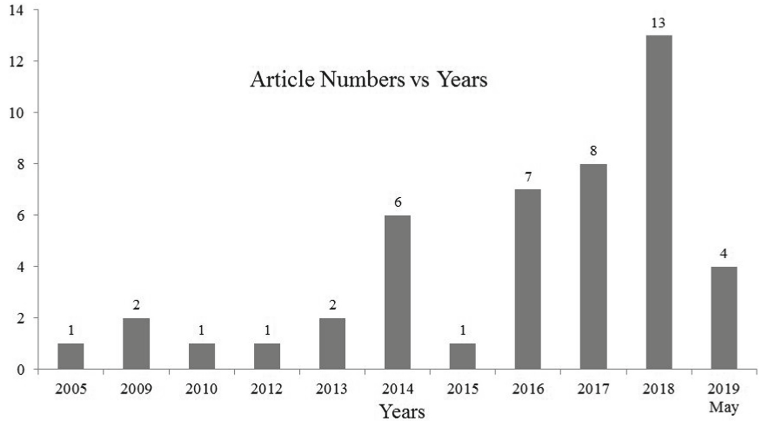

Fig. 2. The distribution of articles according to years

Table 1. The distribution of articles according to content and their referring articles

Type of product	Number of articles	Articles
Tangible	11	(Guneysu Ozgur et al. 2018), (Wang et al. 2017), (Yang et al. 2019), (Kytö et al. 2018), (Yang et al. 2018), (Kytö et al. 2019), (Magnusson et al. 2017), (Pereira et al. 2018), (Vandermaesen et al. 2016), (Goršic et al. 2017), (Vandermaesen et al. 2016)
Virtual reality	8	(Lledó et al. 2016), (Afyouni et al. 2017), (Freitas et al. 2012), (Pinto et al. 2018), (Ferreira et al. 2014), (Tamayo-Serrano et al. 2018), (Lai et al. 2018), (Yates et al. 2016)
Review	7	(Tamayo-Serrano et al. 2018), (Wang et al. 2014), (Nordin et al. 2014), (Masiero et al. 2014), (Tamayo-Serrano et al. 2018), (Kamkarhaghighi et al. 2017), (Oujamaa et al. 2009)
Video games	6	(Jie et al. 2017), (Alankus et al. 2010), (Jaramillo-Alcázar et al. 2018), (Borghese et al. 2013), (Elrefaei et al. 2019), (Burke et al. 2009)
Wearable	4	(Ploderer et al. 2016), (Vasconcelos et al. 2018), (Rajanna et al. 2016), (Yetisen et al. 2018)
HCI	3	(Ploderer et al. 2017), (Johnson 2018), (Karashanov et al. 2016)
Stroke	2	(Yassi and Campbell 2016), (Stroke Association 2018)
Augmented reality	2	(De Leon et al. 2014), (Hondori et al. 2013)

(*continued*)

Table 1. (*continued*)

Type of product	Number of articles	Articles
Rhythm-based	1	(Averell and Knox 2019)
Robotics	1	(Riener et al. 2005)
Serious games	1	(Meenkeri 2015)
Total	46	

Table 2. Number of author keywords repeated more than 8 in 46 articles

Keyword	Number	Keyword	Number	Keyword	Number
Rehabilitation	37	Game-gamification	26	Stroke	24
Interact(ive, ion)	15	Reality	11	Robot(ics)	11
Serious games	11	Tangible	8	Upper	8

4 Discussion and Conclusion

For this study, 110 articles were reviewed. Almost sixty percent of them were excluded since they were related with lower limb or the devices can be used only in physiotherapy centers and need the support of physiotherapists or caregivers. Additionally, cognitive disabilities are not covered, and the study focuses on post-stroke upper limb disabilities. For being used in statistics, 46 of them were selected, and 40 articles were addressed in the bibliography.

It can be deduced that in the last decade of the 20th century and beginning of the 2000s the researchers discussed if the machine and/or device supported rehabilitation is better, and then at the beginning of 2010s they started to study on home-based rehabilitation instead of ones applied in medical centers more. The gamification or gamified devices are the concepts of the 21st century, and they have been using not only in the healthcare industry but also in education, business, and military as well.

Finally, under the light above given information, it can be evaluated that the studies on gamified tangible and wearable rehabilitation devices are continuing, and new approaches are needed to adopt the games and devices to all different societies and different age groups especially elderly ones who are the more resistive group to participate in the repetitive exercises of rehabilitation programs.

In this case, the exercises involve physiological elements, and they are individualized gamified therapy. Thanks to individualization, the motivation of especially elderly person or the patients in depression, which is very common for post-stroke survivors may be kept constant or improved.

To support elderly persons' rehabilitation activities, the device can take some data, for example, detailed movement data, several exercises, and using the collected data; the system may control and alert the patient. The potential of Artificial Intelligence technology to be used for guiding the rehabilitation has been increasing. The collected data may be observed or shared by therapists either for their advice as well. In other words, telerehabilitation methods may be common in mid-term for the treatment of post-stroke survivors.

If the aging of the population of the World is taken into account, the gamified and individualized rehabilitation devices enriched with the abilities of AI-Artificial Intelligence technology may have a big potential for being one of the smart products of near future.

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Prioritization of Factors of Breast Cancer Treatment Using Fuzzy AHP

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Abstract. Breast cancer is a widespread disease that can both be seen at males or females. According to so many different factors such as age, sex, genetics, the shape and size of the tumor, environmental situations, and so on, that affects cancer type directly. With so many alternative cancer types and thus, treatment preference changes, it is vital to make the diagnosis as soon as possible to decide and start the treatment process. Diagnosis time is dependent on both technological equipment and also medical personnel. This study aims to support medical personnel, radiologists, doctors, surgeons, via proposing a multi-criteria decision model to find out which factor is more effective on the breast cancer type. Fuzzy Analytic Hierarchy process is used to prioritize factors of breast cancer treatment alternatives and results are compared to another study which already used Analytic Hierarchy Process but in certain conditions.

Keywords: Breast cancer · Multi-criteria decision making · Fuzzy · Analytical hierarchy process · Healthcare support systems

1 Introduction

Today, cancer is a worldwide disease that is usually uncontrollable. With some treatments, people try to survive against the speed of abnormal cell reproduction. At this point, age is a very important criterion as a young body produces abnormal/normal cells faster than an old body. With the technological improvement and development in the medicine area, people can cope up with different cancer types such as pancreatic, breast, prostate, lung, and so on. One of the most common cancer types is breast cancer, which may both seen on males or females. There are also types of breast cancer, which also differentiate the treatment options. It may start with drugs or chemotherapy or operation than using medicine. It is important to diagnose breast cancer at its early stage and decide the way of the surviving process. For this study, two different drug types are considered for HER2+ type of breast cancer. One of them is Kadcyla, and the other one is Lapatinib plus Capecitabine. Medical personnel are giving a decision for the patient to use which of these drugs in terms of their own disease's properties.

According to so many different factors such as age, sex, genetics, the shape and size of the tumor, environmental situations, and so on, that effects cancer treatment

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directly. With so many alternatives, cancer type and thus, treatment preference changes. It is vital to make the diagnosis as soon as possible to decide and start the treatment process. Diagnosis time is dependent on both technological equipment and also medical personnel. This study aims to support medical personnel, radiologists, doctors, surgeons, via proposing a multi-criteria decision model (MCDM) to find out which factor is more effective on the breast cancer type. Fuzzy Analytic Hierarchy process is used to prioritize factors of breast cancer treatment alternatives, which are mentioned above, and results are compared to another study which already used the Analytic Hierarchy Process but in certain conditions. After the introduction part, a literature review will cover up MCDM and F-AHP. Then F-AHP will be detailed in the methodology part, and analysis will show the results which belong to the selected study. In the end, conclusion and future studies will be mentioned.

2 Literature Review

2.1 Breast Cancer Treatment

The first treatment called Trastuzumab approved in 1998, which is a monoclonal antibody targeting the extracellular domain of the HER2 protein, used as a combination of another type of treatment for HER2 positive (HER2+) breast cancer (Slamon et al. 2001). There are also different types of drugs for HER2+ breast cancer type that are being preferred according to the patients' specific properties. Kadcyla is a combination of Trastuzumab and Emtansine. The main reason to use Kadcyla is breast cancer metastatic characteristic. It may spread to the other parts of the body of the patient. Duty of Trastuzumab is finding cancer cells, and Emtansine tries to destroy the cell because of its toxic structure. This process of the drug minimizes the damage of healthy cells, so this treatment is more preferred than the others to increase the survival rate of the patients (URL-1).

Another drug combination of Lapatinib and Capecitabine helps to heal HER2+ breast cancer. Lapatinib must stop the reproduction of the cancer cells. The material of the drug blocks the receptors of HER2+ cancer cells, and it slows down its growth (URL-2). It may be used as a combination with Capecitabine, which is a regular chemotherapy drug, that is more effective when used together for metastatic breast cancer (Geyer et al. 2006).

There are very different scenarios, which are already studied at literature based on breast cancer. Rostami et al. made a literature review of brain metastasis in brain cancer in 2016. They mentioned about different types of treatments according to patients' genetics and the microenvironment of the brain (Rostami et al. 2016). Wanchai et al. conducted another study about breast cancer-related lymphedema. This type of disease may be treated by combinations of compression therapy, pharmacotherapy, modality approaches, and therapeutic exercises (Wanchai et al. 2016). Borin et al. presented a statistical study that shows melatonin decreases the rate of breast cancer metastasis (Borin et al. 2016).

2.2 Fuzzy Analytic Hierarchy Process

Saaty studied the traditional Analytic Hierarchy Process (AHP) for multi-criteria decision making (Saaty 1980). AHP makes a question as to the subjective numbers of decision makers' and the environment of uncertainty; however, it is easier than the other decision-making methods in terms of mathematical calculations. Fuzzy AHP is more suitable for fuzziness and uncertainty for conducting a hierarchical rating (Zyoud et al. 2016).

Under fuzziness, different methods may be used, while the most common one is fuzzy AHP (F-AHP). Extended analysis is preferred by using F-AHP because of its easy steps despite its disadvantages. F-AHP can cope up with the uncertain environment, and it is steadier than the others. Different criteria are being compared pairwise with the help of triangular fuzzy numbers (Kumar et al. 2017). Methodology part is clearly giving the details of the F-AHP method steps one by one.

There are different examples from the literature that already used F-AHP. At one of the studies, human capital indicators are ranked by using F-AHP (Bozbura et al. 2007). Huang et al. preferred using F-AHP to select a governmental R&D project (Huang et al. 2008). Lee et al. studied F-AHP in Taiwan to evaluate IT departments of the production sector (Lee et al. 2008). Evaluation of hazardous waste transportation by using F-AHP was another study found in the literature (Gumus 2009). Another waste management study is done by Lung Hung, which evaluated municipal solid waste management with F-AHP (Hung et al. 2007).

3 Methodology

More complex and realistic problems may have uncertainties. Solving this kind of situations under uncertainty is sometimes difficult with deterministic models. Fuzzy sets help to make models that include uncertainties within, and thus, it is easier to solve those problems (Kahraman et al. 2003). Uncertainty and fuzziness are important factors of the Fuzzy Analytic Hierarchy Process. This multi-criteria decision-making model is also preferred by decision makers for its natural language to understand the complex model easily (Kahraman et al. 2003).

There are different management and engineering studies that use F-AHP in the literature that is already mentioned. To understand the methodology of this process, Chang introduced triangular fuzzy numbers (Chang 1996). The membership function is assigned between 0–1 for fuzzy sets, which can be seen in Fig. 1 (Kahraman et al. 2003).

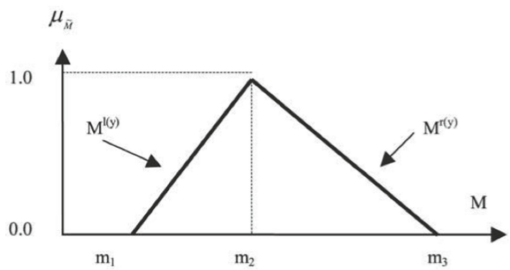

Fig. 1. Triangular fuzzy numbers (Kahraman et al. 2003).

Which is also expressed as the linear presentations interpreting as piecewise function on left and right sides, $\tilde{M}$, in (1).

$$\mu\left(x|\tilde{M}\right) = \begin{cases} 0, & x < m_1 \\ (x - m_1)/(m_2 - m_1), & m_1 \le x < m_2 \\ (m_3 - x)/(m_3 - m_2), & m_2 \le x < m_3 \\ 0, & x \ge m_3 \end{cases} \quad (1)$$

Equation (2) shows the right and left side expression, which are $l(y)$ and $r(y)$, of fuzzy numbers of membership degrees (Chan et al. 2008).

$$\tilde{M} = \left(M^{l(y)}, M^{r(y)}\right) = (m_1 + (m_2 - m_1)y, m_3 + (m_2 - m_3)y)$$
$$where\ y \in [0, 1] \quad (2)$$

Fuzzy AHP procedure is given below (Huang et al. 2008):

– A scale is defined for each criterion related to their relative strength. Each criteria must assign according to the relative strength by triangular fuzzy numbers (Hung et al. 2007).
– Decision makers have to make a pairwise comparison with matrix $\tilde{A}_k$ to construct a fuzzy judgment matrix which is $\tilde{E}$ (3).

$$\widetilde{A_k} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \widetilde{a_{1(n-1)}} & \widetilde{a_{1n}} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \tilde{a}_{n1} & \widetilde{a_{n2}} & \cdots & \widetilde{a_{n(n-1)}} & 1 \end{pmatrix} \quad (3)$$

Where $i = j, a_{ij} = 1$ and $e_{ij} = 1$,

$$\tilde{E} = \begin{pmatrix} 1 & \tilde{e}_{12} & \cdots & \widetilde{e_{1(n-1)}} & \widetilde{e_{1n}} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \tilde{e}_{n1} & \widetilde{e_{n2}} & \cdots & \widetilde{e_{n(n-1)}} & 1 \end{pmatrix} \quad (4)$$

$\tilde{A}_{kl} = \left[\tilde{a}_{ij}^{kl}\right]$ and $\tilde{E}_l = \left[\tilde{e}_{ij}^{l}\right]$, it follows that $\tilde{a}_{ij}^{l} = \left(\tilde{a}_{ij}^{kl}\Theta \ldots . \Theta\tilde{a}_{ij}^{kn}\right)^{1/n}$ and

$$\widetilde{e_{ij}} = \left(\tilde{e}_{ij}^{1}\Theta \ldots . \Theta\tilde{e}_{ij}^{n}\right)^{1/n}$$

i^{th} object's fuzzy value is:

$$S_i = \sum\nolimits_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum\nolimits_{i=1}^{n} \sum\nolimits_{j=1}^{m} M_{gi}^{j}\right]^{-1}$$

where

$$\sum\nolimits_{j=i}^{m} M_{gi}^{j} = \left(\sum\nolimits_{j=1}^{m} l_j, \sum\nolimits_{j=1}^{m} m_j, \sum\nolimits_{j=1}^{m} u_j\right)$$

– Possibilities are calculated such as

$M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ can be defined as

$$V(M_2 \geq M_1) = sup_{y \geq x} \lfloor \min(\mu_{M_1}(x), \mu_{M_2}(x)) \rfloor$$

Furthermore, we need to compare M_2 *and* M_1 values by

$$V(M_2 \geq M_1) \; and \; V(M_1 \geq M_2)$$

Then, $d'(A_i) = min V(S_i \geq S_k)$

– Normalized weights are figured out for $k = 1, 2, \ldots n; k \neq i$, the weight vector can be found as $W' = (d'(A_1), d'(A_2), \ldots d'(A_n)^T$, and the normalized weights,

$W = (d(A_1), d(A_2), \ldots d(A_n))^T$, where W is a crisp value.

4 Model Analysis and Results

In this study, it is aimed to prioritize breast cancer treatment factors by using fuzzy AHP method. Camgöz-Akdağ et al. studied breast cancer treatment factors' prioritization

Table 1. Main and subcriteria of the model

Main criteria	Sub-criteria
C1: Patient-related factors	C11: Age
	C12: General health condition
	C13: Manopause
	C14: Preference
	C15: Ethnicity
C2: Tumor-related factors	C21: Size
	C22: Location
	C23: Stage
C3: Drug related factors	C31: Therapeutic index
	C32: Structure
	C33: Delivery
	C34: Adverse effect grade
	C35: Median survival time
	C36: Recurrence probability
	C37: Frequent usage
	C38: Maximum dosage

using AHP (Camgöz-Akdağ et al. 2019). Factors are gathered from this study to compare AHP and F-AHP results in equality. Firstly, the criteria are evaluated and explained. Table 1 shows the criteria of the model.

Figure 2 shows the hierarchical tree for the selection of breast cancer treatment.

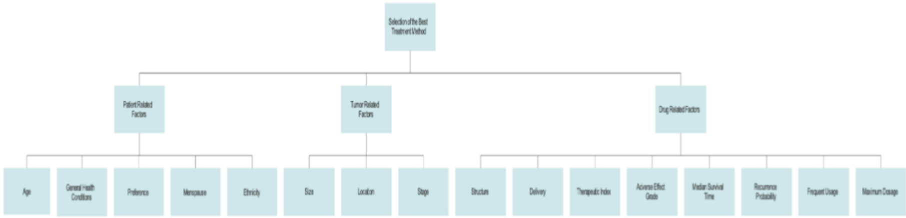

Fig. 2. A hierarchy for selection of the breast cancer treatment

These criteria are asked to the experts to make pairwise comparisons in terms of the five-point scale. After their relative weighting, F-AHP results are taken. Table 2 shows priorities concerning treatment selection.

Table 2. Priorities concerning treatment selection

Rank	Name	Weight
3	Patient-related factors	0.113
1	Tumor-related factors	0.549
2	Drug-related factors	0.338

As shown in the table above, according to the Selection of Treatment, Tumor-Related Factors is the first priority. Next priorities are assigned to Drug-Related Factors and Patient-Related Factors according to the obtained weights.

Following tables are the results of the analysis of subcriteria prioritization. Table 3 shows the patient-related factors' subcriteria ranking.

Table 3. Priorities concerning patient-related factors' sub-criteria

Rank	Name	Weight
2	Age	0.283
1	General health condition	0.446
4	Menopause	0.044
3	Preference	0.227
5	Ethnicity	0

As shown in the table above, according to the Patient-Related Factors, General health condition is the first priority.

Table 4. Priorities concerning treatment selection

Rank	Name	Weight
2	Size	0.049
3	Location	0
1	Stage	0.951

Next priorities are assigned to Age, Preference, Manopause, and Ethnicity according to the obtained weights. Table 4 shows the tumor-related factors' subcriteria ranking. Table 5 shows the drug-related factors' subcriteria ranking.

Table 5. Priorities concerning drug-related factors' sub-criteria

Rank	Name	Weight
4	Therapeutic index	0.102
5	Structure	0.08
6	Delivery	0.06
3	Adverse effect grade	0.196
1	Median survival time	0.267
2	Recurrence probability	0.258
7	Frequent usage	0.034
8	Maximum dosage	0.002

As shown in the table above, according to the Drug Related Factors, Median survival time is the first priority. Next priorities are assigned to Recurrence probability, adverse effect grade, Therapeutic index, Structure, Delivery, Frequent usage, and Maximum dosage according to the obtained weights.

5 Discussion and Conclusion

The results of the F-AHP model of this study is similar to the reference paper. Camgöz-Akdağ et al. used AHP to prioritize breast cancer treatment selection criteria and found that the first rank belongs to tumor-related factors, with nearly 50% of the total. This study inserted fuzziness and uncertainty to the model and solved F-AHP. The results were the same, but they now have different points. All main and subcriteria rankings are the same, but when numbers are considered, there are slight gaps.

Other multi-criteria decision-making models, with more detailed criteria, can be modeled to reach more accurate decision-making. Because of a healthcare problem, errors must be eliminated if possible. This kind of technological supports for medical personnel will decrease diagnosis time, which is very important when considering a cancer treatment process.

For further research, if found, more explicit data can be used, and the method can be changed. Other MCDM topic sets, such as hesitant, neutrosophic sets, can be used to see how the sets affect the final rankings. Furthermore, instead of AHP, other methods, such as ANP, PROMETHEE, TOPSIS, can be used to extend the method analysis.

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Mathematical Models of HIV: Methodologies and Applications

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Abstract. HIV is one of the significant public health threats globally, with approximately 36.9 million people living with HIV and 1.8 million people becoming newly infected in 2017 (WHO fact sheet). To prevent HIV, to decrease its impact and to eventually eliminate this infectious disease; clinical, medical, epidemiological, economic, and modeling studies have been conducted in the last 30 years. In this study, we explore the mathematical modeling studies where HIV has been examined to understand the dynamics and spread of the disease as well as to improve HIV prevention. We surveyed HIV modeling literature, summarized primary modeling methodologies, and briefly discussed relevant studies. For each study included in this paper, we presented their modeling method, interventions included, target populations, implementation process, key results, and insights. Two most widely used modeling methodologies for HIV are Bernoulli process models and dynamic compartmental models similar to other infectious diseases. These methodologies have been discussed in detail in this paper. Other modeling methodologies included Markov models, agent-based simulation models, and discrete-event simulation models. Many studies focused on risk populations such as heterosexual (HET), men who have sex with men (MSM), people who inject drugs (PWID) and jail inmates. We included the cost-effectiveness studies where HIV prevention and treatment interventions and strategies are compared concerning their costs and benefits. In this survey, we provided a summary of existing modeling literature as well as suggestions for future studies. We concluded that application of modeling tools for HIV presents excellent opportunities for both decision-makers and public health policymakers while predicting the future of this disease, establishing the most cost-effective prevention strategies and evaluating possibilities for the elimination of HIV.

Keywords: Mathematical Modeling · Infectious Disease · HIV · AIDS · Bernoulli Model · Compartmental Model · Markov Model · Agent-Based Simulation

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1 Introduction

HIV is one of the leading causes of death globally, and it is a significant public health challenge for all around the world (Joint United Nations Programme on HIV/AIDS 2012). In 2017, approximately 37 million people were living with HIV (PLWH), and this number is increasing with 5,000 new infections every day. To decrease the number of new infections and eventually eliminate HIV as a public health threat, the Joint United Nations Programme on HIV/AIDS (UNAIDS) prepared a new strategy intending to eliminate HIV by 2030. Although some targets such as the number of AIDS-related deaths and the number of new infections have fallen from their peaks, there is still a gap between targets to accomplish this goal and global realities (UNAIDS 2018). Moreover, significant variation exists for these statistics among regions. For example, Sub-Saharan Africa is the most severely affected region by HIV epidemic, and it has the most robust reductions in the AIDS-related mortality and the new infections while HIV epidemic is expanding in the Eastern Europe and several countries of Asia. (UNAIDS 2018; UNAIDS 2012; Piot and Quinn 2013). Overall, there is a need for further research and better strategies in the area of HIV prevention to reach UNAIDS goals and eliminate HIV.

HIV risk groups can be defined as subpopulations that have a higher risk for transmission and/or acquisition of HIV. In the low prevalence countries, risk groups are responsible for the majority of HIV infections. People who inject drugs (PWID, also known as IDU), sex workers (SW), transgender people, prisoners, and gay men and other men who have sex with men (MSM) and their sexual partners are among these key populations (UNAIDS 2017). The HIV prevalence among MSM in capital cities is 27 times higher than that in the general population, and recent data show that there is a rising trend in MSM HIV prevalence. PWIDs are among the population groups that are most severely affected by HIV, and the risk for acquiring HIV is 23 times higher for this group (UNAIDS 2012; UNAIDS 2018).

The recommended treatment for HIV is known as antiretroviral therapy (ART). In 2017, around 22 million, which is 59% of PLWH have access to ART globally (UNAIDS 2018; UNAIDS 2018). Health care organizations and governments have been endeavoring to fight against the disease, and there are some promising signs like advancing ART coverage in recent years. However, considering years of significant efforts, a large percentage of PLWH or people at risk for HIV have yet to have access to prevention, care, and treatment, and there is still no cure (UNAIDS 2018).

A reduction in HIV incidence has been a top priority to control the disease (Piot and Quinn 2013). It requires both to keep tracking of data available and use them in estimations for the future of the epidemic. In addition to this, we need to understand HIV behavior over time and evaluate the prevention efforts in a way that make the outcomes as useful as possible. With the significant increase in the modeling studies about HIV prevention in the last decade, it is apparent that mathematical models have become valuable and vital tools in analyzing the spread of infectious diseases, prevent and control these diseases. Models can be used for analyzing and testing theories, answering specific questions, figuring out the transmission characteristics, and key parameters from data for many infectious diseases (Hethcote 2000). Similarly, there has been a wide variety of mathematical models of HIV to understand disease dynamics and offer better prevention strategies.

In this study, we briefly discussed key methods of mathematical modeling for infectious diseases that included both deterministic and stochastic models. We described and focused on mainly three modeling techniques: (i) Bernoulli process models, (ii) dynamic compartmental models, and (iii) Markov models. We conducted a thorough literature search and summarized critical examples for each model. Although we have not included agent-based simulation in the modeling methods section, we included studies applied agent-based simulation in the literature review table. Our goal is to summarize main infectious disease modeling methods, to list HIV-related modeling studies chronologically, and then for each selected study, to present the study objectives, the model type, populations and interventions included in the study as well as critical insights. Although this list of studies is not comprehensive, it provides a summary of significant studies, and it covers the majority of high-impact research on HIV prevention.

The remainder of this paper is organized as follows. In Sect. 2, we present three main types of modeling methods which are often employed for infectious diseases. In Sect. 3, we present a table of HIV-related mathematical modeling studies.

2 Modeling Methods

Models reduce the complexity of a system to its essential elements; in other words, they represent a simplification of reality at a sufficient level of detail. From the health care perspective, models create mathematical frameworks that are used for the estimation of the consequences for health care decisions (Caro et al. 2012). Therefore, they are essential tools to utilize in exploring the dynamics of HIV infection. Many mathematical models developed for HIV use individual-level data to attain population-level outcomes such as incidence and prevalence of infection (Sayan et al. 2017).

There are many different modeling approaches in the literature. However, three most widely used methods are included in this review, and these methods are Bernoulli process model, dynamic compartmental model, and the Markov model. Other methodologies, such as agent-based simulation models, stochastic models, and system dynamics, are also employed to analyze and project the dissemination of HIV (Akpinar 2012). While we have not included these techniques in this paper, we included studies that used them in Sect. 3. We conducted a search of 3 electronic databases, including PubMed, Web of Science, and Google Scholar for relevant studies published in English from the earliest data available for the database to January 2019. We used a broad search strategy with appropriate keywords and Medical Subject Heading (MeSH) terms to identify HIV mathematical modeling studies. We included the keywords "HIV," "AIDS," "Mathematical Modeling," "Bernoulli Model," "Compartmental Model," "Markov Model," "Agent-Based Simulation" with Boolean operators 'OR' and 'AND.' From the articles and conference papers obtained through the electronic search, we screened based on the abstracts and titles, and we included HIV studies if they were original analyses; included a mathematical model as its main methodology and reported the model results. When we encountered two similar studies, we preferred to include more recent study. We summarized the selected studies in Table 1, where they are grouped based on the modeling technique, and they are ordered chronologically within each group.

2.1 Bernoulli Process Model

Bernoulli process model is based on the assumption that there is a certain probability of transmission each time an HIV infected person engages in some of HIV risk behaviors such as unprotected sex while each type of behavior is considered an independent event. Each event has a small fixed probability of transmission, which is called HIV infectivity, and it accumulates with the repetition of the related risk behavior (Pinkerton and Abramson 1998).

The cumulative probability of transmission for multiple contacts with an infected person is calculated using the following equation. In this equation, α represents infectivity, while n is the number of contacts (Pinkerton and Abramson 1998).

$$P = 1 - (1 - \alpha)^n \tag{1}$$

Today, among people living with HIV, about 9.4 million people do not know their HIV status (UNAIDS 2018). HIV may not show any symptoms for several years. Thus, in many cases, people do not know whether their partner is HIV infected or not. To include this uncertainty to the model, the following equation is proposed and the prevalence of infection, denoted with π, is added as a coefficient that reflects the probability of selecting an infected partner (Pinkerton and Abramson 1998).

$$P = \pi\left[1 - (1 - \alpha)^n\right] \tag{2}$$

Infectivity can be affected by various factors. Protected sexual intercourse is one of the prevention methods, and it reduces the infectivity of HIV. To provide a cumulative probability for a more complex situation, we can include m different sexual partners with k_i protected, and n_i unprotected sexual contacts, respectively. The model becomes following general form for the situation with multiple partners (Pinkerton and Abramson 1998).

$$P = 1 - \prod_{i=1}^{m}\left\{1 - \pi\left[1 - (1 - \alpha_n)^{n_i}(1 - \alpha_k)^{k_i}\right]\right\} \tag{3}$$

2.2 Dynamic Compartmental Model

Infectious diseases have been analyzed using dynamic compartmental models since 1927 (Akpinar 2012). In this type of models, populations divided into subgroups, which are called compartments. The main idea behind the construction of the model is that an infected person comes across with healthy individual and transmit the disease. There are many types of compartmental models such as SI, SIR, SIRS, SEIR, MSEIR, etc. selected based on different characteristics of infectious disease.

SIR compartmental model has three different compartments. In this model, S represents Susceptible, I represents Infected, and R shows the Recovered (or removed) (Fig. 1). For SIR model, we have transitions from S to I, which involves disease transmission and from I to R, which shows that infected patients recover from the disease. These movements occur at some defined rates known as infection rate and recovery or removal rate. To define the model with differential equations, a closed population that has no births and deaths, no migration is taken into account (Keeling and Rohani 2011).

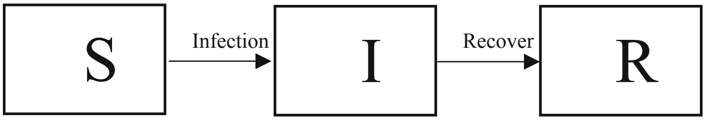

Fig. 1. SIR model diagram (Keeling and Rohani 2011).

SIR model is mathematically defined in the following equations where β is the transmission rate, and γ is removal or recovery rate (Keeling and Rohani 2011).

$$\frac{dS}{dt} = -\beta SI \tag{5}$$

$$\frac{dI}{dt} = -\beta SI - \gamma I \tag{6}$$

$$\frac{dR}{dt} = \gamma I \tag{7}$$

2.3 Markov Model

Markov model is known as a stochastic process that has Markovian property. Markovian property is based on the assumption that the conditional distribution of any future state depends only on the present, and it is shown in the equation as follows (Ross 2007).

$$P\{X_{n+1} = j | X_n = i, X_{n-1} = i_{n-1}, .., X_1 = i_1, X_0 = i_0\} = P\{X_{n+1} = j | X_n = i\} = P_{ij}$$

We assume that X_n is state i at time n and P_{ij} represents the probability that process will move from state i to state j then, this equation defines a model for all states i, j and all n that are greater or equal to 0. (Ross 2007).

Many clinical situations can be described in terms of the conditions that individuals can be in, how they can move among such states, and how likely such moves are (Fig. 2). These correspond to states, transitions, and transition probabilities, respectively. State transition models (STM) are well suited to the decision problems in these situations, and they are found reasonable when the decision problem can be described in terms of states and interactions between individuals are not necessary. Markov models are one of the STM modeling approaches, and they are based on cohort level. Thus, Markov modeling approach presents transparency, efficiency, and ease of debugging. They are recommended if a manageable number of health states are sufficient to describe all relevant characteristics of the problem. These states help biological/theoretical understanding of the disease and reflect the disease process with transitions. Interventions such as screening, diagnostics, and treatment can be included in the model to evaluate their effects (Siebert et al. 2012).

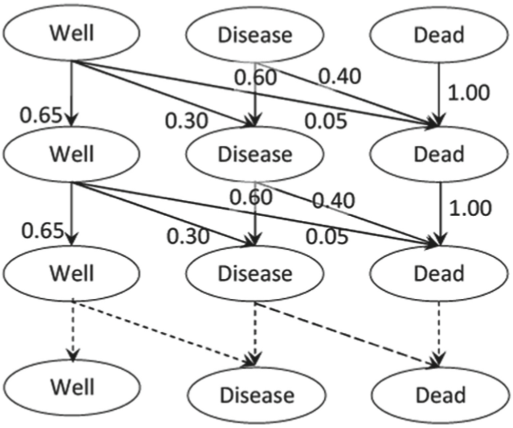

Fig. 2. Markov model diagram (Siebert et al. 2012)

3 HIV Mathematical Modeling Studies

Table 1. Literature review

Authors	Year	Short summary	Model type	Country	Model objective	Interventions	Risk populations	Key results/Insights
Downs et al.	1996	Isotonic regression and Bernoulli Model were performed, and their results were compared	Bernoulli Process Model	Nine different countries involved in the European study	To evaluate the relationship between the number of heterosexual contacts and HIV transmission probability		Heterosexual (HET) couples	The relation between the number of contacts and transmission probability could be well designed by a more complex model approach instead of those with constant per-contact infectivity
Pinkerton and Abramson	1996	The probability of transmission for different infectivity levels with protected and unprotected intercourse and reproductive rate of HIV transmission was found	Bernoulli Process Model		To estimate the dependence of HIV infectivity based on disease stage			Infectivity of HIV and reproductive rates of infection are obtained for the initial period and asymptomatic period of HIV
Pinkerton, Holtgrave, and Valdisseri	1997	The number of HIV infections prevented is determined. Costs and cost-effectiveness of two interventions are compared	Bernoulli Process Model		To decide whether skills-training should be included among HIV interventions	A safer sex lecture and the same lecture with a 1.5-h skills-training group session	Men who have sex with men (MSM)	According to the model results, skills-training was found both cost-effective and cost-saving
Bos et al.	2001	Using total costs and the number of infections averted, the authors estimated costs per life-year gained	Bernoulli Process Model	Netherlands	To investigate the cost-effectiveness of HIV screening for a clinic	HIV screening of STD-clinic patients	STD clinic attendees	Screening of STD-clinic patients for HIV was found cost-effective
Wilson et al.	2003	The authors constructed a model which includes behaviors and estimates individual HIV infection probability by taking into account of sexual histories of partners. Sexual behaviors were obtained from interviews	Bernoulli Process Model	US	To analyze HIV risk behaviors and risky characteristics of Latino couples in California		Latino couples in California	Results indicated that HIV risk of women is higher than men. They also revealed demographic, behavioral, and psychosocial factors affecting HIV risk for both male and female partners
Pearson et al.	2007	The authors worked on a study group, and their model predicted HIV prevalence of unprotected sex, and they extrapolated the results to find the expected number of secondary infections annually. They later estimated the effect of interventions	Bernoulli Process Model	Mozambique	To predict the number of new HIV infections according to the sexual behaviors of a study group taking HAART treatment	Increased condom use and HAART along with syphilis and herpes simplex virus type 2 (HSV-2) treatment	Men and women initiating HAART	The number of HIV infections per year was estimated. HAART, along with syphilis and herpes simplex virus type 2 (HSV-2) treatment could reduce HIV transmission more than increasing condom use

(continued)

Table 1. *(continued)*

Authors	Year	Short summary	Model type	Country	Model objective	Interventions	Risk populations	Key results/Insights
Fox et al.	2011	From a literature search, the odds ratios of factors for HIV exposure risk scores are determined. A model framework which estimates the risk of HIV acquisition based on reported sexual practices, STI status, and partners' infectiousness is developed	Bernoulli Process Model		To generate HIV exposure risk between serodiscordant couples according to biological and behavioral factors		HIV serodiscordant couples	Risk estimates for scenarios concerning male-male, male-female, and female-male transmission were presented. Risk multipliers considered were viral load, stage of HIV infection, and the presence of genital ulcer disease, HSV-2, and type of sex acts
Wang et al.	2011	The authors included the effect of interventions as the change in the sexual behaviors and measured it by the number of infections averted. Then, they performed a cost-effectiveness analysis with disability-adjusted life years (DALY)	Bernoulli Process Model	China	To determine the cost-effectiveness of voluntary testing and counseling	Free HIV voluntary counseling and testing	General population and men who have sex with men (MSM)	Free HIV voluntary counseling and testing strategy were found to be cost-effective for high-risk populations such as MSM other than the general population
Lin et al.	2013	They measured the effectiveness of interventions with the reduction in risk of transmission under different budget allocation strategies	Bernoulli Process Model	California	To analyze how budget cuts on HIV interventions could affect the number of newly infected HIV patients	Testing and risk reduction programs	HET, IDU, and MSM	Budget cuts could result in additional new HIV patients while optimizing the budget effectively could avert these new infections. To achieve that, it was recommended to allocate the budget to cost-effective programs
Adams et al.	2013	By interviewing with jail inmates at different times (30 days before, six months after or 1 year) before incarceration and post-release, behavioral data have been collected and based on data, HIV risks were calculated	Bernoulli Process Model	Northern Virginia	To determine HIV risk behaviors of men and women jail inmates		Jail inmates	HIV risk was found to be decreasing in the inmates after release. Behavioral differences between men and women could be used to develop appropriate intervention programs

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Table 1. (*continued*)

Authors	Year	Short summary	Model type	Country	Model objective	Interventions	Risk populations	Key results/Insights
Lin et al.	2016	The model was developed to estimate the reduced annual HIV risks due to interventions. Costs per averted HIV case and QALY's were also calculated	Bernoulli Process Model	US	To compare alternative preventions and target populations for HIV in terms of cost-effectiveness	HIV testing in clinical and non-clinical settings, partner services, improving linkage to care, retention in care, improving adherence to ART, behavioral interventions for HIV infected and uninfected persons, circumcision, Pre-exposure prophylaxis (PrEP)	MSM, IDU and sexually active heterosexuals	After the economic analysis, the most cost-effective combination of population and interventions were determined. HIV testing and providing care and treatment presented the lowest cost per prevented case and interventions targeting MSM was the most cost-effective
Yaylali et al.	2016	Combination of linear programming and Bernoulli model was used for a resource allocation model. First, the most cost-effective interventions were determined, then a fixed budget has been allocated from the most cost-effective intervention to the least one until it is exhausted. The model was implemented for four health departments in real life	Bernoulli Process Model	US (Philadelphia, Chicago, Alabama and Nebraska)	To maximize the number of new infections averted to find an optimal allocation strategy for a fixed HIV budget	Testing in clinical and non-clinical settings, partner services, continuum-of-care–related interventions designed to improve linkage to care, retention in care, and adherence to ART, and behavioral interventions for HIV-positive and HIV negative persons	MSM, IDU and sexually active HET	According to results, testing for MSM in non-clinical settings was found the most cost-effective intervention, and behavioral interventions were the least cost-effective. Practitioners implemented the model in real life and reported the model as helpful
Lasry et al.	2011	In this study, the authors created a national HIV resource allocation model with SUD compartmental model for various combinations of intervention and populations. They provided a case study of the model application	Compartmental Model	US	To minimize the number of infections over five years	HIV screening interventions and interventions to reduce HIV-related risk behaviors	High-risk heterosexuals, IDU and MSM	Focusing on HIV risk groups such as IDU and MSM improved the effectiveness of resource allocation model
Cipriano et al.	2012	The authors determined the number of infections averted by identifying the status and stages of infection with compartments. They conducted a cost-effectiveness analysis and determined costs, QALYs, and ICERs for each strategy	Compartmental Model	US	To assess the cost-effectiveness of HIV and HCV screening alternatives for IDU population in the US	Screening individuals in opioid replacement therapy for HIV, HCV, or both infections with different testing alternatives and time intervals	IDUs in opioid replacement therapy (ORT)	It was concluded that doing HIV screening with both antibody and viral RNA testing in every 3-6 months was the most cost-effective screening strategy

(*continued*)

Table 1. (*continued*)

Authors	Year	Short summary	Model type	Country	Model objective	Interventions	Risk populations	Key results/Insights
Juusola et al.	2012	The authors developed a mathematical model for estimating the cost-effectiveness of PrEP. The model included awareness of HIV, HIV status, and PrEP use as treatment factor. Outcomes such as HIV incidence and prevalence, costs, and QALY's were calculated	Compartmental Model	US	To investigate the cost-effectiveness of PrEP and its implementation in the high risk and general MSM population	Pre-exposure prophylaxis (PrEP)	MSM	The model suggested that QALYs gained PrEP were cost-effective for high-risk MSM
Lasry et al.	2012	Different allocation scenarios of a fixed HIV budget were assessed by using an optimization model combined with an epidemic model. While the optimization model allocated funds to interventions and subpopulations, the epidemic model calculated the number of new infections	Compartmental Model	US	To develop an optimal resource allocation scenario which minimizes the number of new infections	HIV testing, individual and group-level counseling & education	High-risk heterosexuals, IDU and MSM	The authors suggested that funds for testing MSM and IDU should be increased and interventions should be developed for the high-risk individuals of HIV
Gilmour, Li, and Shibuya	2012	The authors developed a model that consisted of 10 compartments to generate projections of HIV prevalence. Two scenarios were defined according to varying parameter values, which represents the effect of interventions. The study also included a multivariate sensitivity analysis to measure the ranges of outcomes	Compartmental Model	Japan	To project the HIV infection in Japan for the next 30 years	Behavioral interventions such as higher rates of condom use amongst MSM, higher rates of HIV testing, and more effective passive case finding in PLWH	MSM, low-risk men, and low-risk women	When the current situation continued, HIV prevalence would be much higher by 2040 with a significant increase in MSM. Prevalence of HIV could be changed in a positive way with decreasing risky behaviors and increasing testing rates
Sorensen et al.	2012	The authors projected HIV infections among MSM and assessed the national HIV strategy. Model compartments were based on infection status, age groups, and sexual activity levels. They determined the number of HIV infections with the current situation and with different combinations of interventions	Compartmental Model	US	To estimate the potential benefit of interventions applied to decrease new HIV infections among MSM	Improvements in the annual HIV testing rate, notification of test results, linkage to care, earlier initiation of ART, and increase in HIV viral load suppression	MSM in urban population	Results showed that interventions related to test-and-treat could substantially decrease the number of new infections among MSM in New York City. Based on the model, five goals of the national HIV strategy could be achieved

(*continued*)

Table 1. (*continued*)

Authors	Year	Short summary	Model type	Country	Model objective	Interventions	Risk populations	Key results/Insights
Alistar et al.	2014	The authors applied an SIT compartmental model combined with a non-linear optimization model. The model utilized with a single population or multiple independent populations and then two interacting populations	Compartmental Model	Russia and Uganda	To minimize the reproductive rate of infection so that the resources could be allocated efficiently among the HIV prevention and treatment options	Investment in prevention (such as condom promotion and associated counseling) and treatment programs	General population and IDU	For Uganda, condom programs were found to be preferable, and for Russia, it was more efficient to focus on prevention strategies on IDU rather than other populations
Baggaley	2017	The author developed a model considering HIV progression, CD4 count, and diagnosis status. The model calculated HIV incidence and the effect of HIV screening. The study included QALY and ICER estimations for 30 years, 40 years, and 50 years	Compartmental Model	UK	To determine the cost-effectiveness of early HIV diagnosis using data from a randomized controlled trial	Rapid testing for HIV in primary care or called an RHIVA2 trial which is done by primary care physicians	MSM and HET	The results suggested that HIV screening in primary care was cost-effective in the medium-term (33 years)
Sayan et al.	2017	To analyze the dynamics of HIV, the number of HIV cases, and the basic reproduction ratios were calculated from a mathematical model that consisted of 3 compartments. Model results were compared with surveillance data	Compartmental Model	Turkey	To find HIV/AIDS cases and to calculate the reproduction ratios between 1985–2016	No interventions included in the model	General population	Results indicated that there is an increasing reproduction rate of HIV. Thus, the authors concluded that there is a need for more interventions from public health authorities
Longini et al.	1991	Authors developed a model with eight states based on CD4 count. Transitions were progression rates indexed with co-factors such as age, gender, etc. The model employed data from the US Army	Markov Model	US	To estimate HIV progression rates	No interventions included in the model	General population	The authors estimated the mean waiting times between HIV progression stages and the proportion of people with decreased CD4 count. Results showed that age was an essential factor in HIV progression
Sanders et al.	2005	The authors examined no screening, one-time screening, and recurrent screening strategies according to their costs and benefits. Model states defined by the history of disease, awareness, CD4, and viral load count and treatment status	Markov Model	USA	To evaluate the cost-effectiveness of screening for HIV	HIV Screening	MSM, IDU Heterosexual Men, and Women	HIV screening was found to be, and it could potentially provide significant benefits in improving HIV prevention

(*continued*)

Table 1. *(continued)*

Authors	Year	Short summary	Model type	Country	Model objective	Interventions	Risk populations	Key results/Insights
Xuan, Xu, and Li	2009	In this agent-based simulation model, new agents are included with infection and agents removed from the model with deaths. The model included six stages, which are healthy, dangerous, infected, infectious, symptomatic, and deceased	Cellular automata Simulation Model		To understand the dynamics of HIV/AIDS better		General population	The authors concluded that HIV could potentially end up with either extinction or persistence. The factors associated with the increase in the infection level were agents' mobility, population density, initial infection ratio, and the extent of neighborhood increasing
Hontelez et al.	2011	The authors presented a STDSIM, individual-based microsimulation model for a dynamic network of sexual contacts. They evaluated the impact of several re-vaccination strategies depending on coverage (30% and 60%) and time intervals (2 years and 5 years)	Microsimulation model	South Africa	To predict the impact and the cost-effectiveness of HIV vaccination	Vaccination		The authors mentioned that one-time vaccination had limited impact. Results suggested that re-vaccination strategies could be cost-effective for certain coverage and time interval strategies
Gopalappa et al.	2012	A Monte Carlo simulation model was developed to represent the interaction between HIV infected patients and healthy people and their transmission routes. Costs and QALY's under different linkage to care scenarios were assessed with the help of the model	Simulation Model		To find the maximum cost value that could be spent on linkage to care programs without losing the cost-effectiveness of this intervention and to analyze the cost-effectiveness of the national target of linking 85% of HIV infected patients to care	Antiretroviral Treatment Access Study (ARTAS) type intervention, an implementation designed to link people recently diagnosed with HIV to medical care		Increasing the rate of early linkage to care found to be, and the sensitivity analysis showed that CD4 level at the time of diagnosis has the most significant effect on the cost-effectiveness value
Beyrer et al.	2012	The authors defined key factors of HIV for MSM. Then, the importance of these factors was evaluated by calculating the reduction in the model outcomes of each counter-factual scenario based on varying factor values	Agent-Based Network Simulation Model	USA and Peru	To compute the cumulative number of infections over five years		MSM	Based on the results, key drivers of HIV among MSM were obtained. High probability of transmission per act through receptive anal intercourse was found to have an important role, and interventions focused on this factor could be crucial
Bristow et al.	2016	The authors defined four different combinations of HIV and syphilis screening strategies. A model for antenatal patients was developed, and the model outcomes included the expected costs and expected newborn DALY's for each strategy. One-way and Monte Carlo multi-way sensitivity analysis was conducted	Markov Model	Africa	To evaluate the cost-effectiveness of different screening strategies for HIV and syphilis	Screening		Results showed that dual HIV and rapid syphilis test was cost-effective and resulted in fewer DALY's. Based on the multivariate sensitivity analysis, dual HIV and rapid syphilis test was cost-saving for all iterations

4 Conclusion

Many mathematical models have been developed and implemented in estimating and controlling infectious diseases. HIV is one of such diseases with an extensive literature of modeling studies that aimed at the prediction of HIV in different countries and target populations, the evaluation of prevention and treatment strategies in terms of their cost-effectiveness, the optimal allocation of HIV budgets and other many applications. This study summarizes 28 papers about HIV modeling that covers between 1991 and 2018. Different modeling methodologies applied in these studies have been presented, and these methods included the three most common techniques, which are the Bernoulli model, a dynamic compartmental model, and the Markov model. The majority of the papers focus on the economic analysis of prevention strategies, and mathematical modeling is employed to estimate the number of infections averted under different prevention strategies. Determining the incidence and prevalence of the disease in a specific location or for a target population is another popular study objective through understanding the spread of HIV. These studies often analyzed risk groups and their risky behaviors and estimated the health and economic outcomes to inform the decision-makers about the future of epidemic, possible interventions, and their consequences. There are some advantages and limitations of modeling methods used in the studies. Bernoulli model is a static approach while estimations from a compartmental model continue over some time due to its dynamic nature. However, compartmental models assume people in the same compartments are acting and responding to the disease in the same way. Markov models complement the HIV progression process by adding the stochastic framework into the problem. Agent-based simulation systems are useful and displays system in a more realistic way, however, they are data-intensive and cannot be generalized to other regions or populations. Although each methodology has some advantages and disadvantages, they are essential to understand the disease dynamics, and they provide us the opportunity to predict the future of the disease and find appropriate prevention and intervention methods.

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Modelling Hepatitis C Infections Among People Who Inject Drugs in Turkey: Is HCV Elimination Possible?

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Abstract. Hepatitis C (HCV) is one of the major infectious diseases in the world. Injection drug users (PWID) is a population who is at higher risk of acquisition of HCV due to risky behaviors such as needle sharing, and they are considered as an important factor in the spread of the disease. World Health Organization (WHO) aims to eliminate hepatitis C disease by 2030 with the help of approval and dissemination of newly developed direct-acting antiviral treatment regimes. In this study, we evaluated the cost-effectiveness of hepatitis C treatment among injected drug users in Turkey to observe whether it is possible to reach WHO targets. Purpose of our model is to determine the infected population in the future, and we simulated the injected drug user population with a time horizon of 20 years. We developed five scenarios to represent different levels of treatment coverage. We included treatment regimens that are available in Turkey and that are reimbursed by the government health care insurance policies, which roughly covers over 90% of the Turkish population. Our model objective is (i) to predict the spread of HCV in the next 20 years, (ii) to determine the cost of new treatment regimens available to Turkish PWID population and (iii) to estimate the cost-effectiveness of these regimes. Our results indicate that HCV infected PWIDs could significantly decrease with treatment while the lowest total cost of treatment could be achieved with Viekirax Exviera and Mavyret. Also, it is possible to reach WHO targets by 2030 in Turkey if the treatment coverage increases.

Keywords: SIR model · Hepatitis C · Injection drug users · Cost-effectiveness

1 Introduction

The infectious diseases are one the leading causes of death in the worldwide (Bayer College of Medicine n.d.). One of the important infectious diseases is Hepatitis C (HCV) that causes approximately 399,000 million people to die in every year. Globally, it is estimated that the number of people who have chronic HCV infection is 71 million. Hepatitis C is often transmitted with injection sharing, medical procedures, and blood products (World Health Organization 2018). Transmission of HCV is most commonly correlated with injection drug users (PWID). According to the American Journal of Epidemiology, 70–80% of injection drug users are HCV positive in Seattle

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(Hagan et al. 1999). In China, the prevalence of HCV infection is 98% in PWID population; other regions vary between 85–95% (Hagan et al. 2010).

Probability of PWID related HCV could be associated with risky injection behaviors such as needle sharing (Thorpe et al. 2002). In a study by Thomas et al. (1995), 78% of study participants infected with HCV within two years of initiation of injection drug use. Injection risk behaviors include sharing injectors, drug apparatus such as cookers which are used for the preparation of drugs, and sharing syringe/needles (Hagan et al. 1999). It is reported that 37% of HCV infected PWIDs are infected via communion of drug preparing apparatus (Hagan et al. 2010). According to the Centers for Disease Control and Prevention (CDC), the likelihood of HCV infection risk is 0.1% with a single instance of needle sharing (Centers for Disease Control and Prevention n.d.).

It is estimated that there are 185 million persons who are drug users worldwide, which consists of 3% of the total population. Among all drug users, the injection drug user population is estimated to include around 13 million in the world. Developing countries contribute 78% of PWID population (World Drug Report 2004). Moreover, there are 10 million injection drug users who are infected with HCV and 8 million PWIDs with chronic HCV infection. Environmental, financial, societal, and political agents are significant factors to contribute to the acquisition of HCV in PWIDs (Strathdee et al. 2010). To prevent HCV infection in PWIDs; treatment and educational programs about reducing risky injection sharing and injection duration could be implemented. Furthermore, HCV incidence could be decreased with the reduction of injection usage and frequency (Grebely and Dore 2011). In recent years, increasing non-injecting drug use resulted in diminishing HCV ratio in the Netherlands (Van Den Berg et al. 2007).

Recent advances in the treatment of HCV initiated a new era in the prevention and treatment of HCV. Direct acting antiviral treatment (DAA) has a considerable higher sustained viral response (SVR), less side effects, and shorter treatment duration compared to the old standard of care interferon-based treatment. However, it also has a significantly higher cost. In Turkey, which has a national-wide, government-regulated health insurance coverage, DAA is reimbursed for all HCV patients. While DAA reduces the risk of HCV due to better effectiveness of treatment, injection drug users are still a vulnerable population with an increased risk of (re)infection rate. Our study analyses this trade-off and aims to explore the optimal treatment strategy that would minimize the PWID population and the cost of treatment.

In 2016, the World Health Organization (WHO) announced its global plan to eliminate HCV and set targets in diagnosis and treatment by 2020 and 2030 that would eliminate HCV as a public health threat. (World Health Organization n.d.). In this paper, we investigated whether the elimination of HCV is possible among PWID in Turkey by 2030, as suggested by WHO. We developed a dynamic compartmental model, also known as SIR model, where the compartments of the model represented different stages of HCV and diagnosis/treatment status. The purpose of the model is to predict the population of PWIDs by 2030 and to evaluate the cost-effectiveness of available HCV treatment in Turkey.

The remainder of this paper is organized as follows. In Sect. 2, we briefly discuss the literature of infectious disease modeling and HCV related key studies with a focus on cost-effectiveness studies. In Sect. 3, we present a dynamic compartmental model of HCV transmission and progression among PWID in Turkey, including the parameter estimation. In Sect. 4, we present the numerical results of the model, and we discuss our key findings, limitations, and future research directions in Sect. 5.

2 Literature Review

Mathematical modeling is commonly used in many infectious diseases such HIV (human immunodeficiency virus), HCV, HBV (hepatitis B), HEV (hepatitis E), malaria, gonorrhea and pandemic flu (Hethcote 2000). One of the most widely utilized modeling tools for infectious diseases is dynamic compartmental models, which are also known as SIR models. These models were developed by Kermack and McKendrick in 1927. The SIR model is one of the infectious disease models in which we can represent the life cycle of the disease, which enables us to observe the rate of disease spread and the rate of recovery from an infectious disease (Kretzschmar and Wallinga 2010). SIR models could be developed to assess the effectiveness of prevention strategies such as inoculation or vaccination and treatment strategies. Also, they could be utilized for determining the optimal combination of inoculation and treatment strategies, which may reduce the most number of infected persons with the minimum cost (Yusuf and Francis 2012).

There are many examples of SIR models applied to a variety of infectious diseases. For a summary of SIR models and their application, see Hethcote (2000). Stone et al. (2000), for instance, developed a basic SIR model for assessing whether it is possible to eliminate measles with pulse vaccination, which means to vaccinate population repetitively. In another study, the discrete ways of transmission and results of seasonality were analyzed to determine the occurrence of infectious diseases in seasonal variation. For seasonal contagion, a SIR model was used to specify optimal strategies of ordinary and pulse vaccination (Grassly and Fraser 2006). In a similar study, the scale of infection and dissemination of dengue fever were analyzed in the Republic of Indonesia, South Celebes, Selangor, and Malaya. The model results indicated that dengue virus achieved the highest level in a short time in these four countries, and the virus was not endemic (Side and Noorani 2013). More applications of SIR models and how to formulate and utilize these models for infectious diseases can be seen at Kretzschmar and Wallinga (2010).

There are several epidemiologic and economic studies of HCV in the literature. The most common variety of these studies were developed to estimate the economic and medical implications of HCV and the cost-effectiveness of screening and treatment strategies. In a cost-effectiveness study of new DAA treatment in the US, Sofosbuvir and Ledipasvir are found to be cost-effective and safer compared to old standard-of-care treatment based on interferon. However, due to the higher cost of a new treatment, treatment of all HCV patients in the US may require an additional budget of $65 billion in a five years period (Chhatwal et al. 2015). In a similar study, comparison between sofosbuvir based new DAA treatment and old standard treatment concerning cost and effectiveness has been determined in patients with chronic HCV in Switzerland. The study results suggested that sofosbuvir treatment was the most cost-effective compared to standard treatment when the cost-effectiveness threshold was assumed to be ₣100,000 per quality-adjusted life year (QALY) from Swiss medical care system point of view

(Pfeil et al. 2015). In a study focused on jail inmates in the US, the screening of HCV recommended due to higher HCV prevalence in this population although the screening yielded to a higher cost (He et al. 2015). In a similar study, the cost of HCV screening in PWIDs surpassed $100,000/QALY threshold of cost-effectiveness, and it is reported that awareness of HCV status should result in a substantial reduction in needle-sharing behavior for screening to be cost-effective (Cipriano et al. 2012). In Australia, a study evaluated the cost-effectiveness of new DAA treatment, which is provided with interferon-free antiviral among PWIDs. For injection drug users who are infected HCV, the new treatment was found to be cost-effective and resulted in a substantial decrease in the rate of liver-related mortality (Scott et al. 2016).

There are few statistical and economic studies in Turkey, which explores the cost-effectiveness of treatment strategies or the relationship between HCV and PWIDs. However, to the best of our knowledge, there are no studies that combine these two important facets of the HCV epidemic and explores the cost-effectiveness of new DAA treatment among PWIDs in Turkey as our study does. Alaei et al. (2017) examined HCV infection rates among injection drug users between 2012 to 2013, and they reported that nearly 52% of PWIDs were HCV-positive, and the majority of these cases reported sharing of used needles. The authors observed that HCV was 3.5 times more common in PWIDs than HIV. The study most relevant to our work is Örmeci et al. (2017). In this study, the authors evaluated the cost-effectiveness of HCV treatment by 2030 in Turkey and developed scenarios to observe the effect of achieving WHO targets. They developed an Excel-based disease progression model and considered treatment as a coverage without considering the stage of HCV. Their results suggested that achieving WHO targets could reduce HCV prevalence by 70% and the number of liver-related deaths by 65% by 2030 in Turkey. The cost of achieving WHO targets by increasing treatment levels would be around 4.4 billion USD at the end of this period (Örmeci et al. 2017).

3 Methodology

We formulated a dynamic, compartmental model of HCV transmission and progression for 18–65 years old PWID population in Turkey. In our model, only the treatment-naïve HCV population were included, and the model was stratified by disease stage where each compartment represents healthy persons, HCV-infected persons by disease stage and death. HCV stages are based on METAVIR fibrosis score where F0 is the mildest disease severity with no fibrosis, and F4 is the most severe stage with cirrhosis. Other disease stages included decompensated cirrhosis, hepatocellular carcinoma, and liver transplant. It was reported in the medical literature that there are around 10–20% of HCV infections recover during the acute phase before the disease becomes chronic without any treatment due to patients' immune system and we included this phenomenon in our model. We assumed only the patients with end-stage liver diseases are eligible for a liver transplant. As a result, we allowed patients only at Decompensated Cirrhosis, and Hepatocellular Carcinoma phase moves to the Liver Transplant phase. Similarly, we assumed death related to HCV only happens when the disease is in the severe stages such as Decompensated Cirrhosis and Hepatocellular Carcinoma or during/after Liver Transplant. The notation used in the model is as follows.

T: represents the year, where $t = \{0, 1, \ldots, 11\}$, $t = 0$ presents 2019 and $t = 11$ represents 2030.
$S_{(t)}$: The number of HCV-negative PWIDs at time t.
$A_{(t)}$: The number of HCV-positive PWIDs in the acute phase at time t.
$F0_{(t)}$: The number of HCV-positive PWIDs in the F0 phase at time t.
$F1_{(t)}$: The number of HCV-positive PWIDs in the F1 phase at time t.
$F2_{(t)}$: The number of HCV-positive PWIDs in the F2 phase at time t.
$F3_{(t)}$: The number of HCV-positive PWIDs in the F3 phase at time t.
$F4_{(t)}$: The number of HCV-positive PWIDs in the F4 phase at time t.
$DC_{(t)}$: The number of HCV-positive PWIDs in the Decompensated Cirrhosis phase at time t.
$HCC_{(t)}$: The number of HCV-positive PWIDs in the Hepatocellular Carcinoma phase at time t.
$LT_{(t)}$: The number of HCV-positive PWIDs in the Liver Transplant phase at time t.
$DH_{(t)}$: The number of HCV-related deaths at time t.
$R_{(t)}$: The number of PWIDs recovered from HCV at time t.
AR(t): The number of PWIDs who recovers from HCV in the acute phase before the disease becomes chronic without treatment.
μ_i: annual mortality rate where $i = \{0, 1, 2, 3\}$, $i = 0$ represents the annual mortality rate from all causes, $i = 1$ represents the mortality rate of Decompensated Cirrhosis, and $i = 2$ represents the mortality rate of Hepatocellular Carcinoma, $i = 3$ represents the mortality rate of Liver Transplant.
β_1: represents the force of infection, which is the rate of disease acquisition for an uninfected person from an infected person. This is also the rate of flow between Susceptible compartment to Acute compartment.
B_j: represents the rate of flow between compartments where $j = \{2, \ldots, 12\}$. In this model, this is disease progression among different stages of HCV. In other words, $j = 2$ represents the rate of flow from Acute to F0 phase, $j = 3$ represents the rate of flow from F0 to F1 phase, $j = 4$ represents the rate of flow from F1 to F2 phase, $j = 5$ represents the rate of flow from F2 to F3 phase, $j = 6$ represents the rate of flow from F3 to F4 phase, $j = 7$ represents the rate of flow from F4 to Decompensated Cirrhosis phase, $j = 8$ represents the rate of flow from Decompensated Cirrhosis to Hepatocellular Carcinoma phase, $j = 9, 12$ represent the rate of flow from Hepatocellular Carcinoma or Decompensated Cirrhosis phase to Liver Transplant phase, respectively, $j = 10, 11$ represent the rate of flow from F3 or F4 to Hepatocellular Carcinoma phase, respectively.
r_k: represents the recovery rate, where $k = \{1, 2, \ldots, 9\}$, $k = 1$ represents the recovery rate from acute phase, $k = 2, 3, 4, 5$ *and* 6 represent the recovery rate from F0, F1, F2, F3, and F4 phases, respectively, $k = 7$ represents the recovery rate from Decompensated Cirrhosis, $k = 8$ represents the recovery rate from Hepatocellular Carcinoma, $k = 9$ represents the recovery rate from Liver Transplant.
r_e: represents the reinfection rate.
η: annual birth rate.

Figure 1 shows the flow diagram of the dynamic compartmental model. The model allocates all PWID population among compartments, which represent disease status and disease stages. The movement between compartments, if possible, is represented as an annual rate and denoted with an arrow in Fig. 1. Each compartment presents either disease states (HCV-negative or HCV-positive) or disease stage: HCV-negative/susceptible (S), acute phase (A), METAVIR fibrosis stages of HCV (F0-F1-F2-F3-F4), Decompensated Cirrhosis (DC), Hepatocellular Carcinoma (HCC), Liver Transplant (LT), Recovery from HCV (R), death (D), and recovery from acute phase (AR). Death from all causes and recovery are possible from every compartment. Persons within each compartment can remain in the same compartment, or they could move to other compartments if there is a flow towards that compartment. The rate of movement between the compartments relies on the current situation of a person such as a disease stage and adequate contact rate for the persons in the Susceptible compartment. For instance, if an injection drug user who is HCV-negative (S) has a risky contact with an HCV-positive patient from other compartments. As a result, he/she is infected with HCV, then that person is moved to the acute compartment (A). Similarly, injection drug users could stay in different fibrosis stages of HCV, go to recovery states based depends on the patience's annual survival possibility. All possible movements represent infection, disease progression, recovery, or death in Fig. 1 below, and they are formulated as a series of ordinary differential equations.

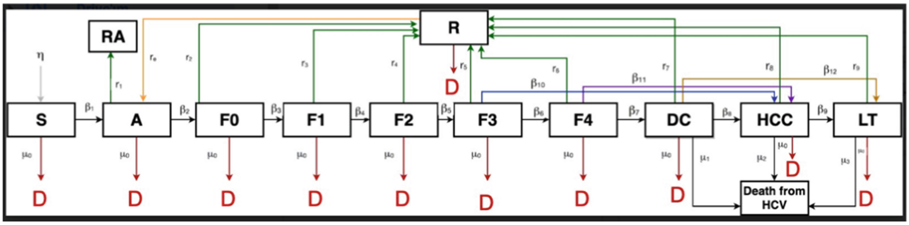

Fig. 1. A dynamic compartmental model of HCV

The population size of each compartment at any time t can be solved using the following differential equations. These equations are developed from basic compartment model equations (Kretzschmar and Wallinga 2010).

$$\frac{dS}{dt} = \eta - \mu_0 S_{(t)} - S_{(t)}\beta_1 \tag{1}$$

$$\frac{dA}{dt} = R_{(t)}r_e + \beta_1 S_{(t)} - \beta_2.A_{(t)} - \mu_0 A_{(t)} - r_1 A_{(t)} \tag{2}$$

$$\frac{dF0}{dt} = \beta_2 A_{(t)} - \beta_3 F0_{(t)} - \mu_0 F0_{(t)} - r_2 F0_{(t)} \tag{3}$$

$$\frac{dF1}{dt} = \beta_3 F0_{(t)} - \beta_4 F1_{(t)} - \mu_0 F1_{(t)} - r_3 F1_{(t)} \tag{4}$$

$$\frac{dF2}{dt} = \beta_4 F1_{(t)} - \beta_5 F2_{(t)} - \mu_0 F2_{(t)} - r_4 F2_{(t)} \tag{5}$$

$$\frac{dF3}{dt} = \beta_5 F2_{(t)} - \beta_6 F3_{(t)} - \mu_0 F3_{(t)} - r_5 F3_{(t)} - \beta_{10} F3_{(t)} \tag{6}$$

$$\frac{dF4}{dt} = \beta_6 F4_{(t)} - \beta_7 F4_{(t)} - \mu_0 F4_{(t)} - r_6 F4_{(t)} - \beta_{11} F4_{(t)} \tag{7}$$

$$\frac{dDC}{dt} = \beta_7 F4_{(t)} - \mu_0 DC_{(t)} - \beta_{12} DC_{(t)} - r_7 DC_{(t)} - \beta_8 DC_{(t)} - \mu_1 DC_{(t)} \tag{8}$$

$$\begin{aligned}\frac{dHCC}{dt} = {}&\beta_8 DC_{(t)} + \beta_{10} F3_{(t)} + \beta_{11} F4_{(t)+} - \mu_2 HCC_{(t)} - \beta_9 HCC_{(t)} \\ &- r_8 HCC_{(t)} - \mu_0 HCC_{(t)}\end{aligned} \tag{9}$$

$$\frac{dLT}{dt} = \beta_9 HCC_{(t)} + \beta_{12} DC_{(t)} - r_9 LT_{(t)} - \mu_3 LT_{(t)} - \mu_0 LT_{(t)} \tag{10}$$

$$\frac{dAR}{dt} = A_{(t)} r_1 \tag{11}$$

$$\begin{aligned}\frac{dR}{dt} = {}&F0_{(t)} r_{2+} F1_{(t)} r_3 + F2_{(t)} r_4 + F3_{(t)} r_5 + F4_{(t)} r_6 + DC_{(t)} r_7 + HCC_{(t)} r_8 \\ &+ LT_{(t)} r_9 - R_{(t)} r_e - \mu_0 R_{(t)}\end{aligned} \tag{12}$$

3.1 Parameter Estimation

We conducted an extensive literature search to collect the required data to estimate the model parameters. If possible, we selected randomized trial data over other data sources. We obtained information related to key parameters of the dynamic compartmental model such as the force of infection, contact rate, the initial population size of HCV-negative and HCV-positive PWIDs, HCV prevalence among PWIDs, birth and mortality rates and the cost of treatment. Unfortunately, data regarding PWID population size in Turkey lack due to lack of surveillance and stigma towards drug users. Hence, we estimated the initial population size of PWIDs based on data on the drug user population in Western and Eastern Europe and Asia. We present the model parameter related to HCV-negative PWIDs (Susceptible) and the force of infection in Table 1.

Model parameters related to disease progression, HCV-positive PWIDs, and mortality rates due to HCV are presented in Table 2. We gathered data from clinical studies and medical literature to estimate the annual rate of transition between disease stages. We also presented initial PWID size in each disease stages. Furthermore, HCV-related annual mortality rates are demonstrated for Decompensated cirrhosis, Hepatocellular Carcinoma, and Liver Transplant phases.

Unfortunately, there are no data or study related to the number or proportion of HCV-positive persons who are on treatment in Turkey. To assess the effect and cost-effectiveness of treatment, we developed scenarios that represent different levels of treatment coverage among PWIDs from the least successful (no treatment) to the most successful (all HCV-positive PWIDs receive the treatment). For instance, scenario 2 assumed that 25% of HCV-positive PWIDs are on treatment. The recovery rate by disease stage, r_k was calculated from treatment coverage and treatment effectiveness. As expected, the recovery rate decreases as the patient deteriorate, and it is the lowest for HC and LT phases. We included three treatment regimens (Harvoni, Viekirax + Exviera, and

Table 1. Key model parameters related to HCV-negative PWIDs and the force of infection

Parameters	Estimated value	Sources
The initial population size of HCV-negative PWIDs (Susceptible)	96,506	Calculated from below parameters
The proportion of HCV-positive persons among PWIDs	63.16%	(EMCDDA Ulusal Raporu 2014)
Drug user (DU) population size in Turkey	557,363	Calculated from (Eastern Europe Population, Western Europe Population, Population: Central Asia n.d.), (Mathers et al. 2008), (Türkiye İstatistik Kurumu (TUIK) 2018)
Proportion of PWIDs among DU in Turkey	47%	Calculated from (Türkcan 1998), (Evren et al. 1996), (Pınarcı 2009), (Türkiye Uyuşturucu ve Uyuşturucu Bağımlılığı İzleme Merkezi (TUBİM) 2013)
The annual number of needles shared	151	Calculated from below parameters
Needle sharing ratio	40.90%	(Ögel et al. n.d.), (Bağımlılık Yapıcı Maddeler ve Bağımlılık ile Mücadele Yılı Ulusal Raporu 2007)
Annual needle usage rate	368	(Ögel et al. n.d.)
Force of infection ($ß_1$)	8.84%	Calculated from the below parameters, an annual number of needles shared and (Hepatitis C and Health Care Personnel n.d.)
Risk of HCV infection from needle sharing	0.10%	(Bağımlılık Yapıcı Maddeler ve Bağımlılık Ile Mücadele Yılı Ulusal Raporu 2007)
HCV prevalence among PWIDs	0.631	(EMCDDA Ulusal Raporu 2014)

Mavyret) that are recommended in the treatment guidelines as the first line of treatment and that are reimbursed through the government-regulated health insurance in Turkey. The government-regulated health insurance covers nearly all of the Turkish population and any drugs reimbursed through this system has a higher volume of usage compared to drugs that are not. Thus, considering only these drugs are sufficient to estimate the cost-effectiveness without including all possible treatment options. Treatment effectiveness of these three drugs was collected from relevant randomized trial data on them and treatment effectiveness of liver transplant were obtained by liver transplant surgery success/survival rate (Table 3).

Table 2. Key model parameters related to disease progression, HCV-positive PWIDs and mortality rates due to HCV

Parameter	Estimated value	Sources
Initial population size		
F0	24,405	(Wandrer et al. 2018)
F1	24,405	(Wandrer et al. 2018)
F2	43,382	(Wandrer et al. 2018)
F3	43,382	(Wandrer et al. 2018)
F4	29,881	(Wandrer et al. 2018)
DC	11,483	(Perz et al. 2006)
LT	248	(Irmak et al. n.d.)
HCC	711	(Irmak et al. n.d.)
Annual rate of transition between disease stages		
Acute to Chronic Phase	0.8	(Herkesin Başına Gelebilir. Hep C ve B… ve Biz n.d.)
F0 to F1	0.128	(Zeremski et al. 2016)
F1 to F2	0.177	(Irmak et al. n.d.)
F2 to F3	0.057	(Irmak et al. n.d.)
F3 to F4 (Compensated Cirrhosis)	0.061	(Irmak et al. n.d.)
F3 to HCC	0.241	(Maor et al. 2016)
F4 to DC	0.129	(Poynard et al. 1997)
F4 to HCC	0.03	(Viral Hepatitis n.d.)
DC to HCC	0.045	(Viral Hepatitis n.d.)
DC to LT	0.063	(Barut n.d.)
HCC to LT	0.063	(Barut n.d.)
The HCV-related annual mortality rate		
DC to Death from HCV	0.063	(Barut n.d.)
LT to Death from HCV	0.021	(Tsoulfas et al. 2009)
HCC to Death from HCV	0.063	(Barut n.d.)

3.2 Cost-Effectiveness Analysis

To determine the cost-effectiveness of treatment scenarios, the cost of treatment is required. We estimated the cost of three treatment regimens that are most widely used in Turkey based on their market prices and treatment durations. It is possible that government-regulated health insurance has lower prices to purchase these drugs. However, this information is not publicly available, and it is hard to obtain. Thus, we preferred utilizing market prices, which resulted in higher total costs and more conservative results. Table 4 shows treatment durations and drug prices in Turkey. Based on the medical expert

Table 3. Treatment coverage scenarios and related recovery rate estimation by disease stage

Recovery rate					
Disease stage	Scenario 1 (0%)	Scenario 2 (25%)	Scenario 3 (50%)	Scenario 4 (75%)	Scenario 5 (100%)
F0-F1-F2-F3	0	0.245	0.49	0.735	0.98
F4	0	0.235	0.47	0.705	0.94
DC	0	0.22	0.44	0.66	0.88
HCC	0	0.169	0.338	0.506	0.675
LT	0	0.215	0.43	0.645	0.86

Table 4. Treatment cost and duration for the three most common HCV treatment regimes in Turkey

Disease stage	**Treatment duration**		
	Harvoni	**Viekirax Exviera**	**Mavyret**
F0	12 weeks	12 weeks	8 weeks
F1	12 weeks	12 weeks	8 weeks
F2	12 weeks	12 weeks	8 weeks
F3	12 weeks	12 weeks	8 weeks
F4	12 weeks	12 weeks	12 weeks
DC	12 weeks+ribavirin	12 weeks	12 weeks
HCC	12 weeks+ribavirin	12 weeks	12 weeks
LT	12 weeks+ribavirin	24 weeks	12 weeks
Genotype	*G1 and G4	*G1 and G4	G3
Price	**₺59,692.62	**₺38,798	**₺57,043

opinion, genotype 1 is more prevalent in Turkey, and we assumed that Genotypes 1 and 4 consist of 90% total HCV cases and rest are Genotypes 2 and 3 in Turkey.

We calculated the incremental cost-effectiveness ratio (ICER), which compares the cost and outcomes of each treatment coverage scenario, relative to the next most higher treatment coverage as follows:

$$ICER = \frac{\Delta C}{\Delta P} \tag{13}$$

where C is the total cost of treatment scenarios, and P is the number of HCV infections prevented.

4 Results

We considered a time horizon for the prediction period of our model as 30 years from 2019 to 2039 to observe whether it is possible to reach WHO targets. Without any treatment (Scenario 1), the model suggested that the number of HCV infected PWIDs would increase to 350,000 cases, and 100% treatment coverage nearly eliminates the disease as WHO aims to do globally with less than 10,000 cases. As expected, the number of HCV infections decreases with treatment coverage increases. Figure 2 presents the estimated number of HCV-positive injection drug users for each scenario. Based on our model results, with enough treatment coverage, it is possible to reach the WHO elimination targets in Turkey by 2039.

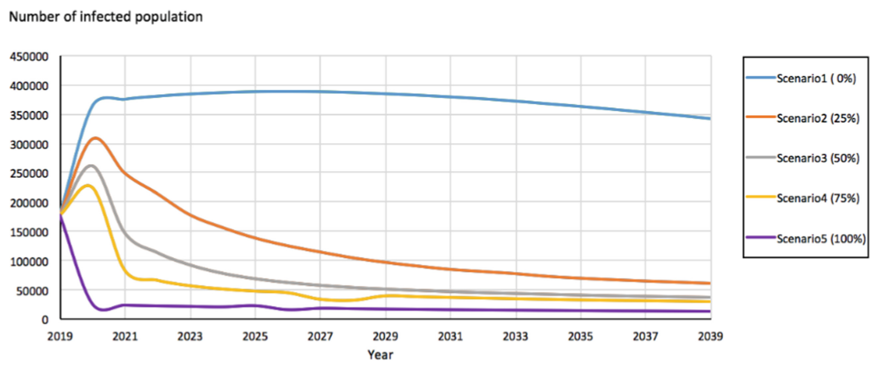

Fig. 2. The estimated number of HCV-positive injection drug users in Turkey, 2019–2039

There are two widely used treatment alternatives for Genotypes 1 and 4 in Turkey: Harvoni and Viekirax Exviera. Since there is no information on the percentage of use for each drug, we considered two different treatment plans where all treatment is assumed to be provided with the selected drug: (i) Harvoni + Ribavirin + Mavyret and (ii) Viekirax Exviera + Mavyret, respectively. We calculated a total number of infections, total treatment cost, the number of infections prevented, incremental treatment cost saved, and ICERs for each treatment plan and scenarios for 2019–2039. Our results suggested that the total cost of treatment increases with a treatment coverage for both treatment plans until 100% coverage. Total cost decreases in Scenario 5 due to the fewer number of HCV infections that is eligible for treatment. Although total treatment cost increases with the treatment level using Harvoni, Ribavirin, and Mavyret medicines for the first four scenarios, the cost decreases in scenario 5. As expected, the total number of infections decreases with treatment coverage. Besides, the marginal change in the number of infections prevented decreases with treatment coverage. Total treatment cost estimated around ₺1-94 billion depending on treatment plan and coverage. Based on ICERs, 25 and 50% treatment coverage scenarios are cost-effective, and 100% treatment coverage scenario is cost-saving for Harvoni + Ribavirin + Mavyret plan, and all treatment coverage scenarios are cost-effective for Viekirax Exviera + Mavyret plan. Cost-effectiveness of treatment plans of Harvoni + Ribavirin + Mavyret and Viekirax Exviera + Mavyret for all scenarios are presented in Tables 5 and 6.

Table 5. Cost-effectiveness of treatment scenarios for the treatment plan of Harvoni + Ribavirin and Mavyret

Treatment Plan:Harvoni+Ribavirin+Mavyret	Total number of infections (2019-2039)	HCV Infection prevented	Total treatment cost	Incremental Treatment Cost Saved	ICER
No treatment (Scenario 1)	3,917,280	-	₺0	-	-
25% treatment (Scenario 2)	1,310,012	2,607,268	₺47,257,952,584	₺47,257,952,584	₺18,125
50% treatment (Scenario 3)	803,340	506,672	₺54,935,953,934	₺7,678,001,351	₺15,154
75% treatment (Scenario 4)	602,581	200,759	₺94,886,130,936	₺39,950,177,001	₺198,996
100% treatment (Scenario 5)	535,985	66,596	₺60,583,075,478	-₺34,303,055,458	Cost saving

Table 6. Cost-effectiveness of treatment scenarios for the treatment plan of Viekirax Exviera and Mavyret

Treatment Plan: Viekirax Exviera+Mavyret	Total number of infections (2019-2039)	HCV Infection prevented	Total treatment cost	Incremental Treatment Cost Saved	ICER
No treatment (Scenario 1)	3,917,280	-	₺0	-	-
25% treatment (Scenario 2)	1,310,012	2,607,268	₺1,120,980,680	₺1,120,980,680	₺430
50% treatment (Scenario 3)	803,340	506,672	₺37,582,342,590	₺36,461,361,910	₺71,962
75% treatment (Scenario 4)	602,581	200,759	₺38,433,478,655	₺851,136,066	₺4,240
100% treatment (Scenario 5)	535,985	66,596	₺41,108,927,284	₺2,675,448,629	₺40,174

5 Discussion and Conclusion

In this study, we explore the relationship between the high-risk population of injection drug users and new DAA treatments with the help of a dynamic compartmental model to determine the cost-effectiveness of the new treatment in Turkey. Our model results suggest that the number of HCV infected injection drug users could significantly decrease when treatment coverage increases even achieving WHO targets with a higher level of treatment coverage. In terms of total treatment cost, Ormeci et al. estimated the total cost of achieving WHO targets in a 15-years interval of around 11 billion USD (2017). Our results, which are for a 30-years interval and in terms of the Turkish lira, are comparable to this estimation. While the cost-effectiveness of treatment varies based on the treatment plan and coverage, for all treatment scenarios the cost of Harvoni + Ribavirin and Mavyret are estimated to be higher than Viekirax Exviera + Mavyret due to lower cost of Viekirax Exviera compared to Harvoni.

There are some limitations to our study. Due to lack of data, we assume different treatment coverage scenarios and treatment plans to assess the cost-effectiveness of HCV treatment as well as the proportion of HCV-infected persons by genotype. We determine the total treatment cost for each plan and scenario instead of the actual cost of treatment as we do not have enough information about how many people receive treatment in Turkey. In this study, we omit the side effects of HCV treatment. This could be incorporated to further versions of the model. Another limitation is that this type of model is deterministic, and it assumes the current disease dynamic would continue in the future. The longer the prediction interval, the lesser the confidence in the model results.

In summary, HCV treatment significantly reduces the number of HCV infections, and it is cost-effective for both treatment plans among PWIDs in Turkey. Our model results support the value of HCV treatment as prevention and its importance in the elimination of HCV.

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