Lecture Notes in Management and Industrial Engineering

Fethi Calisir
Murat Durucu *Editors*

Industrial Engineering in the Covid-19 Era

Selected Papers from the Hybrid Global Joint Conference on Industrial Engineering and Its Application Areas, GJCIE 2022, October 29–30, 2022

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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) 2022. 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 COVID-19 Era." Humanity faced a virus causing the deadly and contagious COVID-19 disease that first occurred in Wuhan, China, at the end of 2019. The definition of "normal life" has changed with this encounter ever since, and the COVID-19 pandemic has disrupted the pre-existing state of affairs, transforming all aspects of manufacturing and service systems. In addition, this pandemic has had severe economic consequences worldwide, which have caused dramatic changes in the way consumers behave and required many businesses to close as it caused extraordinary supply chain disruptions almost in all sectors. Companies have faced several COVID-19-related long-term challenges, such as health and safety of personnel, ambiguity in business environments, production reduction, uncertainty in import and export gates, etc., that pandemics imposed on them. It is evident that industrial engineering can have a vital role in understanding the dynamics of the COVID-19 pandemic and determining the strategies and policies that will reduce the adverse effects of the pandemic and end it. This book will shed light on the role of industrial engineering in this endeavor.

I want to express our gratitude to all the contributors, reviewers, and international scientific committee members who have aided in the publication of this book. I 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 only sponsor of the GJCIE 2022, the Elginkan Foundation.

December 2022

Fethi Calisir
Murat Durucu

Contents

Algorithms for Multiple Autonomous Robotic Systems in Warehouse Order Picking Operations: A General Review

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Abstract. Warehouses have always been indispensable components of supply chains for the smooth flow of materials from supplier to customer. Expansion of e-commerce, requiring faster delivery of smaller orders, promoted stock management and consequently warehouse operations. The search for increased efficiency in stock management and warehouse operations yielded the deployment of autonomous robotic systems. One example of such a system is Amazon's Kiva system. It has been claimed that the Kiva system reduces the unnecessary time and cost of pickers close to zero. These recent developments are invaluable since order picking is the most labor-intensive and capital-intensive operation in all warehouse operations. An enhancement in the order picking process decreases warehouse expenses, increases the throughput of the warehouse and customer service level, and implicitly improves the supply chain performance. Hence, intelligent systems are essential to optimize the order fulfillment process. Increasing the throughput and the speed of the system requires the employment of more pickers. Operating autonomous robotic systems simultaneously is more sophisticated. The problem of batching and routing jointly is complex by itself. When it is required to embed congestion and collision prevention into the batching and routing of multiple pickers, the problem can get prohibitively complex. In this study, we review algorithms for the order picking problem both for single picker and multiple picker cases which form the basis for the development of intelligent batching and routing algorithms for multiple autonomous robotic systems.

Keywords: Autonomous mobile robots · Logistics · Order picking · Warehouse

1 Introduction

Warehouses are major components of supply chains. Recently, the increasing volume of e-commerce sales and the pressure on the speed of delivery forced companies to redesign their logistics operations including those in the warehouses (Ozturkoglu and Hoser 2019).

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The four fundamental warehouse operations are *(i)* receiving, *(ii)* storage, *(iii)* order picking, and *(iv)* shipping. Our focus is on order picking which is collecting items of an order from their storage locations in a warehouse.

Order picking systems are classified by Dallari et al. (2008) as follows, based on who picks the items, who moves in the picking area, whether conveyors are used, and which picking policy is employed: *(i)* picker-to-parts, *(ii)* pick-to-box, *(iii)* pick-and-sort, *(iv)* parts-to-picker, and *(v)* automated picking.

In picker-to-parts systems, the order picker travels between static item locations. Picker-to-parts systems are split into two based on item accessibility from the warehouse floor: (*i*) low-level, and (*ii*) high-level. In low-level picker-to-part systems, items are reachable from the warehouse floor whereas, in high-level picker-to-part systems, equipment is necessary to pick items from their locations. Low-level picker-to-parts order picking systems constitute about 80% of all order picking systems in Western Europe (De Koster et al. 2007).

Order picking constitutes almost 55% of warehouse operating costs by itself (Tompkins et al. 2010). Activities and their percentages in order picking operation for a manual picker-to-parts system are: travel (50%), search (20%), pick (15%), setup (10%), and others (5%) (Tompkins et al. 2010). Since travel has the largest share, it has the greatest potential to reduce the overall order picking time. Reducing the travel time leads to a decrease in delivery times which maximizes the customer service level.

The objective of the order picking problem is to find the best sequence and picking route of items to minimize the total traveled time and/or distance for a single picker system. In the presence of multiple pickers clustering orders to be assigned to each picker must be considered jointly as an objective. The single order picking problem is the counterpart of the Traveling Salesman Problem (TSP) once the distance between item locations is computed.

In literature, different solution approaches are suggested for the single order picking problem, such as exact solution algorithms, rule-based algorithms such as S-shape, largest gap, return, midpoint, composite, aisle-by-aisle, and combined/combined^{+}, or meta-heuristic algorithms such as tabu search, genetic algorithm, and ant colony optimization. The solution methods differ based on the warehouse layout (single block / multi-block) and the number of order pickers.

Together with the complexity of the problem, ergonomic risk factors for humans, and increasing speed requirements motivated the search for alternatives. Nowadays, autonomous robotic systems are the shining stars of warehouses. Intelligent systems become the new trend for warehouses. In addition to human order pickers, warehouses start to use different types of robotic systems in their order picking process. Especially, when Amazon acquired Kiva Systems (currently, Amazon Robotics) in 2012, a new era began in warehouse management.

The objective of this study is to form a basis for intelligent batching and routing algorithms for multiple autonomous robotic systems, by examining available algorithms for human single and multiple-order pickers. With the involvement of multiple autonomous robotics, congestion and collision prevention should also be taken into consideration.

The rest of the study is organized as follows. In the next section, we describe the automation of warehouse operations. Later we explain solution approaches for single-picker and multi-picker problems. Finally, we state our conclusions drawn in the last section.

2 Automation of Warehouse Operations

The increase in online shopping and the vulnerability of humans accelerated the automation in warehouses. During the Covid-19 pandemic, the volume of online shopping increased drastically, requiring faster and more accurate deliveries to stay competitive. Labor shortages, high employee turnover rate, SKU-complexity growth, and elevated service level expectations are other drivers of warehouse transformation. Automation reduces the likelihood and the rate of human error hence increasing the accuracy which in turn increases customer satisfaction and decreases return rates and refunds.

Most of the warehouses are still not fully automated due to high investment costs. Nowadays more flexible and affordable warehouse robots are available which can partially automate fulfillment operations. Warehouses deploy robots for a variety of tasks, such as sorting, picking, packaging, batching, transportation, fulfillment, security, and inspection.

Currently, automated guided vehicles (AGV) and autonomous mobile robots (AMR) become warehouse automation stars. According to SelectHub's '*Warehouse Automation Trends in 2022 and Beyond*' report, the global AGV/AMR market is estimated to reach $ 13.2 billion by 2026. AGV/AMRs can be used within the existing warehouse configuration, without any modifications in the infrastructure as opposed to automated storage and retrieval systems (AS/RS). AMRs can be used on all warehouse floor forms, containing rack-supported mezzanines. AMRs can be deployed within a few weeks. Moreover, AMRs are less expensive compared to AGVs. AGVs follow a fixed route whereas intelligent navigation is possible with AMRs. AGVs can detect obstacles but cannot navigate around them. In case of detecting an obstacle, an AGV stops and waits until the obstacle is removed. AMRs are able to navigate around an obstacle and re-route by selecting the most effective alternative route.

AMRs work together with fulfillment associates to reduce their non-value-added walking times and maximize efficiency. These robots are equipped with Light Detection and Ranging (LIDAR) system. AMRs are linked to the Warehouse Management System (WMS). AMRs are adopted to navigate around the aisles for finding the shortest picking route for selected items in the order pool based on proximity, instead of selecting the items based on first-come-first-served orders. Then, the nearest fulfillment associate picks those items accordingly. In collaborative order picking, fulfillment associates generally stay in their assigned zones, walk less and pick more, compared to traditional order picking. The implementation of AMRs eliminates noteworthy non-productive walking time in warehouses. However, the waiting time of robots for the fulfillment associates is another non-value-added time that should be minimized.

Fortna describes six different types of warehouse robots and discusses key challenges and benefits of their deployment: (*i*) robotic arms, (*ii*) collaborative robots (cobots), which are classified into two groups: (*a*) meet-me cobots, and (*b*) follow-me cobots, (*iii*) mobile rack goods-to-person autonomous mobile robot, (*iv*) roaming shuttle arms, (*v*) unit load transport autonomous mobile robots, and (*vi*) bot sorter autonomous mobile robots.

In 2012, Amazon acquired Massachusetts-based Kiva Systems (which is currently known as Amazon Robotics) and announced that it would use these mobile robotic fulfillment systems for its own operations only and restricted access to these robots to others. However, new companies raised to fill this gap in the logistics robotic market, such as Locus Robotics, 6 River Systems, Fetch Robotics, etc. DHL Supply Chain, a division of Deutsche Post DHL, is the leading customer of Locus Robotics for collaborative automated order picking. In 2017, they started a pilot study with Locus cobots for the life sciences sector in Tennessee. Based on SelectHub, Amazon is the leading company in robot-driven warehouses, with more than 200,000 mobile robots. DHL stated that they would invest $300 million in robots to enhance 60% of their fulfillment centers in the US (SelectHub Homepage 2022).

According to LogisticsIQ's market report, the warehouse automation market is anticipated to be worth $ ~30 billion by 2026, which was valued at $ ~15 billion in 2019 (LogisticsIQ Homepage 2022). According to Interact Analysis's 'Collaborative Robot Market Report 2019', the cobot market is expected to reach $5.6 billion in 2027, which will correspond to 30.2% of the total robot market. Based on Interact Analysis's report, the automotive and electronics industries are the two largest users of cobots in 2018 (Homepage 2022; Interact Analysis Homepage 2022). Yet, logistics is projected to surpass the automotive industry and become the second largest user of cobots soon. Based on the same report, the three major functions of cobots are given as material handling, assembly, and pick-and-place.

Next, we will examine available algorithms for single-picker and multi-picker cases regarding order picking-related problems.

3 Single-picker and Multi-picker Cases for Order Picking Related Problems

Order picking problem (OPP) refers to finding the best picking sequence of items to minimize total traveled distance/time. Generally, OPP is solved jointly with Storage Assignment Problem (SAP)/Order Batching Problem (OBP). SAP deals with the placement of items within the warehouse. OBP is about grouping customer orders into picking orders.

Warehouse layout is also important since customized fast solution algorithms may be developed for particular layout structures. A traditional rectangular warehouse contains parallel pick aisles and cross aisles among rack systems. All warehouses have a front cross aisle and rear cross aisle. The middle cross aisles isolate blocks in a multi-block warehouse. Broadly, we can categorize warehouses as single-block and multi-block.

3.1 Single-picker Case

Once the shortest distance matrix between any pair of items is available, the OPP becomes similar to the TSP which is known to be *NP*-hard.

A polynomial-time optimal algorithm for the OPP in a single-block rectangular warehouse is provided in Ratliff and Rosenthal (1983), which is later generalized to two-block rectangular warehouses in Roodbergen and De Koster (2001). To the best of our knowledge, there is no optimal solution algorithm for warehouses with three or more blocks. The complexity of OPP motivated the development of heuristics. The most frequently used algorithms for single-block warehouses are: (*i*) S-shape, (*ii*) Largest gap, (*iii*) Midpoint, (*iv*) Return, and (*v*) Composite; and for multi-block warehouses are: (*i*) Modified S-shape, (ii) Modified largest gap, *(iii)* Aisle-by-aisle, (*iv*) Combined, (*v*) Combined^{+}.

In addition, meta-heuristics, such as genetic algorithms, tabu search, simulated annealing, and ant colony optimization have also been implemented.

Daniels et al. (1998), Zulj et al. (2018) addressed the joint SAP and OPP in a single-block warehouse. Won and Olafsson (2005), Tsai et al. (2008), Chen et al. (2015), and Cheng et al. (2015) examined the joint OBP and OPP in a single-block warehouse. Ene and Öztürk (2012) considered the joint SAP and OPP in a multi-block warehouse. Matusiak et al. (2014), Lin et al. (2016), Li et al. (2017), and Valle et al. (2017) focused on the joint OBP and OPP in a multi-block warehouse. Hsieh and Huang (2011) examined the joint SAP, OBP, and OPP in a multi-block layout. Kulak et al. (2012) considered the joint OBP and OPP both in single-block and multi-block environments.

3.2 Multi-Picker Case

In literature, the majority of the OBP, SAP, and OPP studies are limited to the single-picker case. However, in reality, multiple pickers move simultaneously in the same field where their interactions may lead to congestion. Picker congestion or picker blocking may occur when the same item location is visited by more than one picker, or when more than one picker navigates the same aisle simultaneously. In the presence of congestion, the non-value-added waiting time should be taken into account and minimized, in addition to the total traveled time.

Like the single-picker case of OPP being equivalent to TSP, the multi-picker case becomes equivalent to multi-TSP (mTSP) which is also NP-hard. Optimal solutions can be found for small-size instances. In mTSP, the shortest route must be found by each salesperson and the objective is to minimize the total traveled distance/time of all salesperson.

The review for the multi-picker case is tabularized in Table 1.

In the multiple order pickers literature, Ardjmand et al. (2018) considered the joint SAP, OBP, and OPP in a single-block warehouse where the objective is to minimize the picking makespan. A parallel hybrid simulated annealing and ant colony optimization algorithm is proposed to solve large-scale problems. Bahrami et al. (2017) conducted a simulation study for the joint SAP, OBP, and OPP in a single-block warehouse with wide aisles with congestion. The performance measures in the simulation study are total traveled distance, the number of collisions between operators (congestion), and order lead times. The effect of nine seed order selection rules and ten accompanying-order selection rules (for the batching method), three types of sorting methods, two storage assignment rules, and two routing policies are tested. Chen et al. (2013) studied OPP in a multi-block narrow-aisle warehouse with congestion. The objective is to minimize

Table 1. Summary of multi-picker case

Article	Warehouse layout				Problem type			Solution approach
	Single-block	Multi-block	Wide-aisle	Narrow-aisle	OBP	SAP	OPP	
Ardjmand et al. (2018)	✓		✓		✓	✓	✓	Parallel hybrid simulated annealing and ant colony optimization algorithm
Bahrami et al. (2017)	✓		✓		✓	✓	✓	Seed algorithm
Chen et al. (2013)		✓		✓			✓	Ant colony optimization algorithm
Chen et al. (2016)		✓		✓			✓	Ant colony optimization algorithm
Franzke et al. (2017)	✓			✓		✓	✓	Agent-based simulation
Hong et al. (2012)	✓			✓	✓			Simulated annealing algorithm
Pan and Wu (2012)	✓			✓		✓	✓	Simulation
Scholz et al. (2017)		✓		✓	✓	✓	✓	Variable neighborhood descent algorithm
Pan and Shih (2008)	✓			✓		✓	✓	Throughput model
Pan et al. (2012)	✓		✓			✓	✓	Heuristic algorithm
Parikh and Meller (2009)	✓		✓				✓	Analytical model

the average picking time and average waiting time of two order pickers. An ant colony optimization-based routing method is proposed. Chen et al. (2016) examined OPP in a multi-block narrow-aisle warehouse with congestion consideration. The objective is to minimize total order service time which is the sum of setup and sort time, pick time, travel time and wait time. An ant colony optimization-based online routing method is developed. Franzke et al. (2017) conducted an agent-based simulation for the joint problem of SAP and OPP in a single-block narrow-aisle warehouse with congestion. The objective is to minimize mean order throughput time. The effect of different routing policies, storage assignment rules, number of order pickers, number of picks per order, and blocking are investigated.

Hong et al. (2012) considered the OBP in a single-block narrow-aisle warehouse with congestion. The objective is to minimize total retrieval time which is the sum of cart loading and unloading, pick time, walk time, and congestion delay time. A mixed integer programming model and a simulated annealing algorithm are proposed. Pan and Wu (2012) studied the joint SAP and OPP in a single-block narrow-aisle warehouse with congestion. The objective is to minimize throughput time which constitutes setup time, unloading time, travel time, and response time. A simulation study is carried out for a different number of pickers, storage assignment policies, number of aisles, and order size. Scholz et al. (2017) studied the joint OBP, SAP, and OPP in a multi-block narrow-aisle warehouse with the objective to minimize total tardiness. A mathematical model and a variable neighborhood descent algorithm are suggested. Pan and Shih (2008) focused on the joint SAP and OPP in a single-block narrow-aisle warehouse with congestion. The objective is to maximize the expected throughput rate. A throughput model is proposed. Pan et al. (2012) examined the joint SAP and OPP in a single-block warehouse with congestion. The objective is to minimize the average order fulfillment time. A heuristic algorithm is proposed and tested under the different number of pickers, storage policies, and order size. Parikh and Meller (2009) investigated the OPP in a wide-aisle warehouse with picker blocking. Analytical models are developed to minimize the percentage of time each picker is blocked.

4 Conclusion

When multiple mobile autonomous robots are deployed for the order picking process, batching is necessary due to the configuration of the robots. This batching should be done by considering the proximity of the customer orders. Batching procedure in such systems generally removes the need for a further sorting operation which is a major advantage for warehouses. After the batching, the best picking route should be found for the items which are included in the batches assigned to a robot. The aforementioned algorithms may be useful as a base when solving the batching and routing problems for multiple autonomous robotics with congestion and collision prevention considerations.

Due to the rising attention to autonomous robotic systems, the number of robots sharing the same platform is increasing in warehouses. Accordingly, warehouses are confronting new constraints. Incorporating robots changes the nature of order batching and picking problems, compared to those problems comprising human warehouse associates. Good coordination is essential to managing warehouse operations in such a complex system.

In future studies, currently used algorithms can be modified and improved to design smart batching and routing policies in the presence of multiple autonomous robotic systems. Algorithms for multi-block layouts can be proposed by considering the algorithms used for single-block as a root. Novel algorithms can also be developed.

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E-Grocery Challenges and a Solution Approach from Multi-objective Perspectives

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Abstract. This paper provides an overview of the complex structure of the e-grocery industry, highlighting recent trends and challenges including the increasing customers' expectations. Customers' satisfaction can be driven by multiple objectives, which can create significant trade-offs. We propose a new approach as a future work for e-grocery businesses to leverage multi-objective perspectives, maximizing product availability and sustainability and minimizing cost. Specifically, we propose an e-grocery store assignment policy while consumers are using apps, which is developed on a real-time data-driven approach from customer ordering behaviors. With the help of data availability and data analytic tools, data-based solutions can foster continuous improvement in businesses. In a simulation study, imitating different demand profiles and online ordering behaviors might help develop a good solution approach for a multi-objective perspective.

Keywords: e-grocery · Online groceries purchasing · Product availability · Last-mile delivery

1 Introduction

Since 1994, when the first true e-commerce transaction took place, online purchasing has never stopped growing. With the outbreak of the COVID-19 pandemic, the global e-commerce market was one of the few sectors positively influenced by the restrictions, experiencing a further boost in growth with the highest increase of online sales in the last 10 years: +897 billion U.S. dollars than 2019 (Statista 2022). However, this new boom in sales was driven not only by information technology and consumer electronics as it used to be but also by a newly rising sector, struggling in growth before the pandemic: e-grocery (Coop 2021).

When e-commerce was born, groceries were immediately considered products for such a channel, but traction remained muted compared to general e-commerce (STIQ

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2021). The term *grocery* refers to consumer goods, which are also known as fast-moving consumer goods (FMCG). These goods are characterized by low unitary value and marginality, and a frequent and quick purchasing process with minimal comparison effort, driven by a low money and time availability of the customer to obtain them. Examples of groceries are foods, beverages, personal care products, and household cleaning products. The features of the products (e.g., low margins, temperature requirements, perishable and fragile, etc.) and the structural heritage of the sector (e.g., inflexible resulting from a strong focus on properties and efficiency) strongly hindered the growth of the e-grocery channel, causing its delay compared to other products' e-commerce (STIQ 2021). However, things have changed in the last few years. The first unlocking of the growth was recorded in the late 2010s, driven by Amazon's acquisition of Whole Foods in 2017 which pushed grocers to start taking e-grocery seriously (STIQ 2021). However, the real boost to the sector took place in 2020, when limitations on personal travel pushed many consumers to try this channel for the first time. According to Acosta (2021a), over half of all shoppers started online shopping after the pandemic began, and 45% of consumers increased online grocery shopping during COVID-19. The growth was outstanding. For instance, the Italian e-grocery sector experienced a 123% growth compared to 2019 (e.g., 1.3 billion euros) (Coop 2021). The result is that this channel has grown to a point that it can no longer be considered a niche add-on service, but it has become an integral part of the average consumer's purchasing habits. Even though 2020's exploit will be difficult to replicate in the coming years, the resulting new consumers' confidence in online grocery purchasing and the high growth potential embedded in the sector makes e-grocery one of the best future development opportunities in retail.

Given the increasing relevance of e-grocery, this paper aims to provide an overview of its complex structure and trends that are shaping this market, and of the main consumers' expectations and satisfaction drivers, pushing this sector to consider the new management insights. Starting from this overview, relevant challenges are also discussed and possible solutions to tackle them are proposed. By merging the different perspectives outlined, we also propose a concept of solution to improve multi-objective perspectives, including customer satisfaction from product availability. The originality of this work lies in the comprehensive overview and simultaneous discussion of issues usually addressed separately in the literature, which is home delivery and product availability.

2 Structure of the e-grocery Industry

The e-commerce landscape presents a wide variety of business models, mainly order fulfillment and last-mile delivery options, with different operational implications.

Considering the business models, the crowd of e-grocers can be clustered into six segments (STIQ 2021): (1) *Bricks and clicks/multiple-channel retailers/online legacy grocers*, which are traditional players that have added an online channel to complement their offline in-store offering; (2) *Clicks/online pureplay grocers*, which entered the grocery industry by offering their products through an online channel only; (3) *Q-commerce/<1 h delivery companies/instant deliveries companies*, which offer rapid delivery of groceries, often as quick as 15 min; (4) *Takeaway delivery companies*, forced to diversify into grocery delivery by the emergence of Q-commerce players; (5) *Meal* *kit companies*, that are focused on an offering of pre-portioned and sometimes partially-prepared food ingredients and recipes to prepare home-cooked meals; (6) *Direct from farm companies*, that focus on fresh products, such as vegetables, typically delivered in boxes directly from the farm. In this paper, we focus on the problems of bricks and clicks and online pure players.

Depending on the business model, typically there can be two approaches for order fulfillment: fulfillment from own stock or pick up from retailers. Bricks and clicks and online pure players mainly adopt fulfillment from their own stock. In that case, according to Hübner et al. (2016), back-end e-grocery fulfillment can be: (1) *In-store fulfillment*, where orders are picked directly from the store shelves, with lower entry costs for bricks and clicks but less efficient operations because of interferences with in-store purchasing experience; (2) *Separate/decentralized fulfillment centers* (like dark stores and micro-fulfillment centers), where orders are picked from dot-com-only fulfillment centers, with higher efficiency and easier control; (3) *Centralized fulfillment centers,* where orders are picked from an integrated central warehouse, maximizing the cost efficiency of picking but worsening the costs of last-mile delivery because of longer average distances.

At the same time, different last-mile delivery options also exist (Hübner et al. 2016): (1) *Home delivery*, where the e-grocer delivers the order directly to the customer's home. It can be attended (the order is delivered to the customer's home in his/her presence) or unattended (the order is delivered to the customer's home regardless of whether he/she is present or not); (2) *Click&Collect*, where customers collect from a physical outlet (e.g., a store, a petrol station, or a post office) the order bought online. It can be an in-store pickup where the order is collected directly at a desk in a store, a curbside pickup where the order is collected by the customer at a station attached to a store or a solitary drive-through station pickup where the order is collected by the customer at a solitary station, independent of stores.

3 Trends Shaping the e-grocery Industry

According to the Tetra Pak Index (2018), among the most important trends that shape the e-grocery sector, there are *convenience, personalization, technology,* and *sustainability*. We discuss each of those trends in detail, in this section. Besides, we add a discussion on customer satisfaction.

3.1 Convenience

E-grocery was born in opposition to the traditional brick-and-mortar experience, proposing itself as an alternative to the annoyance of finding a parking space, spending time in the aisles, waiting in lines, and carrying heavy grocery bags. Convenience is then a building block of the channel. Consumers value a fast and easy process, that they expect to be seamless and friction-free (Tetra Pak Index 2018). Therefore, convenience can be top-of-mind when designing an e-commerce experience. This also implies creating an effortless purchasing process. For instance, through a personalized shopping list or automatic replenishment via subscription, but also offering a home delivery option (Tetra Pak Index 2018). Indeed, despite the growth of click & collect (Coop 2021), home delivery becomes by far the preferred and most valued mode (Acosta 2021a).

3.2 Personalization

E-grocery consumers are more and more valuing a personalized experience, tailored to their needs and habits. Hence, customization of products and personalization in the consumer journey and delivery is expected to be key differentiators (Tetra Pak Index 2018). To do this, e-retailers are strongly leveraging consumer data, more available than in the past thanks to the increasing awareness of the importance of collecting them, and thanks to customers' willingness to engage with retailers through innovative loyalty programs, location-based services, and smartphone apps (McKinsey and Company 2017). However, data privacy consciousness is rising among consumers' priorities, where it is expected to be managed and collected with transparency.

3.3 Technology

To exploit the value embedded in consumer data and improve their collection, technological advancements are covering a crucial role. Indeed, technology has significantly improved in the last years, and it has found increasing application in the channel, becoming an essential element to boost the effectiveness and profitability of e-grocery, as well as to make it less costly to operate undermining in the long term a significant part of physical retail's advantage (Tetra Pak Index 2018). Technological competencies, especially in data management and machine learning, have created the opportunity to offer the convenient and tailored experience that the consumers are looking for, through targeted advertisements, purchasing recommendations, spending-related discounts, targeted coupons, and customized shopping platforms based on purchasing data (Grocery Dive 2021). However, technology creates opportunities from consumer data that go beyond personalization: data can be used also for optimizing the effectiveness of operations, for instance through dynamic pricing for improved profitability, forecast-driven inventory management for minimized stock-outs, fraud identification by comparing transaction data with customers' information (Akter and Wamba 2016), or for smart product substitutions (Walmart 2021). Moreover, data exploitation is not the only opportunity that technology advancements unlocked: robotics and automation are also becoming key elements for winning the high costs of e-grocery logistics activities, especially in warehousing and last-mile delivery. For instance, through robots and drones, the costs of the home delivery can be decreased by up to 80% (Tetra Pak Index 2018).

3.4 Sustainability

The increasing awareness of consumers and governments makes sustainability a hot topic for companies across sectors. For e-grocery, sustainability is mainly addressed in two dimensions: purchasing choices and logistics activities (including packaging) (Ecommerce Europe 2021). However, even if it is true that consumers are increasingly asking for environmentally and socially sustainable products, most of the concerns of research for the e-grocery channel are focused on the environmental sustainability of the logistics activities. This is because global logistics and transport already account for about 13% of the total Green House Gases (GHG) (World Economic Forum 2016), and e-commerce is making supply chains more complex impacting not only on cost but also exacerbating further the growth of emissions. This is true especially looking at last-mile delivery, generally believed to have the greatest impact. For instance, focusing on home delivery the growth of online purchasing has contributed to the growth in van traffic - vans consume more fuel and release more emissions than larger vehicles -, and the frequently failed deliveries involve further travel and then related emissions (Mangiaracina et al. 2015). However, the overall environmental sustainability of B2C e-commerce compared to traditional channels is still uncertain (Mangiaracina et al. 2015). Still, transportation is just one of the areas that affect the environmental impact of e-commerce: as identified by Mangiaracina et al. (2015), the four logistics areas impacting environmental sustainability are transportation planning and management, warehousing (especially for energy usage), packaging (e-grocery may require additional packages) and distribution network design (emissions change with the configuration, fulfillment option and delivery mode). For instance, the results by Siragusa and Tumino (2021) indicate that adopting a holistic perspective e-grocery is potentially more sustainable than bricks-and-mortar shopping, with emissions ranging from 10%–30% lower. However, as deliveries become more frequent and fragmented, reducing carbon footprint - especially in last-mile - is still crucial, and e-grocers are increasingly faced with solving this challenge (Izmirli et al. 2020; Izmirli et al. 2021).

Apart from the mentioned above drivers, customer expectations and satisfaction are also important issue that needs to be examined for the success of an e-grocery business. We discuss this point in the following section.

4 Recent Customer Expectations

Figure 1 shows a statistical summary from a questionnaire that was completed by Acosta (2021b) to investigate U.S. consumers' growing preference for online grocery shopping. According to that, 68%, 60%, and 56% of online customers find e-grocery purchasing convenient, a stress-free experience, and a fast-shopping experience, respectively. While the trend in physical retail is a shift away from supermarkets towards more frequent top-up shopping in local convenience stores, online grocery shopping is much like the traditional weekly trolley shop, with customers that buy to stock up and look for competitive prices (Tetra Pak Index 2018). Consumers stick to what they know also when choosing products, and not only do they expect online the same breadth of assortment that they find on physical shelves but also are quite disappointed when they are not finding the specific products they are looking for, especially given the even more prominent role of product brand in the online channel (Coop 2021). Nevertheless, the online channel does not stand the comparison with traditional supermarkets. Looking at satisfaction drivers, assortment and price are the main sources of dissatisfaction (GfK and mobiquity 2021). Moreover, the availability of goods is reported to be particularly relevant also looking at non-buyer barriers (GfK and mobiquity 2021).

This study focuses on the ways of improving multi-objectives in e-groceries, one of which is increasing the availability of products in stores to increase customer satisfaction. We discuss the details of this issue in the following section.

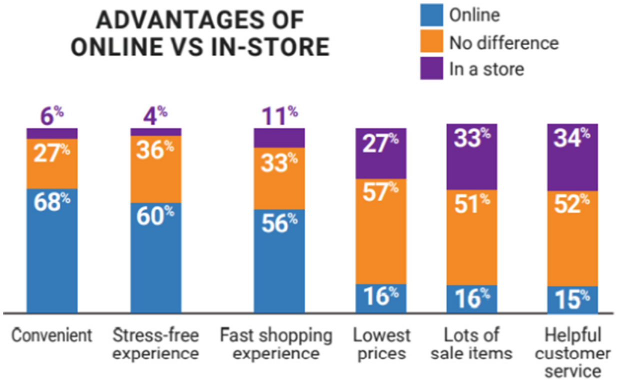

Fig. 1. Advantages of online vs. in-store grocery shopping (Acosta 2021b).

5 Relevant E-grocery Challenges Towards Customer Satisfaction

Among the challenges of e-grocery towards customer satisfaction, in this section we focus on two of the most relevant issues: *product availability* and *home delivery*.

5.1 Product Availability

Product availability is top-of-mind for consumers when shopping for groceries (Acosta 2021a). However, as highlighted previously, it is reported to be among the first drivers of customer dissatisfaction and non-buyer barriers. Product unavailability might happen due to those reasons:

- The product is not included in the offer.
- The product is included in the offer, but it is out of stock.

Whatever the cause of the unavailability, the result would always be the same, the customer would not be able to buy the product that he/she was looking for. According to Lucidworks (2022), this case happens frequently or always for more than half of the shoppers. Thus, dissatisfaction can easily be explained by the reduced convenience of online shopping once customers need to place a second order or visit a physical store to buy missing products. Instead, a larger product assortment relates to greater satisfaction, as it enhances the chances of a match between the consumer's preference and the available alternatives (Mofokeng 2021). Moreover, unavailability has a negative impact on retailers not only indirectly (e.g., on consumer satisfaction, loyalty, and retail image), but also directly, on sales and profit (Breugelmans et al. 2006). Only 30% of shoppers look for a substitute on the same grocery website or app when they can't find a specific item, early half of the shoppers will simply look for the missing product with a different grocer, while nearly a quarter would just not buy anything at all if they can't find what they are looking for (Lucidworks 2022), causing a loss of revenue that can be estimated around 8% of total revenues on average (Berthiaume 2022).

Since product availability is a major issue for e-grocers, to tackle this challenge different approaches can be adopted:

- **Substitutions:** the most common solution adopted in the sector when a product is not available is to replace the missing item with a substitute, i.e., a similar product, and make the customer pay for the lowest priced one (e.g., with a related loss for the seller). The substitute can be decided directly by the e-grocer or by the customer based on recommendations. However, this solves only partially the problem. First, there is a wide range of products based on ingredients, preparation, and brand and shoppers would never accept a substitute (Lucidworks 2022). Moreover, even when potentially acceptable, substitutions performed by the e-grocer or recommended are often unsuitable. The problem of wrong substitutions is very relevant in this industry, and for this reason, the sector is actively searching for solutions to it. For instance, Walmart has introduced artificial intelligence to improve the accuracy of substitutions, considering hundreds of variables - size, type, brand, price, aggregate shopper data, individual customer preference, current inventory, and more – in real-time to determine the best next available item (Walmart 2021).
- **Split deliveries or trans-shipments**: typically, customer demand is fulfilled from the closest fulfillment center. When some products of the customer orders are not available, a solution could be the trans-shipment of stock from a nearby facility or the transfer of the customer order or a part of it so that the order is fulfilled from multiple facilities. Virtual aggregation, i.e., aggregation of inventory without physically storing it in one location, is a unique feature of the e-commerce channel, where the creation of the so-called "window of decision opportunities" between the order and the delivery can be used to understand how to better deliver the order, comparing the orders to available stocks at different locations and checking whether or not the supply can match the demand (Breugelmans et al. 2006). Of course, the downside is that transportation distance may significantly increase.
- **Data-driven inventory and assortment optimization**: when it comes to product availability, starting from consumers' purchasing data, it is possible to develop accurate demand forecasts that can be used to develop an analytics-based inventory and/or assortment optimization, minimizing wastes while maximizing product availability. But to receive a reliable forecast, investments and efforts are needed, and this is problematic especially for online players since they experience more forecasting problems and a much more fluctuating demand than offline actors (Breugelmans et al. 2006).

5.2 Home Delivery

Last mile delivery is the most expensive and inefficient part of order fulfilment. Focusing on the delivery mode, click & collect might be a more cost-efficient solution than home delivery if it is designed well. However, according to a survey conducted by Capgemini (2019) among U.S. consumers, 40% of people rank delivery services as a must-have feature for grocery purchases, and one in five consumers say that they are prepared to switch retailers if delivery services are not provided. Thus, home delivery is an essential option for an e-grocer's success and a challenge that is faced.

Different features make home delivery critical. First, it represents the point of contact between the customer and the company, strongly impacting on customer satisfaction (Hübner et al. 2016). Then, it has a huge impact on sustainability, both from cost and environmental perspectives. Home delivery is the most impacting contributor to the overall supply chain costs, which are declared to be about 40% in Capgemini (2019). Much of the delivery costs incurred in last-mile delivery are variable, meaning that as online grocery delivery volumes increase, so will the costs for last-mile services. The problem is so pronounced that often home delivery models are not profitable, with retailers that must absorb a part of their cost to be able to provide such a service (Capgemini 2019). Companies are then very focused on lowering delivery costs. However, another problematic but often neglected aspect that must be addressed with home delivery is environmental sustainability. Home delivery is the most critical part of the supply chain also from an environmental perspective since it increases congestion and emissions in urban areas due to additional traffic generated by vehicles for deliveries. E-commerce last mile determines 25% of all urban transport-related carbon (CO2) emissions, and from 30% to 50% of particulate matter (PM) and oxides of nitrogen (NOx) (Interreg 2020)). Thus, because of regulations and the push for reducing the negative impact of climate change as well as considering the sustainability shift of the industry, companies may consider the home delivery problem also from an environmental point of view.

Luckily, many synergies can be found to tackle simultaneously the two problems. Indeed, both the cost and environmental challenges can be determined by the higher delivery frequencies of smaller and fragmented orders featured by e-commerce. Hence, both sustainability objectives can be reached by maximizing vehicle utilization and minimizing transportation distances, while trying to ensure a certain level of customer service and satisfaction (Hübner et al. 2016). Also, missed deliveries are particularly daunting challenges: as the attendance of a customer is hard to predict, home delivery usually results in high rates of failures leading to high delivery costs and high emissions in transportation, since the delivery must be repeated (Pan et al. 2017). Thus, reducing missed deliveries can significantly improve cost efficiency, environmental sustainability, and effectiveness of the service.

Many approaches can be adopted to tackle the economic and environmental sustainability problems. These solutions can be generally grouped into four clusters:

- **Optimize the network design:** both environmental and economic improvements can be reached by optimizing the network configuration, especially by reducing travel distances. For instance, designs implementing decentralized fulfillment centers like micro-hubs or grouping points of destinations may benefit the sustainability of last-mile delivery. In addition, it is possible to optimize the network by considering not only the configuration but also the links between nodes, i.e., the routing. Optimization models based on the vehicle routing problem (e.g., with or without time windows) are widely addressed by companies and academic researchers. However, those models tend to optimize a narrow and conventional definition of cost rather than also considering the environmental cost in terms of carbon footprint. Great potential for optimizing routes comes from data, but historical traffic data are rarely studied, and customer-related data are almost never leveraged for last-mile delivery (Pan et al. 2017).

- **Maximize delivery density:** a way to reduce both costs and emissions is to maximize the delivery density, by clustering together as much as possible geographically close orders. For sure, the longer the available time between the order and the expected delivery, the easier it is to merge orders efficiently. However, this is in contrast with the increasing consumers' expectations for quick delivery. Another commonly adopted solution is dynamic pricing. Different prices are associated with different delivery windows, and these prices vary dynamically according to the orders received so to offer lower prices for slots that optimize the routing.
- **Reconsider transport modes:** especially to reduce emissions, the choice of the transport mode is crucial as well as the choice of the vehicle. In the home delivery landscape, new solutions are emerging such as the use of existing public transport, automated guided vehicle lockers, drones, and robots, and also for conventional vans the attention is shifting towards fuel cells and battery electric vehicles. Some of these solutions may contribute to reducing last-mile delivery costs as well. For instance, drones and robots allow reducing both the workforce time because they are autonomous and the travel time because they can avoid road traffic. However, it should be considered that they reduce the delivery density as well and they meet technological and regulatory problems. Another rising trend in the sector on this side is crowd shipping, which involves outsourcing the home delivery of the goods to non-professionals, i.e., the "riders" (Mohamed and Ndiaye 2018). This enables higher flexibility and a diversified application of different modes of transport, as well as a potentially lower cost, but it rises issues on the social sustainability side.
- **Minimize missed deliveries:** to minimize missed deliveries, a possible solution could be unattended home delivery approaches (Hübner et al. 2016). For instance, these are delivery boxes, shared reception boxes, delivery to neighbors or gatekeepers, delivery to the car, delivery inside the home when the customer is away, etc. However, these solutions may rise major security problems that can impact the customer's experience and satisfaction. Another solution could be to give the opportunity to the customer to select the delivery time windows. In that way, it would be much more unlikely not to find the person at home, decreasing the probability of missed deliveries, but this hinders route optimization.

6 Improving Customer Satisfaction by Leveraging Data

Currently, the two challenges of product availability and home delivery are mostly studied separately. Usually, e-grocers serve their customers from their stores or e-depots based on the closeness of the household address, to minimize the distance traveled and the emissions and cost of home delivery (Torabi et al. 2015). When a customer places an order, the availability of the products is then mostly based on that dedicated store with missing items managed through substitutions. However, this can rise the issues of customer satisfaction, which may outbalance the savings from the lower distance traveled. A possible solution to further improve availability is to merge several store product availabilities in the store application. However, this might cause delivery costs and sustainability concerns to increase due to receiving products from longer travel distances.

Improving customer satisfaction is also essential to support the growth of e-grocery and its success. Hence, finding effective ways of maximizing product availability, without making home delivery more burdensome than what already is, is important. A solution for this might be inspired by the help of technological developments and the personalization trends of the sector. High customer data availability and data analytic tools can help maximize customer satisfaction from that perspective while assessing costs and sustainability implications in the delivery as well. For instance, e-groceries can consider a score-based solution for assigning e-groceries to their customers while they tend to do online purchasing. Namely, based on the customer purchasing behavior, to increase the product availability for that customer, the dedicated e-grocery might be changed dynamically by real-time tracking of personalized data. Consequently, the availability of products and customer satisfaction may increase for the buyer compared to the simple assignation of the closest depot, as well as by assigning a single depot the travel distance may also decrease compared to split deliveries. This is a very promising option for the e-groceries sector. For its feasibility, there is a need to study its impact on customer satisfaction in terms of product availability, transportation cost, and environmental sustainability of home delivery, and consequently to define the features of an effective assignment policy. To perform this analysis, a simulation approach can be adopted: what-if scenarios by combining different consumer demand scenarios and product availability states can be analyzed to assess their effects on the multi-objectives considered. A Monte Carlo simulation can be used for random data creation of demand and availability profiles. This proposed approach is under work as a future study.

7 Conclusion

This paper studies e-grocery working principles, trends, and customer expectations by proposing a new business strategy from multi-objective perspectives: maximizing product availability and sustainability and minimizing cost. We provide e-grocery challenges and a solution approach to alter those. By focusing on one of the major drivers, customer satisfaction in e-groceries, we provide an e-grocery store assignment policy based on a data-driven perspective as a future strategy for e-grocery businesses. By involving a multi-objective approach, not only product availability but also some other critical objectives, home delivery, and sustainability issues, are also considered in the solution proposed. It should be noted that product availability is perceived as a major barrier by consumers in e-groceries. With the rising consumer data availability and data management advancements, data-driven solutions can be developed, one of which is proposed to be the use of a dynamic score-based depot assignment policy for customers, based on their purchasing behaviors. Trade-offs between those three-performance metrics would be worth exploring. A simulation study, imitating different demand profiles and an online ordering environment, might help find out a good assignment policy for that. The novelty of this work lies in the comprehensive overview and the multi-objective perspective. Future works can focus on assessing the features for the effectiveness of such assignment policies and the impact on multi-objective performance metrics on online grocery purchasing operations.

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Product Recovery Option Evaluation for Different Departmental Objectives via Fuzzy AHP

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Abstract. Product recovery has an important role in providing a sustainable environment and economy. Reuse, refurbishment, repair, remanufacturing, and recycling are some of the recovery options considered within the decision process of the product recovery system. Since each recovery option has different monetary and non-monetary effects on the system, evaluation of the options is important to minimize the total cost. Rental products make up a special subset of recovery products because their lifecycle takes a long time, and they have many returns. Additionally, the effect of the same recovery option changes with respect to the type of department in a company as their own targets differs from each other. Hence, it becomes important to determine the recovery option evaluation factors and their importance weights concerning different departments such as purchasing, sales, marketing, customer relations, and so on. For this purpose, an application is performed in a telecommunication company. Modems that are used as rental products in the company are considered within the recovery process. The factors used in the evaluation of various recovery options are revealed and their importance weights are obtained via the Fuzzy Analytic Hierarchy Process (FAHP) method for the marketing and customer relations departments of the company. It is concluded that the importance weights of the evaluation factors for recovery options vary with respect to the type of department.

Keywords: Recovery Options · Rental products · Sustainability · FAHP

1 Introduction and Literature Review

The importance of providing a sustainable world has been realized by practitioners and academics in recent years (Topgul et al. 2021). Numerous studies and projects have been performed and more than them are on the agenda of both firms and academics. Recovery of used products is also one of the important topics considered within this context and plays an important role in the circular economy.

During the recovery process of used products, there are various options to consider. Reuse, refurbishment, repair, remanufacturing, and recycling are some of the alternatives in practice. Each of the options has different properties and there are various evaluation methods in the literature. However, even for the same company, the value of a recovery

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option changes concerning the role of the department in managerial decisions. The dominance of departments in the company becomes effective in the option decisions. For instance, under the effect of the marketing department, the decisions are much more on the side of reuse. On contrary, the material recycling option is popular under the effect of the customer relations department. Hence, while determining the recovery option's value, it is important to clarify the role of the departments to maximize the benefits of the whole system.

While determining the value of a recovery option for a department, evaluation factors are utilized in a formulation. Therefore, the type and importance weight of evaluation factors play an important role in this process. Hence, to reach the final recovery decision, the importance weights of departments, and evaluation factors should be taken into. In this study, the scope is limited and it is focused on the determination of evaluation factors and their importance weights. However, the issue of determining the department weights is noteworthy but out of the scope of this study because of its comprehensibility.

The literature is rich in terms of studies including recovery option evaluations. As Alamerew and Brissaud (2018) state that determining the value of recovery options plays an important role while selecting the best recovery option. One of the biggest problems while determining the recovery option value is the uncertainty about how the product is used and what physical conditions it has at the end of use. Additionally, another important difficulty is the dense uncertainty about the design of products and various studies have been performed on this topic (Özceylan and Paksoy 2013; Ayvaz et al. 2015; Jiang et al. 2019). To overcome this uncertainty, different methods including fuzzy logic, stochastic-based techniques, and decision tree-based algorithms were used. More specifically, some of the related studies are as follows:

Kleber et al. (2002) proposed a linear inventory model for the product recovery system with multiple options. Agrawal et al. (2016) used graph theory and a matrix approach to determine the best recovery option for mobile phones. An improved co-evolutionary algorithm was developed by Meng et al. (2016) for determining recovery options and applied to the numerical data set. Wadhwa et al. (2009) proposed a fuzzy-based multi-criteria decision-making MCDM technique for recovery option selection. Similarly, Dhouib (2014) utilized multi-criteria decision analysis for determining the best recovery option for automobile tire wastes. Lastly, Ondemir and Gupta (2014) also used an MCDM model for the recovery of products including sensors.

In brief, different from the existing literature, the rental products (modems) in a telecommunication company are considered in this study. The factors for recovery option evaluations are revealed and FAHP which is a popular method in MCDM is utilized to determine the importance weights of the evaluation factors concerning marketing and customer relations departments.

The rest of this study is organized as follows: Sect. 2 presents the theoretical background of FAHP. Section 3 provides the application in a telecommunication company and finally, the conclusion is given in Sect. 4 with the references following.

2 Fuzzy AHP

Analytic Hierarchy Process (AHP) proposed by Saaty (1988) is one of the most frequently used MCDM techniques in the literature (Yalcin et al. 2022). It is mainly based on the consistent pairwise comparisons made by the experts or decision makers. After its introduction to the literature, various applications have been performed in different fields (Kilic et al. 2014). However, due to the usage of crisp values within classic AHP, it has become insufficient to handle vagueness in decision-making environments. Hence, Fuzzy AHP was developed to overcome this difficulty by utilizing the fuzzy set theory proposed by Zadeh (1965). Many versions of FAHP were developed by different authors including van Laarhoven and Pedrycz (1983), Buckley (1985), and Chang (1996).

The developments in the fuzzy approach have continued with the use of intuitionistic (Abdullah and Najib 2014) and neutrosophic numbers (Abdel-Basset et al. 2018) and seem to improve much more in the future. However, in this study, Buckley's FAHP approach has been validated by various studies in different selection problems such as mining method selection (Azadeh et al. 2010), supplier selection (Ayhan and Kilic 2015), and personnel selection (Samanlioglu et al. 2018) is utilized. The reason for using Buckley's approach does not only depend on its frequent use but also depends on its usability in terms of the required data and operational requirements.

In this study, FAHP is performed to obtain the importance weights of the factors which are used for recovery option evaluations. The steps of FAHP steps are as follows (Buckley 1985; Kilic et al. 2014):

Step 1: Factor comparison including criteria or alternatives is performed by getting data from the experts or decision makers via the scale provided in Table 1.

Table 1. Triangular fuzzy preference scale

Saaty's Scale	Explanation	Triangular fuzzy scale
1	Equally importance	(1, 1, 1)
3	Moderate importance of one over another	(2, 3, 4)
5	Essential or strong importance	(4, 5, 6)
7	Demonstrated importance	(6, 7, 8)
9	Extreme importance	(9, 9, 9)
2 4 6 8	Intermediate values between two adjacent judgments	(1, 2, 3) (3, 4, 5) (5, 6, 7) (7, 8, 9)

The pair-wise comparison matrices are constructed as in Eq. 1 including values that show the kth decision maker's choice of one factor over another.

$$\widetilde{A}^k = \begin{bmatrix} \widetilde{d}_{11}^k \ \widetilde{d}_{12}^k \ \ldots \ \widetilde{d}_{1n}^k \\ \widetilde{d}_{21}^k \ \ldots \ldots \ \widetilde{d}_{2n}^k \\ \ldots \ \ldots \ldots \ \ldots \\ \widetilde{d}_{n1}^k \ \widetilde{d}_{n2}^k \ \ldots \ \widetilde{d}_{nm}^k \end{bmatrix} \tag{1}$$

Step 2: Each comparison matrix is checked with respect to consistency level. As Leśniak et al. (2018) propose, firstly the related comparison matrix is defuzzified via

Eq. 2, and then Saaty's classic consistency procedure is applied. The acceptable level for inconsistency is 0.1.

$$D(\widetilde{d}_{ij}) = \frac{l + 4m + u}{6} \tag{2}$$

Step 3: In case the number of decision-makers is more than one, the arithmetic average calculation of all $(\widetilde{d}_{ij})$ decision makers' judgment values is performed as in Eq. 3.

$$\widetilde{d}_{ij} = \frac{\sum_{k=1}^{K} \widetilde{d}_{ij}^{k}}{K} \tag{3}$$

Step 4: The fuzzy weight of each factor is gathered by applying the geometric mean method as indicated in Eq. 4.

$$\widetilde{r}_i = \left(\prod_{j=1}^{n} \widetilde{d}_{ij} \right)^{1/n}, \quad \mathrm{i} = 1, 2, \ldots, \mathrm{n} \tag{4}$$

Afterward, each factor i's fuzzy weight is obtained as in Eq. 5.

$$\begin{aligned} \widetilde{w}_i &= \widetilde{r}_i \otimes (\widetilde{r}_1 \otimes \widetilde{r}_2 \otimes \ldots \otimes \widetilde{r}_n)^{-1} \\ &= (lw_i, mw_i, uw_i) \end{aligned} \tag{5}$$

Step 5: The defuzzification method, Centre of Area (COA), is applied and the non-fuzzy value Mi of the fuzzy number is computed via Eq. 6 and then normalization is applied to Mi values and Ni values are obtained.

$$M_i = \frac{lw_i + mw_i + uw_i}{3} \tag{6}$$

Step 6: After the determination of Ni values, the global weights of all factors (Wi) are determined via the multiplication of the normalized values of the local criteria and the related main dimension.

3 Application in a Telecommunication Company

The evaluation factors play an important role in the value determination of recovery options and there is no constant formulation valid for every case as explained in the literature review part. Different from the existing literature, rental modems in the telecommunication sector are considered in this study. The application is performed in one of the biggest telecommunication companies in Turkey and it is aimed to determine the evaluation factors and their importance weights via FAHP.

As the first step of the application, the recovery options and the evaluation factors effective in the recovery option value determination process are obtained at the end of interviews with the company staff. The recovery options are “direct resell”, “refurbishment”, “repair/maintenance”, “spare parts” and “material recycling” and evaluation factors are represented in the hierarchical structure of FAHP as in Fig. 1. There are three main factors, namely inventory status, device history, and device status and there are eleven subfactors from E1 (Daily suitable stock forecast) to E11 (First analysis score of the device).

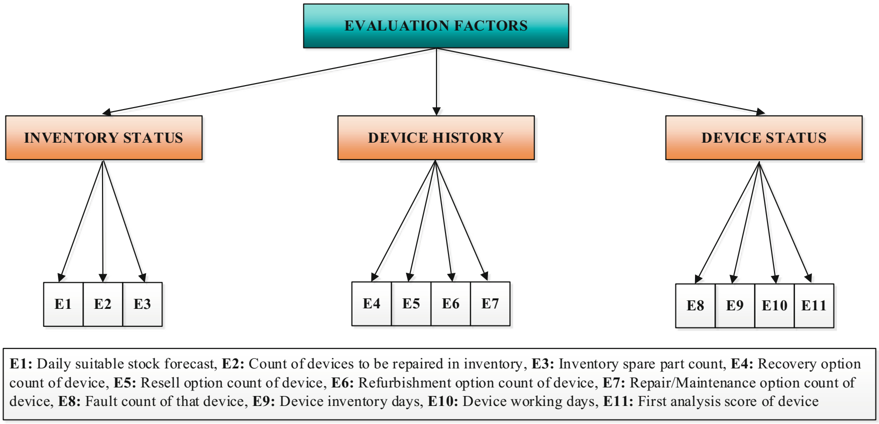

Fig. 1. The hierarchical structure for determining the importance of reasons.

Another situation in the company is that the importance weights of recovery options change with respect to the departments namely, marketing and customer relations. While the marketing department focuses on the increase in sales, the customer relations department aims to increase customer satisfaction. The importance weights of evaluation factors should be found for each recovery option and department. However, considering the page limitation, the steps of FAHP are only applied for the “direct resell” recovery option and the marketing department as follows.

Step 1: The pairwise comparison matrices for main and sub-factors which are indicated in Fig. 1 are determined via the consensus of related staff in the company and indicated in four tables (Tables 2, 3, 4 and 5).

Table 2. Pairwise comparison of the main factors

1st matrix	Inventory status	Device history	Device status
Inventory status	(1, 1, 1)	(4, 5, 6)	(3, 4, 5)
Device history	(1/6, 1/5, 1/4)	(1, 1, 1)	(1/4, 1/3, 1/2)
Device status	(1/5, 1/4, 1/3)	(2, 3, 4)	(1, 1, 1)

Table 3. Pairwise comparison of the sub-factors under "Inventory status" main factor

2nd matrix	E1	E2	E3
E1	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)
E2	(1/3, ½, 1)	(1, 1, 1)	(1, 2, 3)
E3	(1/4, 1/3, ½)	(1/3, ½, 1)	(1, 1, 1)

Table 4. Pairwise comparison of the sub-factors under "Device history" main factor

3rd matrix	E4	E5	E6	E7
E4	(1, 1, 1)	(2, 3, 4)	(5, 6, 7)	(4, 5, 6)
E5	(1/4, 1/3, 1/2)	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)
E6	(1/7, 1/6, 1/5)	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/4, 1/3, 1/2)
E7	(1/6, 1/5, 1/4)	(1/3, 1/2, 1)	(2, 3, 4)	(1, 1, 1)

Table 5. Pairwise comparison of the sub-factors under "Device status" main factor

4th matrix	E8	E9	E10	E11
E8	(1, 1, 1)	(7, 8, 9)	(5, 6, 7)	(1, 2, 3)
E9	(1/9, 1/8, 1/7)	(1, 1, 1)	(1/3, 1/2, 1)	(1/5, ¼, 1/3)
E10	(1/7, 1/6, 1/5)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)
E11	(1/3, ½, 1)	(3, 4, 5)	(1, 2, 3)	(1, 1, 1)

Step 2: The inconsistency value of each of the four matrices is computed and shown in Table 6. It is seen that all inconsistency values are less than 0.1 and acceptable.

Table 6. Inconsistency ratios

Matrix No	Inconsistency Ratio
1	0.074
2	0
3	0.032
4	0.01

Step 3: Since compromise judgments are utilized in the pairwise comparison matrices, this step is skipped.

Step 4: The fuzzy weight, $\widetilde{w}_i$, of each main and sub-factor is gathered from the related comparison matrices and indicated in Tables 7 and 8.

The main factor's fuzzy weights are shown in Table 7.

Table 7. The main factor's fuzzy weights

Main factor	Fuzzy weight ($\tilde{w}_i$)
Inventory status	(0.486, 0.674, 0.921)
Device history	(0.074, 0.101, 0.148)
Device status	(0.157, 0.226, 0.326)

The sub-factors fuzzy weights are shown in Table 8.

Table 8. The sub-factors fuzzy weights

Sub factor	Fuzzy weight ($\tilde{w}_i$)
E1-Daily suitable stock forecast	(0.278, 0.540, 0.958)
E2-Count of devices to be repaired in inventory	(0.153, 0.297, 0.603)
E3-Inventory spare count	(0.097, 0.163, 0.332)
E4-Recovery option count of the device	(0.379, 0.573, 0.849)
E5-Resell option count of the device	(0.127, 0.221, 0.369)
E6-Refurbishment option count of the device	(0.046, 0.069, 0.111)
E7-Repair/Maintenance option count of the device	(0.087, 0.138, 0.236)
E8-Fault count of that device	(0.346, 0.565, 0.884)
E9-Device inventory days	(0.042, 0.064, 0.111)
E10-Device working days	(0.067, 0.115, 0.210)
E11-First analysis score of devices	(0.142, 0.255, 0.469)

Step 5: The defuzzification process is performed and Mi values are found. Then, Ni values are obtained by normalizing Mi values.

The Mi and Ni values for the main factors are shown in Table 9.

Table 9. Mi and Ni values for the main factors

Main factor	M_i	N_i
Inventory status	0.694	0.669
Device history	0.108	0.104
Device status	0.236	0.228

The Mi and Ni values for the sub-factors are shown in Table 10.

Table 10. Mi and Ni values for the sub-factors

Sub factor	M_i	N_i
E1-Daily suitable stock forecast	0.592	0.519
E2-Count of devices to be repaired in inventory	0.351	0.308
E3-Inventory spare count	0.197	0.173
E4-Recovery option count of the device	0.600	0.562
E5-Resell option count of device	0.239	0.224
E6-Refurbishment option count of device	0.075	0.071
E7-Repair/Maintenance option count of device	0.153	0.144
E8-Fault count of that device	0.599	0.549
E9-Device inventory days	0.072	0.066
E10-Device working days	0.131	0.120
E11-First analysis score of devices	0.289	0.265

Step 6: The global weights of all factors (Wi) are determined via the multiplication of the normalized values of the sub-factor and the related main factor as shown in Table 11. In addition to the results obtained from the marketing department, the results for customer relations are also indicated in Table 11.

Firstly, it is seen that the main factors' importance weights differ among the departments. For the marketing department, the rank of main factors is inventory status, device status, and device history, respectively. Whereas, the rank is as device history, device status, and inventory status for the customer relations department. On the other hand, when the sub-factors are analyzed, it is observed that the top three for the marketing department are Daily suitable stock forecast (E1), Count of devices to be repaired in inventory (E2), and Fault count of that device (E8) and for the customer relations department, the rank is as Recovery option count of the device (E4), Fault count of that device (E8) and Repair/Maintenance option count of the device (E7). Hence, it is concluded that there are differences between the departments concerning the evaluation factors' importance weights, and in general, it is observed that the revenue-based factors are on the front for the marketing department, and contrary to this case, the factors related to customer satisfaction take priority for the customer relations department.

Table 11. Local and global weights of the sub-factors for marketing and customer relations departments

Factors	Marketing Department		Customer Relations Department	
	Local weight	Global weight	Local weight	Global weight
E1	0.519	0.347	0.678	0.083
E2	0.308	0.206	0.186	0.023
E3	0.173	0.116	0.136	0.017
E4	0.562	0.058	0.525	0.312
E5	0.224	0.023	0.071	0.042
E6	0.071	0.007	0.130	0.077
E7	0.144	0.015	0.274	0.163
E8	0.549	0.125	0.642	0.182
E9	0.066	0.015	0.062	0.017
E10	0.120	0.027	0.186	0.052
E11	0.265	0.060	0.111	0.031

4 Conclusion

Recovery of used products plays an important role in providing sustainability concerning the economy and environment. It has become more important under the effect of increasing consumption. However, directing the used products to the right options requires a systematic procedure based on evaluation factors. Within this context, another important point is to consider the varying effect of recovery options on different departments of a firm. The recovery option decisions should be made considering the benefits of the whole system rather than focusing on the individual desires of a specific department. Hence, the structure of recovery evaluation systems affects the decisions. In this study, an important part of that structure, evaluation factors are regarded and an application is performed in a telecommunication company. Firstly, the recovery options (5 options) and evaluation factors (3 main, 11 subfactors) are determined via contacting the two effective departments in the decision process, namely the marketing and customer relations departments. Afterward, the importance weights of factors are computed via FAHP for one of the recovery options (Direct resell) considering the two departments. It has been concluded that the values of importance weights change among the departments.

Due to the limited space in this publication type, the scope is limited, and therefore, the study has limitations. Firstly, the study only focuses on the evaluation factors and their importance weights. The importance weights of departments are not taken into account. Additionally, the quantitive formulations are not provided within the evaluation system. For further studies, a decision support system (DSS) can be developed. It can run on the forecasted sales and return data and then determine the importance weights of the departments. Moreover, the extensions of the classic fuzzy approach, such as the intuitionistic and neutrosophic sets can be used within MCDM methods.

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A Novel Hesitant Fuzzy Association Rule Mining Model

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Abstract. In this paper, a new Hesitant Fuzzy Association Rule model is proposed for the first time to mine the Frequent itemset and generate the rule by hesitant transaction matrix instead of the Boolean database. One fast FFI miner algorithm is used to find the frequent itemset without candidate generation. Also, pruning strategies are used to decrease the algorithm's run time and ignore the unnecessary itemsets. Another strength of our study is calculating the support and confidence metrics based on Hesitant Maximum Scalar Cardinality. A numerical example is conducted to show the performance of the proposed FFI-Miner algorithm compared to the Apriori-based approaches in terms of execution time and the number of evaluated itemsets.

Keywords: Hesitant fuzzy sets · Association rule mining · Frequent itemset

1 Introduction

Data mining is an essential technology for the efficient, accurate, and rapid utilization of large amounts of data, which is based on recognizing new and useful knowledge, logical relationships, and existing data patterns. It uses different approaches and algorithms to find the knowledge hidden in the data. As a result of the increase in data storage capacity, many strategic sales and marketing decisions have been made by processing these data. In this era, data is one of the crucial buzzwords that can change our insight into the world. Descriptive Analytics is the first stage of data processing that outlines historical data to acquire helpful information and organize the data for advanced analysis. In analyzing and classifying data from a statistical perspective, fuzzy sets and logic have become valuable tools to either model and handle inaccurate data or establish flexible techniques to deal with precise data. There are many misunderstandings and unclear aspects of Descriptive Analytics under fuzziness because of the novelty of this field. Fuzzy Association Rules mining is one of the most popular descriptive analytics approaches. Data mining techniques are generally divided into supervised and unsupervised techniques. Association Rules Mining is known as an unsupervised technique. Association Rules Mining (ARM) tries to find the dependency between collected data with the "If_Then" statement (Pérez-Alonso et al. 2021). It was introduced by Hájek et al. to analyze market baskets to recognize dependencies and rules in customers' shopping behavior. The most

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famous ARM algorithms in the literature are Apriori and Elactinstead (Tajbakhsh et al. 2009). Mining Association Rules from quantitative attributes increase the complexity of the problem. Fuzzy Association Rule (FAR) solves this problem by converting the crisp data to fuzzy data to decrease the granularity (M. Delgado et al. 2003). Due to the popularity of Association rules, widely use of Fuzzy Association rules is not far from expected. Fuzzy Association rules provide a new framework for mapping crisp data to uncertain data. Instead of using 0_1 logic, Fuzzy Sets can be used to handle the imprecise nature. This mapping improves the semantic content of the rules and makes them more understandable and sensible to humans (Miguel Delgado et al. 2014). Fuzzification of Association Rules can be done by applying each element of it. The new extension of Fuzzy Association Rules can be suggested by adding fuzziness in items, transactions, and rules components. FARs can be obtained by using Fuzzy transactions that use a fuzzy subset of items Where the degree of each item is interpreted as the degree of its membership in the transaction (M. Delgado et al. 2003). This method is widely used in literature to fuzzification the ARM. Measuring is the other important issue in the Fuzzification of Association Rules for assessing the rules. There are many different measuring techniques in the literature, but generally, none is proven as best. Most of the FARs approaches in the literature used the sigma-count cardinality measure (M. Delgado et al. 2003). On the other hand, different extensions of Fuzzy sets proposed many Fuzzy Association Rules methods. Chen et al. (2015) proposed Fuzzy Association Rule Mining with Type-2 Membership Functions. In another study, an Apriori-based mining technique was proposed for mining linguistic association (Choo et al. 2008). Zheng Pei (2008) used Intuitionistic fuzzy sets and Hamming distance to mine the association rule between condition and conclusion. A hybrid Fuzzy Association Rule method was proposed by integrating rough set theory and fuzzy set in (Roy & Chatterjee, 2015). Intuitionistic Association Rules mining and many hybrid methods that integrate with it were proposed in many articles (Geetha et al. 2017; Sreenivasula Reddy et al. 2022). Other extensions of fuzzy sets were applied for FARs, such as Type2 (J. Chen et al. 2022), Interval type 2 (Madbouly et al. 2021), and Interval Fuzzy sets (Burda et al. 2020), etc.

Very extensions of fuzzy sets have been proposed since Zadeh defined fuzzy sets for the first time (Xu, 2014). Each of them has advantages and disadvantages. The hesitant Fuzzy set introduced by Torra is a new extension of Fuzzy sets that intends to model the uncertainty originated by the hesitation that might arise in the assignment of membership degrees of the elements to a fuzzy set based on the different expert opinions (Faizi et al. 2018). It rapidly applied in many articles in a short time to handle the hesitancy situation of uncertain data. In addition, many operators for HFSs and extensions have been introduced to deal with such information in different applications where decision-making has been the most remarkable (Council, 2010). So in this study, Hesitant Fuzzy Association Rule is proposed to mine data regulations by considering the different expert views.

The rest of the study is constructed as follows: Some basic study concepts are defined in the second section. The suggested Hesitant ARM Model is presented and explained in Sect. 3. To prove the applicability and validity of the model, one numerical example is solved by the proposed model in Sect. 4, and finally, the results are discussed in the conclusion section.

2 Preliminaries

Defintion 1. Suppose that $I = \{I_1, I_2, I_3, \ldots, I_m\}$ be a set of items, $D = \{t_1, t_2, t_3, \ldots, t_n\}$ be n transactions that each of them is a subset of I, Then $A \rightarrow B$ is Association Rule if:

1- $the\, A \in I, B \in I, A \cap B = \varnothing$
2- Support $(A \rightarrow B) \geq \delta_s$
3- Confidence $(A \rightarrow B) \geq \delta_c$

where δ_s is a minimum threshold for support value and δ_c is a minimum threshold for confidence value. So the right side of the rule is usually called Antecedent and the left side is consequent (Marín et al. 2016).

Defintion 2. Triangular norms are binary operations $\otimes : [0, 1] \times [0, 1] \rightarrow [0, 1]$ which satisfy Commutativity, Associativity, Monotonicity, and Boundary conditions for each $x, y, z \in [0, 1]$. Many articles have studied T_norm, but the most common forms are (Burda et al. 2020):

1- Gödel (minimum) t-norm: $\min(x, y)$
2- Goguen (product) t-norm: $x \times y$
3- Łukasiewicz t-norm: $\max(0, x + y - 1)$

Defintion 3. Suppose that A is a Hesitant Fuzzy set that $A = \{\langle x_i, h_A(x_i)\rangle | x_i \in U\}$, then $\vartheta = 1$ calculate Maximal scalar cardinality, $\vartheta = 0$ calculate Minimum scalar cardinality and $\vartheta = \frac{1}{2}$ calculate the Neutral scalar cardinality:

$$|A|_0 = \sum\nolimits_{i=1}^{n} h_A^-(x_i) \tag{1}$$

$$|A|_1 = \sum\nolimits_{i=1}^{n} h_A^+(x_i) \tag{2}$$

$$|A|_{\frac{1}{2}} = \sum\nolimits_{i=1}^{n} \frac{h_A^-(x_i) + h_A^+(x_i)}{2} \tag{3}$$

where $h_A^-(x_i)$ is the minimum membership degree of $h_A(x_i)$ and $h_A^+(x_i)$ is the maximum membership degree of $h_A(x_i)$ (Zhang & Yang, 2020).

3 The Proposed Hesitant FARM Model

In this section, the new Hesitant FARM model is built to mine the rules from crisp data that can handle the uncertainty of data with a Fuzzy structure and overcome the hesitancy in membership assignment by HFSs. It means that, instead of using one fuzzification method we can use multi fuzzification methods which can improve the accuracy of our transformed data. Generally, Frequent Itemset Mining and Rule Generation are two faces of ARM. There are Frequent Itemset Mining algorithms in the literature that have different run times. Lin et al. (2015) proposed a Fuzzy Frequent Itemset (FFI)-Miner algorithm for all FFIs without candidate generation sets. It used a novel fuzzy-list structure to keep the essential information for the later mining process. An efficient pruning strategy is also developed to reduce the search space, thus speeding up the mining process to discover the FFIs directly. In this study, we modify this algorithm with Hesitant Fuzzy Sets to find the Frequent Itemsets. The steps of the proposed model are provided as follows:

1- **Fuzzification step:** In this step, we change the crisp transaction matrix to a Hesitant Fuzzy transaction matrix that contains membership degrees instead of crisp numbers. For example, suppose a market basket list that contains two items of milk and bread with 2 and 3 values. In this list,2 and 3 numbers do not mean anything to us, but when we change these values to the membership degree of linguistic variables "Low", "Middle" and "High" it becomes meaningful. Suppose $I = \{I_1, I_2, I_3, \ldots, I_m\}$ be a set of items, $QD = \{T_1, T_2, T_3, \ldots, T_n\}$ be n transactions that each of them is a subset of I. In the proposed model, we change the quantitative values of the transaction matrix to Hesitant Fuzzy Sets by Eq. (4).

$$f_{iq} = \langle \mu_i^{Tr}(v_{iq}), \mu_i^{Trap}(v_{iq}) \rangle = \langle \left(\frac{fv_{iq1}^{Tr}}{R_{i1}} + \frac{fv_{iq2}^{Tr}}{R_{i2}} + \ldots + \frac{fv_{iql}^{Tr}}{R_{il}} \right), \left(\frac{fv_{iq1}^{Trap}}{R_{i1}} + \frac{fv_{iq2}^{Trap}}{R_{i2}} + \ldots + \frac{fv_{iql}^{Trap}}{R_{il}} \right) \rangle \quad (4)$$

where l is the number of fuzzy terms, R_{il} is the l_th fuzzy term and fv_{iql}^{Tr} and fv_{iql}^{Trap} are Triangular and Trapezoidal membership degree (fuzzy value) of v_{iq} of i in the l-th fuzzy terms, respectively, based on Triangular and Trapezoidal fuzzification models.

Maximum Scalar Cardinality Strategy: After transforming the quantitative values to fuzzy numbers, used Maximum Scalar Cardinality to prevent dimension increasing. It means that with Maximum Scalar Cardinality, the number of transformed terms used in the process is equal to the number of the original items.

Support Ascending Strategy: After applying the Maximum Scala Cardinality, the support of each fuzzy term calculate by Eq. (5) and sorted in ascending order to build the k_itemset ($k \geq 2$). Based on these two strategies original dataset was transformed into a fuzzy dataset.

$$support(R_{il}) = \sum\nolimits_{R_{il} \subseteq T_q \wedge T_q \in QD'} fv_{iql}^{+} \quad (5)$$

$$support(x_1, x_2) = \left\{ x_1, x_2 \in R_{il} | \sum\nolimits_{R_{il} \subseteq T_q \wedge T_q \in QD'} \left(fv_{x_1ql}^{+} \otimes fv_{x_2ql}^{+} \right) \right\}$$

where $\otimes$ shown t_norm of k_itemset and QD' is the new Hesitant Fuzzy transaction set.

2- **Mining Frequent Itemset:** After previous steps transformed the original database, the remaining fuzzy terms in the first level are used to build their own fuzzy list structures. All the fuzzy terms in the fuzzy list structure have three attributes:

- Transaction TID (tid), which indicates a transaction T_q containing R_{il}.
- Internal fuzzy value (if), which indicates the fuzzy value of R_{il} in T_q.
- Resting fuzzy value (rf), which indicates the maximum fuzzy value of the resting fuzzy terms after R_{il} in T_q.

In this step to mining the frequent itemset, all fuzzy lists in each level are examined by two metrics which are defined in Eq. (6) and Eq. (7):

$$sum.R_{il}.if = \sum_{R_{il} \subseteq T_q \wedge T_q \in QD'} if(R_{il}, T_q) \tag{6}$$

$$sum.R_{il}.rf = \sum_{R_{il} \subseteq T_q \wedge T_q \in QD'} rf(R_{il}, T_q) \tag{7}$$

Search Space Strategy: This strategy is used to build the enumeration tree and has two limitations: 1-For an itemset K, if $sum.k.if \geq \delta_s \times |QD|$, then k be a frequent itemset and can combine with the other frequent itemsets in the next levels. 2-If $sum.R_{il}.rf < \delta_s \times |QD|$, any extensions of k will not be fuzzy frequent itemsets and can be directly ignored to avoid the construction phase of the fuzzy-list structures of the extensions of k.

3- **Generating the rules:** Finally, Hesitant Fuzzy Association Rules are generated in this section. So All potential rules for each extracted frequent itemsets are listed and calculated Confidence degree by Eq. (8) for all of them. Rules with a confidence value greater than minimum confidence are selected as Association Rules.

$$confidence(\boldsymbol{A} \rightarrow \boldsymbol{B}) = \frac{\boldsymbol{support}(\boldsymbol{A}, \boldsymbol{B})}{\boldsymbol{support}(\boldsymbol{A})} \tag{8}$$

4 A Numerical Application

This section evaluates the proposed Hesitant Fuzzy Association Rules mining by a numerical example. Suppose we have a quantitative market sales database. It consists of five items and eight transactions, as shown in Table 1.

Table 1. A quantitative database Items

	A	B	C	D	E
1	5		10	2	9
2	8	2	3		
3		3	9		

(*continued*)

Table 1. (*continued*)

	A	B	C	D	E
4	5	3	10		3
5	7		9	3	
6		2	8	3	
7	5	2	5		
8	3		10	2	2

Based on steps defined in the proposed model, the quantitative transaction matrix is transformed into the Hesitant Fuzzy transaction matrix by the Triangular and Trapezoidal membership functions shown in Fig. 1.

Final Hesitant Fuzzy transaction matrix based on maximum scalar cardinality in 3-term linguistic is represented in Table2. Based on support ascending order, our sorted list in level 1 is $D.l < B.l < A.M < C.H$. Based on this order, the initial fuzzy list structure of fuzzy terms is illustrated in Fig. 2.

Based on this initial solution, all D.l, B.l, A.M, C.H are frequent itemsets and can combine with others to build 2_itemset, but C.H itself cannot produce any new itemsets.

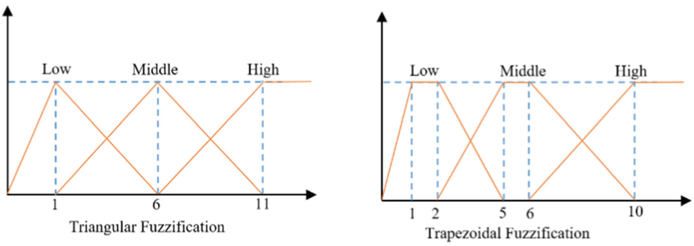

Fig. 1. The used linear membership functions of linguistic 3-terms

Table 2. Hesitant Fuzzy transaction matrix

	A.M	B.l	C.H	D.l
1	⟨0.8, 1⟩		⟨0.8, 1⟩	⟨0.8, 1⟩
2	⟨0.6, 0.5⟩	⟨0.8, 1⟩		
3		⟨0.6, 0.67⟩	⟨0.6, 0.75⟩	
4	⟨0.8, 1⟩	⟨0.6, 0.67⟩	⟨0.8, 1⟩	
5	⟨0.8, 0.75⟩		⟨0.6, 0.75⟩	⟨0.6, 0.67⟩
6		⟨0.8, 1⟩	⟨0, 0.5⟩	⟨0.6, 0.67⟩
7	⟨0.8, 1⟩	⟨0.8, 1⟩		
8			⟨0.8, 1⟩	⟨0.8, 1⟩

D.l		
tid	if	rf
1	⟨0.8, 1⟩	⟨0.8,1⟩
5	⟨0.6, 0.67⟩	⟨0.8,0.75⟩
6	⟨0.6, 0.67⟩	⟨0.8,1⟩
8	⟨0.8, 1⟩	⟨0.8,1⟩
sum	3.34	3.75

sum.if *sum.rf*

B.l		
tid	if	rf
2	⟨0.8, 1⟩	⟨0.6,0.5⟩
3	⟨0.6, 0.67⟩	⟨0.6,0.75⟩
4	⟨0.6, 0.67⟩	⟨0.8,1⟩
6	⟨0.8,1⟩	⟨0,0.5⟩
7	⟨0.8, 1⟩	⟨0.8,1⟩
sum	4.34	3.94

A.M		
tid	if	rf
1	⟨0.8, 1⟩	⟨0.8,1⟩
2	⟨0.6, 0.5⟩	⟨0, 0⟩
4	⟨0.8, 1⟩	⟨0.8, 1⟩
5	⟨0.8, 0.75⟩	⟨0.6,0.75⟩
7	⟨0.8, 1⟩	⟨0, 0⟩
sum	4.4	2.75

C.H		
tid	if	rf
1	⟨0.8, 1⟩	⟨0, 0⟩
3	⟨0.6, 0.75⟩	⟨0, 0⟩
4	⟨0.8, 1⟩	⟨0, 0⟩
5	⟨0.6, 0.75⟩	⟨0, 0⟩
6	⟨0, 0.5⟩	⟨0, 0⟩
8	⟨0.8, 1⟩	⟨0, 0⟩
sum	5	0

Fig. 2. The initial constructed fuzzy-list structures

So the next level fuzzy list is represented as follows. As shown in Fig. 3, D.l_C.H, B.l_AM, and AM_C.H are frequent itemset, but none of the nodes can not create the new k_itemset. So final rules that can be generated from frequent itemsets with a minimum confidence threshold of 0.5 are represented in Table 3.

D.l_B.l		
tid	if	rf
6	⟨0.6, 0.67⟩	⟨0.8,1⟩
sum	0.67	1

D.l_AM		
tid	if	rf
1	⟨0.8,1⟩	⟨0.8,1⟩
5	⟨0.6,0.67⟩	⟨0.6,0.75⟩
sum	1.67	1.75

D.l_CH		
tid	if	rf
1	⟨0.8,1⟩	⟨0,0⟩
5	⟨0.6,0.67⟩	⟨0,0⟩
6	⟨0,0.5⟩	⟨0,0⟩
8	⟨0.8,1⟩	⟨0,0⟩
sum	3.17	0

B.l_AM		
tid	if	rf
2	⟨0,0.5⟩	⟨0,0⟩
4	⟨0.6,0.67⟩	⟨0.8,1⟩
7	⟨0.8,1⟩	⟨0,0⟩
sum	2.17	1

B.l_CH		
tid	if	rf
3	⟨0.6,0.67⟩	⟨0,0⟩
4	⟨0.6,0.67⟩	⟨0,0⟩
6	⟨0,0.5⟩	⟨0,0⟩
sum	1.84	0

AM,CH		
tid	if	rf
1	⟨0.8,1⟩	⟨0,0⟩
4	⟨0.8,1⟩	⟨0,0⟩
5	⟨0,0.5⟩	⟨0,0⟩
sum	2.5	0

Fig. 3. The second constructed fuzzy-list structures

Table 3. Fuzzy association rules with 50% of confidence value

	Fuzzy_confidence
$D.l \rightarrow C.H$	0.94
$C.H \rightarrow D.l$	0.63
$B.l \rightarrow A.M$	0.5
$A.M \rightarrow B.l$	0.49
$A.M \rightarrow C.H$	0.56
$\mathrm{C}.H \rightarrow A.M$	0.5

5 Conclusion

In this study, the Hesitant Fuzzy Association Rule mining approach is proposed for the first time that fuzzifies boolean database to Fuzzy database based on Hesitant Fuzzy sets. It means that instead of using one fuzzification method, we can use multi-fuzzification methods to improve our transformed data's accuracy. Another contribution of our study is calculating the support and confidence metrics based on Hesitant Maximum Scalar Cardinality. The result of numerical examples represents the proposed model's validity and applicability, and the number of mined frequent itemsets with this method is decreased compared with Apriori Algorithm. So the whole time to mining the association rules with the proposed model and complexity of the model is decreased compared with other FARM models. For the future study, we want to apply the proposed model to the real data to determine the real accuracy of this method.

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Evaluating the Criteria in the Dimensions of the Kraljic Purchasing Portfolio Matrix

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Abstract. The Kraljic purchasing portfolio model is an approach for categorizing a company's purchased components into four quadrants based on the significance of the components (specified by the impact that they have on the profitability of the firm) and the complexity (or risk) of the supply market (such as the number of suppliers, lead time, logistical proximity). The Kraljic model enables the company to identify the most appropriate purchasing strategies for the four types of components. The neutrosophic concept can handle inconsistent and vague information with the membership functions of truth, indeterminacy, and falsity. Therefore, we integrated the neutrosophic concept the with AHP method to evaluate the criteria for defining the Kraljic matrix and compute their weights.

Keywords: Kraljic portfolio matrix · Neutrosophic sets · AHP · Purchasing

1 Introduction

The purchasing process is significantly responsible for determining the features of procured components and materials, choosing appropriate suppliers, and managing the transaction for timely delivery of purchases. To achieve 'strategic purchasing', the purchaser should specify and manage the procurement strategy based on a deep understanding of the business strategy and its products (Lee and Drakef 2010). Purchasing portfolio model, proposed by Kraljic in 1983, is a consolidated model that first includes the categorization of purchased commodities and secondly, the assessment of the strength of the supply market. Regarding the categorization of purchased products, the Kraljic portfolio model which is shown in Fig. 1 takes into consideration both the significance of the purchased product and the complexity of the supply market and classifies the products in terms of strategic impact (high/low) and supply risk (high/low) in a 2×2 matrix. The primary objective of this model is to identify strategic items with high-profit impact and high supply risk (Bianchini et al. 2019). While other approaches have been proposed (i.e., Kamann 2007; Dubois and Pedersen 2002; Tryggvason and Johansen 1996), the Kraljic portfolio model (KPM) has become the dominant approach in the literature and the basis of purchasing strategies for several companies (Montgomery et al. 2018).

While KPM has greatly influenced professional procurement and inspired academic literature to date, it has also come under a reasonable degree of criticism. One of the main

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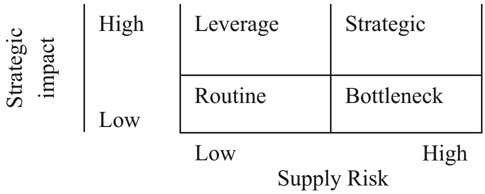

Fig. 1. Kraljic portfolio model

criticisms and observations is the difficulty of determining the criteria that define the dimensions of KPM (strategic impact and supply risk) (Padhi et al. 2012). In this case, it is normal for individuals to be indecisive and inconsistent in the evaluation process. Subjective and uncertain judgments of individuals can lead to great uncertainty in the process.

Neutrosophic set concept is influential in handling ambiguity and uncertainty. It can process inconsistent and ambiguous information with the membership functions of truth, indeterminacy, and falsity. Moreover, interval-valued neutrosophic sets (IVNSs) can better demonstrate uncertain, indeterminate, and unstable information that arises in the real world. Therefore, we integrated INVSs with the AHP method to evaluate these factors and compute their weights. The outline of this study follows: Sect. 2 demonstrates the steps of the proposed approach. Section 3 illustrates an application to prove the feasibility of the proposed model. The last section provides the conclusion.

2 Proposed Model

In this section, the steps of the proposed approach are presented. Before that, the essential operations and equations of interval valued neutrosophic numbers (IVNNs) are given in the paper of Bolturk and Kahraman (2018).

2.1 INVSs and Their Operations

Definition 1. There are a truth-membership function T_A (x), an indeterminacy-membership function I_A (x) and a falsity-membership function F_A (x) in any neutrosophic set A in X. There is no restriction on the summation of T_A (x), I_A (x) and F_A (x), therefore $0^- \leq \sup T_A(x) + \sup I_A(x) + \sup F_A(x) \leq 3^+$.

Definition 2. An interval valued neutrosophic number (IVNN) can be demonstrated as $A = (T_A, I_A, F_A) = \left([T_a^L, T_a^U], [I_a^L, I_a^U], [F_a^L, F_a^U]\right)$, where $\left[T_A^L, T_A^U\right] \subseteq [0, 1]$, $\left[I_A^L, I_A^U\right] \subseteq [0, 1]$, $\left[F_A^L, F_A^U\right] \subseteq [0, 1]$ and $0 \leq T_A^U + I_A^U + F_A^U \leq 3$.

Definition 3. Let $\tilde{A} = \left([T_a^L, T_a^U], [I_a^L, I_a^U], [F_a^L, F_a^U]\right)$ and $\tilde{B} = \left([T_b^L, T_b^U], [I_b^L, I_b^U], [F_b^L, F_b^U]\right)$ be two IVNNs. Their arithmetic operations and relations are demonstrated by Eqs. 1–5 (Bolturk and Kahraman 2018).

$$\tilde{A}^c = \left(\left[F_a^L, F_a^U\right], \left[1 - I_a^U, 1 - I_a^L\right], \left[T_a^L, T_a^U\right]\right) \tag{1}$$

$$\tilde{A} = \tilde{B} \text{ if and only if } \tilde{A} \subseteq \tilde{B} \text{ and } \tilde{A} \subseteq \tilde{B} \tag{2}$$

$$\tilde{\mathrm{A}} \oplus \tilde{\mathrm{B}} = \left(\left[T_a^L + T_b^L - T_a^L T_b^L, T_a^U + T_b^U - T_a^U T_b^U\right], \left[I_a^L I_b^L, I_a^U I_b^U\right], \left[F_a^L F_b^L, F_a^U F_b^U\right]\right) \tag{3}$$

$$\tilde{\mathrm{A}} \ominus \tilde{\mathrm{B}}s = \left(\left[T_a^L - F_b^U, T_a^U - F_b^L\right], \left[\max\left(I_a^L, I_b^L\right), \max\left(I_a^U, I_b^U\right)\right], \left[F_a^L - F_b^L, F_a^U - F_b^U\right]\right) \tag{4}$$

$$\tilde{\mathrm{A}} \otimes \tilde{\mathrm{B}} = ([T_a^L T_b^L, T_a^U T_b^U], [I_a^L + I_b^L - I_a^L I_b^L, I_a^U + I_b^U - I_a^U I_b^U], [F_a^L + F_b^L - F_a^L F_b^L, F_a^U + F_b^U - F_a^U F_b^U]) \tag{5}$$

Definition 4. Let $\tilde{\mathrm{A}} = \left(\left[T_a^L, T_a^U\right], \left[I_a^L, I_a^U\right], \left[F_a^L, F_a^U\right]\right)$ be an INN. A new deneutrosophication equation of an INN is developed by Bolturk and Kahraman (2018) as shown in Eq. 6 (Bolturk and Kahraman 2018).

$$\mathrm{D} = \left(\left(T_a^L + T_a^U\right)/2 + \left(1 - \left(I_a^L + I_a^U\right)/2\right) \cdot \left(I_a^U\right) - \left(F_a^L + F_a^U/2\right) \cdot \left(1 - F_a^U\right)\right) \tag{6}$$

AHP has been proposed by Saaty (1990) and it helps individuals to decompose a complicated problem into a hierarchical structure. While AHP is popular for handling multi-criteria decision-making problems, it has been criticized for its inability to handle uncertainty in human judgments. In the conventional AHP approach, the values used to compare various criteria are represented by precise numbers on a scale of 1–9. In the real world, individuals may not be able to express their judgments on these criteria with exact values due to the lack of available information. To deal with this issue, IVN-AHP is presented, in which each pairwise comparison judgment is demonstrated as an interval-valued neutrosophic number. In this paper, to determine the weights of the criteria, the steps of the IVN-AHP proposed by Bolturk and Kahraman, (2018) are shown as follows:

(1) Determine the evaluation scale as demonstrated in Table 1.
(2) Establish the pairwise comparison matrices by employing IVNSs.
(3) The deneutrosophication formula shown in Eq. 6 is utilized to measure the consistency of the pairwise comparison matrices. The neutrosophic pairwise comparison matrix is considered consistent if the consistency ratio of the neutrosophic pairwise comparison matrix is less than 0.10.
(4) Determine the significance weights of the criteria by employing the IVN evaluation scale in Table 1 proposed by Bolturk and Kahraman (2018).

- Initially, the values in each column are summed.
- Then, an upper value is selected for each parameter and each term is divided by its corresponding value. Thus, normalized values are derived.
- Finally, the significance weights of the criteria are calculated by averaging the values in the normalized rows. Next, the deneutrosophication formula given in Eq. (6) is applied to obtain the exact value of the significance weights of the criteria.

Table 1. Linguistic terms and neutrosophicated importance weights

linguistic term	T_L	T_U	I_L	I_U	F_L	F_U
Equal ımportance (EqI)	0,5	0,5	0,5	0,5	0,5	0,5
Weakly more importance (WEI)	0,5	0,6	0,35	0,45	0,4	0,5
Moderate importance (MI)	0,55	0,65	0,3	0,4	0,35	0,45
Moderately more importance (MMI)	0,6	0,7	0,25	0,35	0,3	0,4
Strong importance (SI)	0,65	0,75	0,2	0,3	0,25	0,35
Strongly more importance (SMI)	0,7	0,8	0,15	0,25	0,2	0,3
Very strong importance (VSI)	0,75	0,85	0,1	0,2	0,15	0,25
Very strongly more importance (VSMI)	0,8	0,9	0,05	0,1	0,1	0,2
Extreme importance (ExI)	0,9	0,95	0	0,05	0,05	0,15
Extremely high importance (EHI)	0,95	1	0	0	0	0,1
Absolutely more importance (AMI)	1	1	0	0	0	0

3 Application

We interviewed an expert on purchasing to evaluate the criteria of supply risk and strategic impact dimensions. The criteria used in the Kraljic portfolio matrix are extracted from most-cited studies (Kraljic 1983; Gelderman and Mac Donald 2008; Padhi et al. 2012; Arantes et al. 2015; Medeiros and Ferreira 2018). The criteria for the strategic impact dimension are product profitability (P1), impact on business growth (P2), volume purchased (P3), the impact of product quality (P4), importance of purchase (P5), bargaining power of the buyer (P6) and material cost (P7). Moreover, the criteria for the supply risk dimension are the number of suppliers (S1), make or buy opportunities (S2), storage risks (S3), substitution possibilities (S4), legal requirements (S5), logistical proximity (S6), lead time (S7), entry barriers (S8), availability/scarcity (S9), cultural differences (S10). After determination, the relevant criteria, and the significance weights of the criteria are calculated by the purchasing expert. The pairwise comparison matrices of strategic impact dimension criteria and supply risk dimension criteria are established as shown in Table 2 and Table 3, respectively.

Table 2. The pairwise comparisons of the strategic impact criteria.

	P1	P2	P3	P4	P5	P6	P7
P1	EI	EXI	SMI	MI	SI	AMI	MI
P2	EXI^c	EI	MI^c	SI^c	MI^c	MI	SI^c
P3	SMI^c	MI	EI	MI^c	WMI^c	SI	WMI

(*continued*)

Table 2. (*continued*)

	P1	P2	P3	P4	P5	P6	P7
P4	MI^c	SI	MI	EI	WMI	VSI	WMI^c
P5	SI^c	MI	WMI	WMI^c	EI	SMI	MI^c
P6	AMI^c	MI^c	SI^c	VSI^c	SMI^c	EI	VSI^c
P7	MI^c	SI	WMI^c	WMI	MI	VSI	EI

Table 3. The pairwise comparisons of the supply risk criteria.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
S1	EI	SMI	AMI	SI	EHI	EXI	EXI	SMI	MI	AMI
S2	SMI^c	EI	SI	MI	MI	WMI	WMI	EI	WMI^c	SI
S3	AMI^c	SI^c	EI	WMI^c	WMI^c	MI^c	MI^c	SMI^c	VSI^c	WMI^c
S4	SI^c	MI^c	WMI	EI	SI	MI	MI	MI^c	WMI^c	SMI
S5	EHI^c	MI^c	WMI	SI^c	EI	WMI^c	WMI^c	SI^c	SMI^c	MI
S6	EXI^c	WMI^c	MI	MI^c	WMI	EI	EI	MI^c	SI^c	WMI^c
S7	EXI^c	WMI^c	MI	MI^c	WMI	EI	EI	WMI^c	SI^c	WMI
S8	SMI^c	EI	SMI	MI	SI	MI	WMI	EI	WMI^c	SI
S9	MI^c	WMI	VSI	WMI	SMI	SI	SI	MI	EI	VSI
S10	AMI^c	SI^c	WMI	SMI^c	MI^c	WMI	WMI^c	SI^c	VSI^c	EI

Then, the consistency ratio of the pairwise comparison matrices in Table 4 and Table 5 are calculated by employing the deneutrosophication equation given in Eq. (6). The deneutrosophicated matrices in Table 4 and Table 5 were found to be consistent, so the neutrosophic matrices are consistent.

Table 4. Column sums of the pairwise comparison matrix of the criteria of the strategic impact.

	P1						P2					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
P1	0.50	0.50	0.50	0.50	0.50	0.50	0.90	0.95	0.00	0.05	0.05	0.15
P2	0.05	0.15	0.95	1.00	0.90	0.95	0.50	0.50	0.50	0.50	0.50	0.50
P3	0.20	0.30	0.75	0.85	0.70	0.80	0.55	0.65	0.30	0.40	0.35	0.45
P4	0.35	0.45	0.6	0.7	0.55	0.65	0.65	0.75	0.20	0.30	0.25	0.35
P5	0.25	0.35	0.7	0.8	0.65	0.75	0.55	0.65	0.30	0.40	0.35	0.45

(*continued*)

Table 4. (*continued*)

	P1						P2					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
P6	0.00	0.00	1.0	1.00	1.00	1.00	0.35	0.45	0.60	0.70	0.55	0.65
P7	0.35	0.45	0.6	0.7	0.55	0.65	0.65	0.75	0.20	0.30	0.25	0.35
Sum	1.70	2.20	5.10	5.55	4.85	5.30	4.15	4.70	2.10	2.65	2.30	2.90
	P3						P4					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
P1	0.70	0.80	0.15	0.25	0.20	0.30	0.55	0.65	0.30	0.40	0.35	0.45
P2	0.35	0.45	0.60	0.70	0.55	0.65	0.25	0.35	0.70	0.80	0.65	0.75
P3	0.50	0.50	0.50	0.50	0.50	0.50	0.35	0.45	0.60	0.70	0.55	0.65
P4	0.55	0.65	0.30	0.40	0.35	0.45	0.50	0.50	0.50	0.50	0.50	0.50
P5	0.50	0.60	0.35	0.45	0.40	0.50	0.40	0.50	0.55	0.65	0.50	0.60
P6	0.25	0.35	0.70	0.80	0.65	0.75	0.15	0.25	0.80	0.90	0.75	0.85
P7	0.40	0.50	0.55	0.65	0.50	0.60	0.50	0.60	0.35	0.45	0.40	0.50
Sum	3.25	3.85	3.15	3.75	3.15	3.75	2.70	3.30	3.80	4.40	3.70	4.30
	P5						P6					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
P1	0.65	0.75	0.20	0.30	0.25	0.35	1.00	1.00	0.00	0.00	0.00	0.00
P2	0.35	0.45	0.60	0.70	0.55	0.65	0.55	0.65	0.30	0.40	0.35	0.45
P3	0.40	0.50	0.55	0.65	0.50	0.60	0.65	0.75	0.20	0.30	0.25	0.35
P4	0.50	0.60	0.35	0.45	0.40	0.50	0.75	0.85	0.10	0.20	0.15	0.25
P5	0.50	0.50	0.50	0.50	0.50	0.50	0.70	0.80	0.15	0.25	0.20	0.30
P6	0.20	0.30	0.75	0.85	0.70	0.80	0.50	0.50	0.50	0.50	0.50	0.50
P7	0.55	0.65	0.30	0.40	0.35	0.45	0.75	0.85	0.10	0.20	0.15	0.25
Sum	3.15	3.75	3.25	3.85	3.25	3.85	4.90	5.40	1.35	1.85	1.60	2.10

	P7					
	Tl	Tu	Il	Iu	Fl	Fu
P1	0.55	0.65	0.30	0.40	0.35	0.45
P2	0.25	0.35	0.70	0.80	0.65	0.75
P3	0.50	0.60	0.35	0.45	0.40	0.50
P4	0.40	0.50	0.55	0.65	0.50	0.60
P5	0.35	0.45	0.60	0.70	0.55	0.65
P6	0.15	0.25	0.80	0.90	0.75	0.85
P7	0.50	0.50	0.50	0.50	0.50	0.50
Sum	2.70	3.30	3.80	4.40	3.70	4.30

Column sums of the pairwise comparison matrix of the criteria of the strategic impact and supply risk are demonstrated in Table 4 and Table 5, respectively. The normalized values are calculated by dividing the upper value into the corresponding columns. Then, the significance weights of the criteria are obtained by averaging the elements in the rows. Neutrosophic weights of the criteria are shown in Table 6 and Table 7.

Table 5. Column sums of the pairwise comparison matrix of the criteria of the supply risk.

	S1						S2					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
S1	0.50	0.50	0.50	0.50	0.50	0.50	0.70	0.8	0.15	0.25	0.20	0.30
S2	0.20	0.30	0.75	0.85	0.70	0.80	0.50	0.50	0.50	0.50	0.50	0.50
S3	0.00	0.00	1.00	1.00	1.00	1.00	0.25	0.35	0.70	0.80	0.65	0.75
S4	0.25	0.35	0.70	0.80	0.65	0.75	0.35	0.45	0.60	0.70	0.55	0.65
S5	0.00	0.10	1.00	1.00	0.95	1.00	0.35	0.45	0.60	0.70	0.55	0.65
S6	0.05	0.15	0.95	1.00	0.90	0.95	0.40	0.50	0.55	0.65	0.50	0.60
S7	0.05	0.15	0.95	1.00	0.90	0.95	0.40	0.50	0.55	0.65	0.50	0.60
S8	0.20	0.30	0.75	0.85	0.70	0.80	0.50	0.50	0.50	0.50	0.50	0.50
S9	0.35	0.45	0.6	0.70	0.55	0.65	0.50	0.60	0.35	0.45	0.40	0.50
S10	0.00	0.00	1.00	1.00	1.00	1.00	0.25	0.35	0.70	0.80	0.65	0.75
Sum	1.60	2.30	8.20	8.70	7.85	8.40	4.20	5.00	5.20	6.00	5.00	5.80
	S3						S4					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
S1	1.00	1.00	0.00	0.00	0.00	0.00	0.65	0.75	0.20	0.30	0.25	0.35
S2	0.65	0.75	0.20	0.30	0.25	0.35	0.55	0.65	0.30	0.40	0.35	0.45
S3	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.50	0.55	0.65	0.50	0.60
S4	0.50	0.6	0.35	0.45	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S5	0.50	0.6	0.35	0.45	0.40	0.50	0.25	0.35	0.70	0.80	0.65	0.75
S6	0.55	0.65	0.30	0.40	0.35	0.45	0.35	0.45	0.60	0.70	0.55	0.65
S7	0.55	0.65	0.30	0.40	0.35	0.45	0.35	0.45	0.60	0.70	0.55	0.65
S8	0.70	0.80	0.15	0.25	0.20	0.30	0.55	0.65	0.30	0.40	0.35	0.45
S9	0.75	0.85	0.10	0.20	0.15	0.25	0.50	0.60	0.35	0.45	0.40	0.50
S10	0.50	0.60	0.35	0.45	0.40	0.50	0.20	0.30	0.75	0.85	0.70	0.80
Sum	6.20	7.00	2.60	3.40	3.00	3.80	4.30	5.20	4.85	5.75	4.80	5.70
	S5						S6					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
S1	0.95	1.00	0.00	0.00	0.00	0.10	0.90	0.95	0.00	0.05	0.05	0.15
S2	0.55	0.65	0.30	0.40	0.35	0.45	0.50	0.60	0.35	0.45	0.40	0.50
S3	0.40	0.50	0.55	0.65	0.50	0.60	0.35	0.45	0.60	0.70	0.55	0.65
S4	0.65	0.75	0.20	0.30	0.25	0.35	0.55	0.65	0.30	0.40	0.35	0.45
S5	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.50	0.55	0.65	0.50	0.60
S6	0.50	0.60	0.35	0.45	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S7	0.50	0.60	0.35	0.45	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S8	0.65	0.75	0.20	0.30	0.25	0.35	0.55	0.65	0.30	0.40	0.35	0.45
S9	0.70	0.80	0.15	0.25	0.20	0.30	0.65	0.75	0.20	0.30	0.25	0.35
S10	0.35	0.45	0.60	0.70	0.55	0.65	0.50	0.60	0.35	0.45	0.40	0.50
Sum	5.75	6.60	3.20	4.00	3.40	4.30	5.40	6.15	3.65	4.40	3.85	4.65

(*continued*)

Table 5. (*continued*)

	S7						S8					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
S1	0.90	0.95	0.00	0.05	0.05	0.15	0.70	0.80	0.15	0.25	0.20	0.30
S2	0.50	0.60	0.35	0.45	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S3	0.35	0.45	0.60	0.70	0.55	0.65	0.20	0.30	0.75	0.85	0.70	0.80
S4	0.55	0.65	0.30	0.40	0.35	0.45	0.35	0.45	0.60	0.70	0.55	0.65
S5	0.40	0.50	0.55	0.65	0.50	0.60	0.25	0.35	0.70	0.80	0.65	0.75
S6	0.50	0.50	0.50	0.50	0.50	0.50	0.35	0.45	0.60	0.70	0.55	0.65
S7	0.50	0.50	0.50	0.50	0.50	0.50	0.40	0.50	0.55	0.65	0.50	0.60
S8	0.50	0.60	0.35	0.45	0.40	0.50	0.50	0.50	0.50	0.50	0.50	0.50
S9	0.65	0.75	0.20	0.30	0.25	0.35	0.50	0.60	0.35	0.45	0.40	0.50
S10	0.40	0.50	0.55	0.65	0.50	0.60	0.25	0.35	0.70	0.80	0.65	0.75
Sum	5.25	6.00	3.90	4.65	4.00	4.80	4.00	4.80	5.40	6.20	5.20	6.00
	S9						S10					
	Tl	Tu	Il	Iu	Fl	Fu	Tl	Tu	Il	Iu	Fl	Fu
S1	0.55	0.65	0.30	0.40	0.35	0.45	1.00	1.00	0.00	0.00	0.00	0.00
S2	0.40	0.50	0.55	0.65	0.50	0.60	0.65	0.75	0.20	0.30	0.25	0.35
S3	0.15	0.25	0.80	0.90	0.75	0.85	0.40	0.50	0.55	0.65	0.50	0.60
S4	0.40	0.50	0.55	0.65	0.50	0.60	0.70	0.80	0.15	0.25	0.20	0.30
S5	0.20	0.30	0.75	0.85	0.70	0.80	0.55	0.65	0.30	0.40	0.35	0.45
S6	0.25	0.35	0.70	0.80	0.65	0.75	0.40	0.50	0.55	0.65	0.50	0.60
S7	0.25	0.35	0.70	0.80	0.65	0.75	0.50	0.60	0.35	0.45	0.40	0.50
S8	0.40	0.50	0.55	0.65	0.50	0.60	0.65	0.75	0.20	0.30	0.25	0.35
S9	0.50	0.50	0.50	0.50	0.50	0.50	0.75	0.85	0.10	0.20	0.15	0.25
S10	0.15	0.25	0.80	0.90	0.75	0.85	0.50	0.50	0.50	0.50	0.50	0.50
Sum	3.25	4.15	6.20	7.10	5.85	6.75	6.10	6.90	2.90	3.70	3.10	3.90

Table 6. Neutrosophic and crisp weights of strategic impact criteria

	Tl	Tu	Il	Iu	Fl	Fu	Crisp weight
P1	0.185	0.202	0.045	0.062	0.056	0.075	0.192
P2	0.081	0.099	0.170	0.184	0.160	0.175	0.104
P3	0.117	0.135	0.130	0.149	0.129	0.148	0.137
P4	0.141	0.171	0.094	0.115	0.100	0.120	0.162
P5	0.122	0.151	0.114	0.141	0.117	0.142	0.148
P6	0.054	0.066	0.194	0.216	0.182	0.203	0.078
P7	0.141	0.169	0.102	0.129	0.104	0.130	0.167

Lastly, under the strategic effect dimension, it is found that the most effective criterion is the profitability of the product, while the most ineffective criterion is the bargaining power of the buyer. Moreover, under the supply risk dimension, while the criterion with the highest weight is the number of suppliers, the criterion with the lowest weight is the criterion of cultural difference.

Table 7. Neutrosophic and crisp weights of supply risk criteria

	Tl	Tu	Il	Iu	Fl	Fu	Crisp weight
S1	0.149	0.160	0.018	0.027	0.024	0.038	0.151
S2	0.093	0.109	0.072	0.089	0.077	0.093	0.105
S3	0.051	0.066	0.126	0.142	0.116	0.131	0.074
S4	0.090	0.108	0.077	0.095	0.079	0.097	0.106
S5	0.058	0.077	0.111	0.127	0.106	0.122	0.079
S6	0.068	0.085	0.105	0.120	0.100	0.115	0.087
S7	0.070	0.088	0.098	0.114	0.097	0.112	0.087
S8	0.096	0.112	0.067	0.084	0.072	0.088	0.108
S9	0.111	0.129	0.050	0.068	0.058	0.076	0.122
S10	0.052	0.067	0.117	0.134	0.112	0.128	0.071

4 Conclusion

While KPM has greatly affected purchasing specialists, it has also received a considerable degree of criticism. It is difficult to select dimensions such as supply risk and strategic impact, and the criteria that determine the dimensions of KPM are difficult to obtain (Padhi et al. 2012). It can also be difficult for managers to identify the most suitable criteria in terms of strategic impact and supply risk. In this case, it is normal for individuals to be indecisive and inconsistent in the evaluation process. Subjective decisions of individuals can lead to great uncertainty in the process. IVNSs can better present the vague, ambiguous, and unstable information that arises in the real world. Therefore, we integrated INVSs with the AHP method to evaluate these factors and calculate their weights.

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Predicting Sovereign Credit Ratings Using Machine Learning Algorithms

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Abstract. Sovereign credit ratings are major indicators of a country's financial structure as they provide an assessment of the creditworthiness of a country and its capability to meet its financial obligations. On the other side, how they are established by credit rating agencies (CRAs) is considered as not transparent and objective enough. This study aims to suggest a prediction framework for sovereign credit ratings based on machine learning (ML) algorithms using the following predictors: Credit Default Swap, Government Bond Yield, GDP/Capita, Consumer Price Index, Currency Volatility, and Political Risk.

Keywords: Sovereign credit ratings · LDA · QDA · KNN · Decision tree · Bagging · Random forest · SVM · XGboosting · lightGBM

1 Introduction

Sovereign credit ratings, issued by most influential international CRAs such as Fitch, Moody's, and S&P's, are important indicators of a country's financial development. A country's creditworthiness and its government's ability to meet its financial obligations can be interpreted using these ratings (Bissoondoyal-Bheenick 2005). In addition, they influence the interest rate of credit that countries can get from global capital markets. International organizations like World Bank and IMF use them for providing credit and aid to countries. They are also monitored by investors and managed funds with international portfolios with the purpose to decide on investing and providing credits. Therefore, countries' access to global capital markets is affected by these assessment scores (Mathur et al. 2018).

Fitch, Moody's, and S&P's, which are rating more than 150 countries by December 2018 (Sanz 2020), generally reassess countries within three years. Ratings are intended to reflect creditworthiness through the cycle: perceived vulnerability to cyclical downturns, but not the current position in the cycle, should influence a rating (Kiff et al. 2012). They are assigned by using various numeric and non-numeric variables (economic, social, and political) and CRAs' own methodologies.

Due to the Financial Crisis between 2007–2009 and the euro area debt crisis afterward, especially in Europe, many advanced countries' sovereign risk profiles deteriorated markedly. Considering crisis, major CRAs have reassessed their variables and methodology. They updated their methodology so that they count more on numeric inputs than

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before and increased the level of transparency (Amstad and Packer 2015). Despite these improvements, and sharing the methodological guidelines, it is still considered as not transparent enough and not easily replicable (Sanz 2020). The procedure of rating still has a high level of subjectivity (Gartner et al. 2011; D'Agostino and Lenkh 2016).

The purpose of this study is to employ different Machine Learning (ML) algorithms such as Linear Discriminant analysis (LDA), Quadratic Discriminant Analysis (QDA), K-Nearest Neighbors, Decision Tree, Bagging, Random Forest (RF), Support Vector Machine (SVM), eXtreme Gradient Boosting (XGboost), light Gradient Boosting Machine (lightGBM) to suggest a prediction framework for sovereign credit ratings by CRA: Fitch using following quantitative predictors: Credit Default Swap (CDS), Government Bond Yield, GDP/Capita, Consumer Price Index, Currency Volatility, Political Risk Factor. The data set includes 48 countries' monthly data from 2015 to 2022, 4000 observations in total.

The following section will include a literature review. Then methodology and data used will be shared. Section 4 will be devoted to the findings. Section 5 is the conclusion part of the study which also includes a suggestion for future research.

2 Literature Review

In 1996, Cantor and Parker employed a linear regression using some macroeconomic variables for 49 countries in order to verify S&P and Moody's ratings. Per capita income, GDP growth, inflation, external debt, level of economic development, and default history were the variables that are found to contribute to the prediction most. Alexe et al. (2003) employed a non-recursive regression model to explain country credit ratings. Trevino and Thomas (2001) developed a model for predicting sovereign credit ratings using ordered probit regression techniques. Gültekin-Karakaş et al. (2011) employed ordered probit models separately for developed and emerging countries and checked if there is a biased towards developed countries. Yim and Mitchell (2005) employed hybrid artificial neural network analysis (hANN) to predict country risk ratings and compared it with logit and probit models. Their conclusion is that hANN outperforms logit and probit models. Bennell et al. (2006) employed the ANN model to predict country risk rating and found it superior to ordered probit modeling.

Chen et al. (2011) employed SVM in order to provide a prediction for German Firms' default risks and found it superior to the benchmark logit model. Bellotti et al. (2011) employed SVM to predict international banks' ratings and found it superior to ordered choice models. Chang et al. (2018) employed logistic regression, self-organized algorithms, SVM, and extreme gradient boosting to provide a prediction framework for financial institutions' risk portfolios. Their conclusion is that the Xgboost classifier outperforms other models. Wang et al. (2021) employed K-nearest neighbor classification, decision tree, and XGBoost to build a credit risk evaluation model, and found XGBoost superior to others with very good accuracy performance. Cheng (2021) applied an enterprise multi-index classification scoring model based on the XGBoost algorithm to provide a prediction for the credit rating of 302 small and medium-sized enterprises.

3 Methodology and Data

3.1 Methodology

In this study, the following ML algorithms are employed. The prediction accuracy of each algorithm is calculated. And this is repeated for two different class groups. The first one is the Fitch Ratings from "AAA" to "CCC" and the second one is the groups of these ratings from "Highest Credit Quality" to "Substantial Credit Risk"). So in the initial one, there will be 16 classes and in the second one, there will be 7 classes.

3.1.1 Linear Discriminant Analysis

In LDA the distribution of the inputs are modeled separately in each output groups and then using Bayes' theorem (Eq. 1) density functions are estimated $Pr(Y = k|X = x)$. The observation is assigned to the group for which function shown in Eq. 2 is the largest.

$$\Pr(Y = k|X = x) = \frac{\pi_k f_k(x)}{\sum_{l=1}^{K} \pi_l f_l(x)} \tag{1}$$

$$\delta_k(x) = x^T \Sigma^{-1} \mu_k - \frac{1}{2} \mu_k^T \Sigma^{-1} \mu_k + \log \pi_k \tag{2}$$

3.1.2 Quadratic Discriminant Analysis

In QDA, with the assumption of each class having its own covariance matrix, the observation is assigned to the group for which function shown in Eq. 3 is the largest.

$$\delta_k(x) = -\frac{1}{2} x^T \Sigma_k^{-1} x + x^T \Sigma_k^{-1} \mu_k - \frac{1}{2} \mu_k^T \Sigma_k^{-1} \mu_k - \frac{1}{2} log|\Sigma_k| + log\pi_k \tag{3}$$

3.1.3 KNN Classification

The KNN algorithm takes its name from the fact that it uses information about its closest neighbors to classify unlabeled samples (Lantz 2013). The letter k, the most important tuning parameter for KNN, is a variable term that implies that any number of closest neighbors can be used.

3.1.4 Decision Tree

Decision Tree algorithm is a simple algorithm that employs a technique called recursive partitioning. With this algorithm, the predictor space is divided into a number of zones (R_m). Division is performed so that Gini index (Eq. 4) is minimized.

$$G = \sum_{k=1}^{K} \hat{p}_{mk} \left(1 - \hat{p}_{mk}\right) \tag{4}$$

3.1.5 Bagging

Bagging (bootstrap aggregation) is a technique developed to decrease the variance. It consists of creating different models using same sample and then getting the aggregation of the predictions belong to each model.

3.1.6 Random Forest

RF uses bootstrapped training samples like bagging, but differently, a random sample of predictors is chosen as split candidates from the full set of predictors (James et al. 2013). RF usually outperforms individual trees as it is mostly robust to outliers (Raschka 2015).

3.1.7 Support Vector Machine

The maximal margin hyperplane is the separating hyperplane that has the farthest minimum distance to the training observations. Although maximal margin hyperplane classify training observations well, addition of a single observation in the data set can dramatically change the result, in other words this is far from being robust. Support Vector Classifier is a robust version of maximal margin hyperplane by simply adding a Cost (negative tuning) parameter into the optimization problem. And SVM is an extension of Support Vector Classifiers which can produce non-linear class boundaries.

3.1.8 eXtreme Gradient Boosting

The boosting algorithm introduced by Friedman in 2001 combines weak classifiers to form strong classifiers (Ju et al. 2019). eXtreme Gradient boosting introduced by Tianqi Chen and Carlos Guestrin in 2016 is an efficient and scalable implementation of gradient boosting with the aim to minimize the loss function.

3.1.9 Light Gradient Boosting Machine

Another tree-based technique LightGBM, introduced by Microsoft in 2017, has an advanced histogram algorithm that includes a regularization effect and can effectively prevent overfitting (Ke et al. 2017).

3.2 Data

In this study, the data set includes 6 predictors and 1 response (Fitch Scores) for 4000 observations which belong to 48 countries for the horizon of 2015 to 2022 in a monthly based. In Table 1 predictors list and in Table 2 country list are shared. Data is extracted from Bloomberg terminals.

Table 1. Predictors list

Predictors	Definiton	Unit
CDS 5y	Credit default swap premium 5 year	Basis point
CPI	Consumer price index monthly change	%
Currency volatility	Currency volatility 3 month	%
GDP/capita	Gross domestic product (at purchasing power parity)/capita	Int$
Goverment bond yield	Goverment bond yield 5 year	%
Political risk	Political risk factor by bloomberg	Score between 1 to 100

Table 2. Country list

Argentina	Czech republic	Latvia	Russia
Australia	Denmark	Lithunia	Saudi Arabia
Austria	Finland	Malaysia	Slovakia
Belgium	Germany	Mexico	South Africa
Brazil	Greece	Morocco	South Korea
Bulgaria	Hong Kong	Netherlands	Spain
Canada	Hungary	Norway	Switzerland
Chile	India	Peru	Turkey
China	Indonesia	Poland	Thailand
Colombia	Israel	Portugal	USA
Costa Rica	Italy	Qatar	UK
Croatia	Japan	Romania	Vietnam

4 Findings

R and the following packages is used to employ the ML algorithms: ISLR, readxl, MASS, e1071, xgboost, lightgbm. Employed Machine Learning algorithms are LDA, QDA, KNN, Decision Tree, Bagging, Random Forest, SVM, XGboost, and light GBM. Data (4000 observations) is divided into two groups (3280/720) for modeling and validation purposes. Models are fit according to the first group, 3280 observations, and then tested using the second group, 720 observations. And prediction accuracy of each ML algorithm is calculated. This is repeated two times. The first one is performed using Sovereign Credit Ratings as a response and the second one via using Sovereign Credit Rating Groups. Prediction accuracies of ML algorithms for both response groups are shared in Table 3.

Table 3. Prediction accuracies

Machine learning algorithm	Pred. Acc. of ratings # of class:16	Pred. Acc. of rating Gr. # of class:7
LDA	38.33%	65.55%
QDA	37.50%	49.86%
KNN k = 3 (CV*)	30.69%	51.52%
Decision Tree	37.77%	69.30%
Decision Tree *(pruned after 19 terminal node (CV))*	38.61%	69.30%
Bagging	62.90%	82.08%
Random Forest, $m = 3$ $(p = 6)$	64.86%	**84.30%**
Random Forest, $m = 2$ $(p = 6)$	**65.27%**	80.97%
SVM Radial, *cost = 100,gamma = 2 (CV)*	58.30%	65.27%
SVM Polynomial, *cost = 100,degree = 2 (CV)*	45.70%	
SVM Polynomial, *cost = 100,degree = 3 (CV)*		69.16%
XGboost	53.46%	76.53%
lightGBM	59.03%	81.67%

* *CV is the abbreviation for Cross-Validation*

As seen in Table 3, the highest prediction accuracy for both response classes is obtained via Random Forest.

4.1 Details of Prediction, 1st Response Class-Sovereign Credit Rating

The highest prediction accuracy is obtained with Random Forest where m = 2 (p = 6). The Confusion Matrix is as follows and the prediction accuracy of the model is 65,27% (470 successful predictions/720 total observations). This means that Random Forest $m = 2$ ML algorithm successfully predicts the Fitch Sovereign Credit Rating by 65,27% using 6 predictors: CDS, CPI, Currency Volatility, Government Bond Yield, GDP/Capita, and Political Risk. The confusion Matrix (CM) of the model is shown in Table 4.

Table 4. Confusion matrix of RF $m = 2$ – class: sovereign credit ratings

Predictions	Actuals															
	AAA	AA +	AA	AA –	A +	A	A –	BBB +	BBB	BBB –	BB +	BB –	BB	B +	B	CCC
AAA	111	1		4												
AA +	3	6		14												
AA			12	10												
AA –	6	23		50	3											
A +				12	22	20	9		2							
A					1	37	9			3						
A –				2	1	3	26	15					3			
BBB + +					3			15	4	7			8		1	
BBB				1			1	9	78	12	4				1	
BBB –									5	50	16		2		0	
BB +											4	4			1	
BB –												25				
BB												1	17		11	
B +															6	8
B															2	1
CCC																15

As seen in Fig. 1, considering the impacts of excluding the selected variable from the model, political risk and GDP/c are the two most impactful variables in the model.

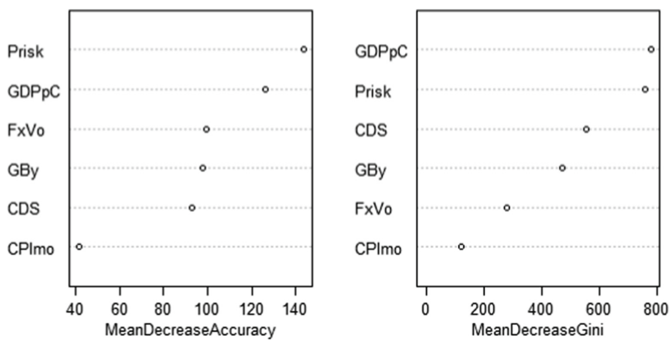

Fig. 1. Importance rate of predictors – class: sovereign credit ratings

4.2 Details of Prediction, 2nd Response Class-Sovereign Credit Rating Groups

The highest prediction accuracy is obtained with Random Forest where m = 3 (p = 6). Confusion Matrix is as follows and the prediction accuracy of the model is 84,30% (607 successful predictions/720 total observations). This means that the Random Forest *m*

= *3* ML algorithm successfully predicts the Fitch Sovereign Credit Rating Groups by 84,30% using the same predictors. CM of the model is shown in Table 5.

Table 5. Confusion matrix of RF, $m = 3$ – class: sovereign credit rating groups

Predictions	Actuals						
	Highest Credit Quality	Very High Credit Quality	High Credit Quality	Good Credit Quality	Speculative	Highly Speculative	Substantial Credit Risk
Highest Credit Quality (AAA)	111	3					
Very High Credit Quality (AA +, AA, AA −)	9	117					
High Credit Quality (A +, A, A −)		14	129	15	3		
Good Credit Quality (BBB +, BBB, BBB −)		1	6	178	32	2	
Speculative (BB +, BB, BB −)				7	49	12	
Highly Speculative (B +, B, B −)						8	9
Substantial Credit Risk (CCC)							15

As seen in Fig. 2, considering the impacts of excluding the selected variable from the model, political risk and GDP/c are the two most impactful variables in the model.

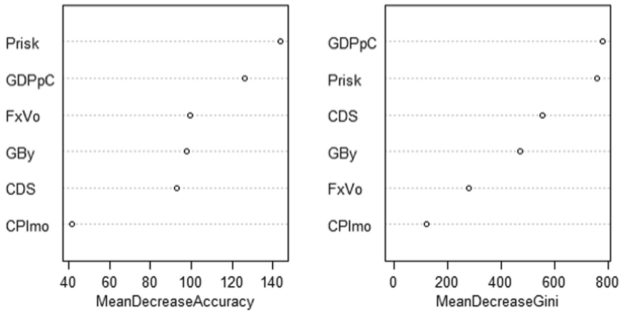

Fig. 2. Importance rate of predictors – class: sovereign credit rating groups

5 Conclusion

Sovereign credit ratings are major indicators of a country's financial structure as they provide an assessment of the creditworthiness of a country and its capability to meet its financial obligations. On the other side, although credit rating agencies (CRAs) provide procedures about how ratings are established, this is considered not transparent and objective enough.

In this study, different ML algorithms such as LDA, QDA, KNN, Decision Tree, Bagging, RF, SVM, XGboosting, and lightGBM suggest a prediction framework for sovereign credit ratings by Fitch. Also, we run the same ML algorithms for Fitch Sovereign Credit Rating groups to see how the prediction accuracies change. Random Forest algorithm successfully predicts the Fitch Sovereign Credit Rating by 65,27% and the Fitch Sovereign Credit Rating Groups by 84,30%. And for both response groups, GDP/capita and Political Risk Factors seem most important variables for classification.

Future studies can focus on inclusion of different predictors showing the financial, economic and political risk of the countries more comprehensively while keep using the latest ML techniques.

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Healthcare Waste Disposal Method Selection in the Era of COVID-19: A Novel Spherical Fuzzy CRITIC TOPSIS Approach

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Abstract. Healthcare waste disposal method selection is among the most important decisions that must be made by healthcare organizations, particularly in light of the COVID-19 pandemic issue. Such a problem has a number of contradictory criteria and alternatives, and decision experts may have considerable uncertainty while evaluating the problem. In this paper, a new fuzzy multi-criteria decision-making (MCDM) methodology is provided for evaluating the healthcare waste disposal method selection problem. The CRiteria Importance Through Intercriteria Correlation (CRITIC) is used for obtaining criterion weights in an objective manner, and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is used for ranking the predetermined alternatives. For modeling the uncertainty in the nature of the problem, the proposed methodology is developed in a three-dimensional spherical fuzzy atmosphere. The step-by-step solution of the proposed methodology is followed by a sensitivity analysis. This study contributes to the work of both academics and practitioners in the healthcare industry, as well as other sectors facing similar types of problems.

Keywords: Healthcare waste disposal · Multi-criteria decision making · Spherical fuzzy sets · CRITIC TOPSIS

1 Introduction

During COVID-19, one of the most significant challenges that healthcare facilities all around the globe are up against is the problem of properly managing the waste produced by their operations (Yu et al. 2020). Due to the infectious nature of the illness, improper disposal of a broad range of hazardous goods, such as old needles and personal protective equipment, may be very harmful. Improper disposal of healthcare waste may accelerate the spread of COVID-19 and pose a significant threat to society. In this context, the problem of selecting a method for disposing of medical waste requires immediate attention.

A healthcare waste method selection problem can be considered an MCDM type of problem because it includes multiple criteria and alternatives. On the other hand, experts

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who make evaluations of such a problem can only evaluate the qualitative criteria in a linguistic manner. While MCDM methodologies enable converting these evaluations into a numerical format, fuzzy logic can be used to handle the uncertainty in these linguistic expressions.

On the other hand, in MCDM problems, determining the criterion weights is a critical phase that has an impact on the model's outcome, and Criteria Importance Through Inter-criteria Correlation (CRITIC) (Diakoulaki et al. 1995) is a method used to calculate the objective weights of the criteria. Based on the evaluation matrix analysis, CRITIC captures all of the preference information included in the evaluation criteria, i.e., each criterion's intrinsic information is quantified to achieve the objective weight. In this methodology, the objective weight of the criterion is evaluated using the contrast intensity of the criteria, which is approximated as the standard deviation, and conflicts between criteria are calculated using the correlation coefficient.

Spherical fuzzy sets (Kutlu Gundogdu and Kahraman 2019), with a three-dimensional spherical shape, are one of the most recent extensions of ordinary fuzzy sets. In spherical fuzzy sets, the sphere is regarded as a volume, and this enables us to define membership, non-membership, and hesitation parameters independently and within a wider range than in the majority of other fuzzy sets.

In this study, a novel spherical fuzzy CRITIC TOPSIS methodology is presented for the healthcare waste method selection problem, which is one of the important issues of the pandemic and post-pandemic periods, and in this context, the CRITIC method is used for determining the weights of criteria in an objective manner, and through TOPSIS, alternatives are ranked.

In Sect. 1.1, relevant research is provided in order to further illuminate the themes of our study and to clarify the originality of our work. In this regard, important CRITIC-based studies and their respective application domains are outlined. In Sect. 1.2, the motivation and contribution of the study are given.

1.1 Related Work

The CRITIC method has been successfully used to compute the objective weights of criteria in a range of real-world MCDM applications. Naik et al. (2021) evaluated the prequalification of construction contractors utilizing the CRITIC EDAS method, and Zafar et al. (2021) provided a blockchain evaluation system by integrating CRITIC with WSM, TOPSIS, and VIKOR methods. In addition, Tuş and Aytaç Adalı (2019) developed a CRITIC WASPAS method and handled a software selection problem. The above-mentioned authors provided their approaches in a crisp environment.

The CRITIC methodology has been combined with other fuzzy sets and MCDM methodologies to solve a variety of problems. Kahraman et al. (2021) introduced a spherical fuzzy CRITIC to rank supplier selection criteria. Liu et al. (2020) employed probabilistic hesitant fuzzy sets with the CRITIC approach to estimate alternative weights for investment alternatives. Some scholars have developed hybrid methodologies based on the CRITIC approach. Rostamzadeh et al. (2018) assessed sustainable supply chain risk management by introducing a triangular fuzzy CRITIC TOPSIS. Mishra et al. (2021) designed a Fermatean fuzzy CRITIC EDAS for a provider selection problem in logistics. Liang (2020) suggested an intuitionistic fuzzy CRITIC EDAS tool to predict the preference order of green building energy-saving solutions. Keshavarz Ghorabaee et al. (2017) evaluated logistics providers using a type-2 fuzzy CRITIC WASPAS technique with interval-valued characteristics.

Moreover, Peng et al. (2019, 2021) proposed Pythagorean and interval-valued fuzzy COCOSO CRITIC methods for industry evaluation and intelligent healthcare management problems, and Rani et al. (2021) presented a neutrosophic fuzzy CRITIC MULTIMOORA methodology with an application from the food industry. Haktanir and Kahraman (2022) presented a CRITIC REGIME methodology in a picture fuzzy atmosphere and handled a wearable health technology selection problem. Kamali Saraji et al. (2021) developed a Fermatean fuzzy CRITIC COPRAS framework for analyzing the obstacles to industry 4.0 adoption for sustainable digitalization.

1.2 Motivation and Contribution

Healthcare waste management is a critical issue that requires immediate attention. On the other hand, according to an extensive literature review, no research has been conducted on the integration and use of the CRITIC TOPSIS approach in a spherical fuzzy environment. The purpose of this study is to establish a unique MCDM approach by using the benefits of CRITIC and TOPSIS methodologies, as well as spherical fuzzy sets, and applying it to the selection of the most effective way for the disposal of healthcare waste in the era of COVID 19. The primary advantage of the proposed methodology is its ability to aid with the healthcare waste disposal selection problem by objectively weighing the criteria, rating the alternatives in a widely accepted manner, and modeling the problem's uncertainty in a comprehensive manner.

2 Methodology

This section integrates the CRITIC and TOPSIS methodologies in a spherical fuzzy atmosphere. In Sect. 2.1, the fundamental mathematical operations of spherical fuzzy sets employed in the methodology are presented and in Sect. 2.2, the steps of the proposed spherical fuzzy CRITIC TOPSIS are described in detail.

2.1 Preliminaries of Spherical Fuzzy Sets

In this section, the definition and basic mathematical operations of spherical fuzzy sets are summarized (Kutlu Gundogdu and Kahraman 2019).

Definition 1. A spherical fuzzy set (SFS) $\tilde{A}_S$ of the universe of discourse U is given by

$$\tilde{A}_S = \left\{ \left\langle u, \mu_{\tilde{A}_S}(u), \nu_{\tilde{A}_S}(u), \pi_{\tilde{A}_S}(x) | u \in U \right\rangle \right\} \tag{1}$$

where

$$\mu_{\tilde{A}_S}(u) : U \to [0, 1],\ \ \nu_{\tilde{A}_S}(u) : U \to [0, 1],\ \ \pi_{\tilde{A}_S}(u) : U \to [0, 1],$$

and

$$0 \leq \left(\mu_{\tilde{A}_S}(x)\right)^2 + \left(v_{\tilde{A}_S}(x)\right)^2 + \left(\pi_{\tilde{A}_S}(x)\right)^2 \leq 1, \forall u \in U \quad (2)$$

$\mu_{\tilde{A}_S}(u)$, $v_{\tilde{A}_S}(u)$ and $\pi_{\tilde{A}_S}(u)$ are the degrees of membership, non-membership, and hesitancy of u to $\tilde{A}_S$, respectively.

Definition 2. The fundamental operations of spherical fuzzy sets are listed below.

Multiplication:

$$\widetilde{A}_S \otimes \widetilde{B}_S = \left\{ \begin{array}{l} \mu_{\tilde{A}_S}\mu_{\tilde{B}_S}, \left(v^2_{\tilde{A}_S} + v^2_{\tilde{B}_S} - v^2_{\tilde{A}_S} v^2_{\tilde{B}_S}\right)^{1/2}, \\ \left(\left(1 - v^2_{\tilde{B}_S}\right)\pi^2_{\tilde{A}_S} + \left(1 - v^2_{\tilde{A}_S}\right)\pi^2_{\tilde{B}_S} - \pi^2_{\tilde{A}_S}\pi^2_{\tilde{B}_S}\right)^{1/2} \end{array} \right\} \quad (3)$$

Multiplication by a scalar: $\lambda > 0$

$$\lambda.\widetilde{A}_S = \left\{ \left(1 - \left(1 - \mu^2_{\tilde{A}_S}\right)^{\lambda}\right)^{1/2}, v^{\lambda}_{\tilde{A}_S}, \left(\left(1 - \mu^2_{\tilde{A}_S}\right)^{\lambda} - \left(1 - \mu^2_{\tilde{A}_S} - \pi^2_{\tilde{A}_S}\right)^{\lambda}\right)^{1/2} \right\} \quad (4)$$

Spherical Weighted Geometric Mean (SWGM) with regard to, $w = (w_1, w_2, ..., w_n)$; $w_i \in [0, 1]$; $\sum_{i=1}^{n} w_i = 1$, SWGM is defined as:

$$\begin{aligned} SWGM_w &= (\tilde{A}_1, ..., \tilde{A}_n) = \tilde{A}^{w_1}_{S1} + \tilde{A}^{w_2}_{S2} + ... + \tilde{A}^{w_n}_{Sn} \\ &= \left\{ \begin{array}{l} \prod_{i=1}^{n} \mu^{wi}_{\tilde{A}_{Si}}, \left[1 - \prod_{i=1}^{n} \left(1 - v^2_{\tilde{A}_{Si}}\right)^{wi}\right]^{1/2}, \\ \left[\prod_{i=1}^{n} \left(1 - v^2_{\tilde{A}_{Si}}\right)^{wi} - \prod_{i=1}^{n} \left(1 - v^2_{\tilde{A}_{Si}} - \pi^2_{\tilde{A}_{Si}}\right)^{wi}\right]^{1/2} \end{array} \right\} \end{aligned} \quad (5)$$

The score function is defined as;

$$Score(\tilde{A}_S) = \left(\mu_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 - \left(v_{\tilde{A}_S} - \pi_{\tilde{A}_S}\right)^2 \quad (6)$$

Normalized Euclidean distance for SFS is defined as;

$$D(A_i, A^-) = \sqrt{\frac{1}{2n} \sum\nolimits_{i=1}^{n} \left(\left(\mu_{x_i} - \mu_{x^-}\right)^2 + \left(v_{x_i} - v_{x^-}\right)^2 + \left(\pi_{x_i} - \pi_{x^-}\right)^2\right)} \quad (7)$$

2.2 Proposed Spherical Fuzzy CRITIC TOPSIS

The proposed methodology is built by the integration of CRITIC and TOPSIS methodologies in a spherical fuzzy environment. The details of the steps are as follows:

Define an MCDM problem with a set of alternatives and the most related criteria. Let $A_i = (A_1, A_2, ..., A_m)$ be the alternatives and $C_j = (C_1, C_2, ..., C_n)$ be the selected criteria set.

Stage 1. Obtain criteria weights based on the CRITIC method.

Table 1. Linguistic terms and corresponding spherical fuzzy numbers.

Linguistic term	μ	v	Π
Absolutely more importance (AMI)	0,90	0,10	0,10
Very high importance (VHI)	0,80	0,20	0,20
High importance (HI)	0,70	0,30	0,30
Slightly more importance (SMI)	0,60	0,40	0,40
Equally importance (EI)	0,50	0,50	0,50
Slightly low importance (SLI)	0,40	0,60	0,40
Low importance (LI)	0,30	0,70	0,30
Very low importance (VLI)	0,20	0,80	0,20
Absolutely low importance (ALI)	0,10	0,90	0,10

Step 1. The decision-makers assess the alternatives in terms of each criterion through the linguistic phrases listed in Table 1.

Step 2. Each decision-maker's judgment is translated into spherical fuzzy numbers in a matrix form. This task is done using the linguistic scale listed in Table 1. After that, all of these matrices obtained from the decision-makers are combined to form a singular collective alternative evaluation matrix *AEM*. For the aggregation operation, the geometric mean that is given in Eq. 5 is used. The structure of *AEM* is seen in Eq. 8.

$$AEM = C_{\mathrm{j}}(A_i)_{\mathrm{mxn}} = \begin{pmatrix} (\mu_{11}, \nu_{11}, \pi_{11}) & (\mu_{12}, \nu_{12}, \pi_{12}) & \cdots & (\mu_{1n}, \nu_{1n}, \pi_{1n}) \\ (\mu_{21}, \nu_{21}, \pi_{21}) & (\mu_{22}, \nu_{22}, \pi_{22}) & \cdots & (\mu_{2n}, \nu_{2n}, \pi_{2n}) \\ \vdots & \vdots & \cdots & \vdots \\ (\mu_{m1}, \nu_{m1}, \pi_{m1}) & (\mu_{m2}, \nu_{m2}, \pi_{m2}) & \cdots & (\mu_{mn}, \nu_{mn}, \pi_{mn}) \end{pmatrix} \tag{8}$$

Step 3. The singular collective alternative evaluation matrix *AEM* is normalized as in Eq. 9.

$$x_{ij} = \frac{\sqrt{\frac{1}{2}\left(\left(\mu_{ij} - \mu_{-}\right)^2 + \left(\nu_{ij} - \nu_{-}\right)^2 + \left(\pi_{ij} - \pi_{-}\right)^2\right)}}{\sqrt{\frac{1}{2}\left((\mu_{+} - \mu_{-})^2 + (\nu_{+} - \nu_{-})^2 + (\pi_{+} - \pi_{-})^2\right)}} \tag{9}$$

where μ_{+}, ν_{+}, π_{+} and μ_{-}, ν_{-}, π_{-} are the membership, non-membership, and hesitancy parameters of the maximum and minimum solutions, respectively. Maximum and minimum solutions are obtained by comparing the crisp values of the attributes in a singular collective alternative evaluation matrix. For this purpose, the score function that is given in Eq. 6 is used.

Step 4. The correlation coefficient ρ_{jk} between every pair of attributes is computed as in Eq. 10.

$$\rho_{jk} = \frac{\sum_{i=1}^{m} (x_{ij} - \overline{x}_j)(x_{ik} - \overline{x}_k)}{\sqrt{\sum_{i=1}^{m} (x_{ij} - \overline{x}_j)^2 \sum_{i=1}^{m} (x_{ik} - \overline{x}_k)^2}} \quad (10)$$

where $\overline{x}_j$ and $\overline{x}_k$ are the mean values of jth and kth attributes can be calculated by utilizing Eq. 11.

$$\overline{x}_j = \frac{1}{n} \sum_{j=1}^{n} x_{ij};\ i = 1, 2, ..., m \quad (11)$$

Step 5. The standard deviation σ_j for each criterion is computed as shown in Eq. 12.

$$\sigma_j = \sqrt{\frac{1}{n-1} \sum_{j=1}^{n} (x_{ij} - \overline{x}_j)^2;\ i = 1, 2, ..., m} \quad (12)$$

Step 6. The C index for each criterion is calculated as shown in Eq. 13.

$$C_j = \sigma_j \sum_{k=1}^{n} (1 - \rho_{ik});\ j = 1, 2, ..., n \quad (13)$$

Step 7. The significance weight w_j of each criterion is calculated as in Eq. 16. For the final ranking, criterion weights are ordered in decreasing order.

$$w_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \quad (14)$$

The criterion weights determined at the end of the first stage are used in the second phase, i.e., the TOPSIS component of the methodology.

Stage 2. Rank the alternatives based on TOPSIS methodology.

Step 8. Multiply the singular collective alternative evaluation matrix by the criterion weights obtained in Step 7 to get the decision matrix. The multiplication operation is carried out using multiplication by a scalar operator that is given in Eq. 5.
Step 9. Obtain the crisp form of the decision matrix by utilizing the score function, i.e., the defuzzification operator that is given in Eq. 6. Then determine the spherical fuzzy positive A^+ and negative ideal A^- solutions based on these crisp values. Note that fuzzy numbers can be ranked using the crisp form of fuzzy numbers.
Step 10. Calculate the total distance of each alternative A_i to positive and negative ideal solutions $D(A_i,A^+)$ as given in Eq. 15.

$$D(A_i, A^+) = \sqrt{\frac{1}{2n} \sum\nolimits_{i=1}^{n} \left(\left(\mu_{x^+} - \mu_{x_i}\right)^2 + \left(\nu_{x^+} - \nu_{x_i}\right)^2 + \left(\pi_{x^+} - \pi_{x_i}\right)^2 \right)} \quad (15)$$

where $D(A_i,A^+)$ is the total distance of *i*th alternative to positive ideal solution. Calculate $D(A_i,A^-)$ in the same way.
Step 11. Calculate the appraisal scores AS_i of alternatives as in Eq. 16. The alternative with the highest appraisal score is the best. Rank all alternatives correspondingly.

$$AS_i = \frac{D(A_i, A^-)}{D(A_i, A^-) + D(A_i, A^+)} \tag{16}$$

3 Application

The suggested methodology is used to select the best healthcare waste disposal method in the era of COVID-19. In this context, four waste disposal methods are evaluated with respect to five relevant criteria derived from the existing literature and prominent scientific databases. Brief descriptions of selected alternatives and criteria are presented in Sect. 3.1. In Sect. 3.2, a numerical solution is provided, and in Sect. 3.3, a sensitivity analysis is given.

3.1 Alternatives and Criteria

The alternatives are as follows:

A1 Chemical disinfection. Chemical disinfection entails mixing healthcare waste with a certain concentration of disinfectant and ensuring that it has adequate contact area and time with the disinfectant. During the disinfection procedure, healthcare waste is degraded and bacteria are destroyed. Maximum contact between disinfectant and medical waste is a necessary condition for achieving an effective treatment (Xu et al. 2020).
A2 Landfill. The landfill method is the burying of healthcare waste in the ground and allowing microorganisms to break it down into harmless compounds over time. If the medical waste dump system lacks anti-seepage measures, numerous hazardous compounds, pathogens, radioactive substances, etc. may permeate the soil with rain, and dangerous substances will reach the human body through the food chain, posing a threat to human health (Yi and Jusoh 2021).
A3 Electromagnetic wave sterilization. Technologies for sterilizing using electromagnetic waves include microwave and radio wave methods. Microwave sterilization uses electromagnetic waves with a high frequency, while radio wave sterilization employs electromagnetic waves with a low frequency, which have more penetrating strength than microwaves. Electromagnetic waves have the ability to be absorbed by water, fat, and protein, which is the basis for their use in sterilization (Xu et al. 2020).
A4 Encapsulation. Encapsulation is the technique of immobilizing healthcare waste in a solid block inside a steel drum or plastic container. This method has several advantages for immobilizing healthcare waste. In this method, the steel drums or plastic containers must be emptied and cleaned such that a trace amount of previously stored hazardous substances is not present. After filling with the necessary trash, cement or a cement/lime combination is used to immobilize solid or semi-solid waste with a considerable volume of water (Kaur and Singh 2020).

The criteria are as follow:

C1 Annual operating cost. Expenses incurred when running the operations of waste disposal method, may include payments for personnel, electricity, etc. (Ozkan 2013).
C2 Reliability. This criterion represents the long-term reliability of a certain healthcare waste treatment approach (Manupati et al. 2021).
C3 Waste residuals. This criterion examines the quantity of residual waste created following the operation of a certain healthcare waste disposal method (Manupati et al. 2021).
C4 Infrastructure requirement. This criterion considers the fundamental physical and organizational structures and facilities (e.g., buildings, power supply, and equipment) required for the functioning of a certain healthcare waste disposal approach (Manupati et al. 2021).
C5 Treatment efficiency: Treatment efficiency is the acceptability and competence of a given healthcare waste disposal method over the long run (Manupati et al. 2021).

3.2 Numerical Solution

In the evaluation procedure, there are three decision-makers *DM1, DM2*, and *DM3* with the same degree of expertise having equal weights (1/3). The numerical solution of the suggested methodology is presented in the following manner:

Step 1. Linguistic evaluations of candidates *A1, A2, A3,* and *A4* with respect to selected criteria *C1, C2, C3, C4,* and *C5* by three decision-makers are obtained in Table 2.

Table 2. Linguistic evaluations of alternatives.

		C1	C2	C3	C4	C5
DM1	A1	VHI	SMI	VHI	EI	HI
	…	…	…	…	…	…
…	…	…	…	…	…	…
DM3	…	…	…	…	…	…
	A4	EI	EI	LI	SMI	EI

Step 2. The linguistic assessments of decision-makers are transformed to their corresponding spherical fuzzy forms, and the corresponding matrices are then aggregated to produce a singular collective alternative evaluation matrix as given in Table 3.

Table 3. Singular collective alternative evaluation matrix.

	C1	C2	C3	C4	C5
A1	0.61, 0.42, 0.33	0.69, 0.34, 0.35	0.58, 0.44, 0.36	0.37, 0.64, 0.40	0.63, 0.41, 0.32
A2	0.41, 0.61, 0.34	0.25, 0.76, 0.28	0.70, 0.31, 0.32	0.38, 0.64, 0.30	0.62, 0.39, 0.41
A3	0.83, 0.17, 0.17	0.70, 0.31, 0.32	0.60, 0.40, 0.40	0.53, 0.47, 0.47	0.66, 0.35, 0.36
A4	0.56, 0.44, 0.44	0.39, 0.61, 0.40	0.29, 0.71, 0.30	0.66, 0.35, 0.36	0.53, 0.47, 0.47

Steps 3–7. The singular collective alternative evaluation matrix is normalized and the standard deviation, C index, and weight of each criterion is calculated as in Table 4.

Table 4. Standard deviation, C index, and criterion weights.

	C1	C2	C3	C4	C5
Standard deviation	0,356	0,421	0,376	0,381	0,389
C index	0,905	1,138	1,507	2,020	1,117
Criterion weights	0,135	0,170	0,225	0,302	0,167

Steps 8. The decision matrix and corresponding spherical fuzzy positive A^+ and negative ideal A^- solutions are calculated as in Table 5.

Table 5. Decision matrix and spherical fuzzy positive X^+ and negative X^- ideal solutions.

	C1	C2	C3	C4	C5
A1	0.25, 0.89, 0.16	0.32, 0.83, 0.20	0.30, 0.83, 0.21	0.21, 0.87, 0.24	0.29, 0.86, 0.17
A2	0.16, 0.94, 0.14	0.11, 0.95, 0.12	0.37, 0.77, 0.20	0.22, 0.87, 0.18	0.28, 0.86, 0.22
A3	0.38, 0.79, 0.11	0.33, 0.82, 0.18	0.31, 0.81, 0.24	0.31, 0.80, 0.31	0.30, 0.84, 0.19
A4	0.22, 0.89, 0.21	0.17, 0.92, 0.18	0.14, 0.93, 0.15	0.40, 0.73, 0.25	0.23, 0.88, 0.24
A^+	0.38, 0.79, 0.11	0.33, 0.82, 0.18	0.37, 0.77, 0.20	0.40, 0.73, 0.25	0.30, 0.84, 0.19
A^-	0.16, 0.94, 0.14	0.11, 0.95, 0.12	0.14, 0.93, 0.15	0.22, 0.87, 0.18	0.23, 0.88, 0.24

Steps 10–11. Appraisal scores of alternatives and corresponding rankings are obtained in Table 6.

Table 6. Appraisal scores and final rankings of alternatives.

Alternative	Appraisal score	Ranking
A1	0.527	2
A2	0.393	4
A3	0.758	1
A4	0.403	3

The appraisal scores based on the proposed decision support model indicate that the best candidate is *A3*.

3.3 Sensitivity Analysis

To examine the influence of decision-maker weights on final rankings, a sensitivity analysis is conducted. Given that the sum of the weights of three decision-makers is one,10 unique scenarios are formed. For each of these scenarios, the proposed methodology is solved by giving varying values to the weights of the decision-makers. The ranking of alternatives determined in this way is shown in Fig. 1.

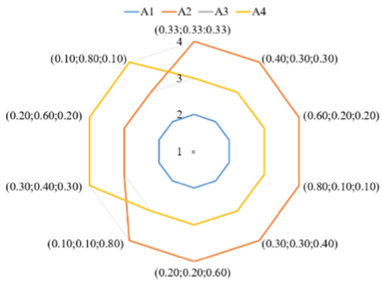

Fig. 1. Sensitivity analysis results for decision-maker weights

It is noticed that alternative *A3* rates highest in every scenario, whereas alternative *A1* ranks second. *A4* and *A3* are ranked third and last, except in three instances in which their places are switched. In general, the ranks of alternatives are well-balanced, and sensitivity analysis reveals that the recommended spherical fuzzy CRITIC TOPSIS approach delivers consistent outcomes independent of the weight distribution of the decision-maker.

4 Conclusion and Future Remarks

In this study, a novel decision-making model for the healthcare industry is established, and the problem of waste disposal method selection is addressed. For this purpose, a novel spherical fuzzy CRITIC integrated TOPSIS methodology is developed. Spherical fuzzy sets allow for independent modeling of expert hesitancy, the CRITIC methodology enables objectively defining criterion weights, and the TOPSIS technique ranks the alternatives by considering the evaluations of experts with respect to criteria.

The proposed methodology is straightforward and practical, and healthcare facilities can utilize it to solve the problem of selecting a waste disposal method. In addition, as a result of its adaptable structure, it can be extended to any other decision-making problem by employing basic mathematical software. Examining the presented model in terms of rank-reversal phenomena and developing it further by incorporating a larger range of criteria, alternatives, and experts are both possible. Methods of machine learning, such as logistic regression, decision trees, and naive Bayes, might be included in the proposed approach in order to make use of the institution's accessible data.

The following are recommended as research extensions: The CRITIC method may also include several types of spherical fuzzy sets, such as triangular spherical fuzzy sets, trapezoidal spherical fuzzy sets, and hesitant spherical fuzzy sets. CRITIC is compatible with other freshly developed MCDM approaches for generating objective weights for criteria. Spherical fuzzy sets and their extensions, such as interval-valued spherical fuzzy sets, may be used to strengthen other recently created MCDM approaches, and their applicability in other fields, including finance, engineering, and the military, can be examined.

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Online Learning and Lab Courses vs. Traditional Ones in Chemistry During the COVID-19 Pandemic: The Comparative Perceptions of the Undergraduate Students

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Abstract. This study aimed to reveal the comparative perceptions of the students of the online and physical chemistry lab courses, and their comparative perceptions of the contributions of online learning and in-class learning modes in increasing their knowledge, laboratory skills, and social skills during the COVID-19 pandemic. This online questionnaire-based study was conducted at Istanbul Technical University (ITU) with the participation of 58 students who did take the chemistry lab courses in-class and online using the Zoom platform. Our results show that online chemistry lab classes were perceived as too far away to be better than traditional chemistry lab classes. In addition, online learning was perceived as too far away to be better than in-class learning in increasing students' knowledge, lab skills, and social skills. Since in-class lab learning is vital in chemistry education, traditional lab exposure has to be ensured in educating undergraduate students and should be used together with effective online teaching as much as possible in the future. However, effective online teaching necessitates unique knowledge about how technology and pedagogical practices could be best integrated and then used in teaching chemistry-specific content.

Keywords: Covid-19 · Chemistry · Online labs · Turkey

1 Introduction

Coronavirus-2019 (COVID-19) outbreak emerged in Wuhan, China in December 2019 and was called a pandemic by the World Health Organization (WHO) on March 11, 2020 (World Health Organization 2020). The whole world continues to fight against it since then. Due to the high rate of transmission in the first months of the pandemic, the devastating turmoil and chaos experienced all over the world caused people to feel hopeless and helpless. Hence, the COVID-19 pandemic has adversely affected all sectors around

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the world, including the education sector (Daniel 2020). Many governments have taken very strict measures such as temporarily closing educational institutions to prevent the rapid spread of the virus, and these closures have affected more than 91% of the world's student population (UNESCO 2020). These strict measures taken made it necessary to switch from in-class education to online education in higher education institutions for the continuation of education (Crawford et al. 2020; Tigaa and Sonawane 2020; Cobo et al. 2021; Mouratidis and Papagiannakis 2021). However, the online education given during this period was essentially emergency online education, and universities in developing countries such as Turkey, which have financial constraints and infrastructure problems, face significant difficulties during this period.

In response to the COVID-19 pandemic, all educational institutions in Turkey were closed, and an urgent transition to distance education was forced by the Turkish authorities. In the meantime, the Higher Education Council of Turkey quickly published its directive for all universities to switch to online education and started to provide support services to universities not prepared for online education before. Due to these developments, all universities in Turkey had to enter into online learning collectively. Synchronous and asynchronous online tools and platforms were used to give all courses even the labs.

In the superseding period of about one and a half years, the pandemic increased its effect and became a challenging problem in various aspects, and then recently death and transmission rates have been significantly reduced with the introduction of effective vaccines and medicine. However, the different variants of the virus seem to be still developing and posing a serious threat all over the world. As of June 29, 2022, there were more than confirmed 551 million cases and 6 million 354 thousand deaths and Turkey has been one of the hardest-hit countries with more than 15 million confirmed cases and close to 100 thousand deaths (Johns Hopkins University 2022).

2 Literature Review

2.1 Online Learning

Online learning is a subset of distance education and is defined as learning via the Internet, intranet, or extranet using simulations, animations, audio/video content, online mentoring, online sharing of learning and source materials, and discussion groups (Keengwe and Kidd 2010). There are two delivery modes of online learning namely synchronous and asynchronous (Abramenka 2015). In the case of synchronous mode, instructors and students can interact and communicate in real-time regardless of their locations (Clark and Mayer 2016). On the other hand, the asynchronous mode does not require real-time presence since learning takes place whenever the learner wants to use it (Gagne et al. 2005). Therefore, it gives full locus of control of the learning process and the opportunity for self-paced and self-directed learning to the learners. Most higher education institutions around the world offer these two modes of online learning through web-based online learning platforms and video conferencing tools such as Zoom.

Online education has been around for a long time (Dumford and Miller 2018) and has become the most popular education mode, especially during the COVID-19 era. Online education has its advantages and disadvantages for students and instructors just like any other education mode. In addition to the epidemiological benefits of online learning during the COVID-19 era, it has other advantages such as increased flexibility and accessibility (Parsad et al. 2008; Zhao et al. 2021), reduction in educational resources (Nguyen 2015), cost-effectiveness (Friedman and Friedman 2011), and ease of degree attainment (Nguyen 2015). Online learning also has some limitations and disadvantages. These include hindered interaction among the participants (Davies and Graff 2005; Clark-Ibanez and Scott 2008; Driscoll et al. 2012), structural and technical problems (Houlden and Veletsianos 2019), and insufficient knowledge and skills of participants (Baczek et al. 2021).

Despite the increase in the transition of higher education institutions to online learning during the COVID-19 period, studies evaluating online learning in terms of its effectiveness in achieving learning goals give conflicting results. When we look at the related studies in the literature, we can understand that the majority of the studies did not find a significant difference between online learning and in-class learning in terms of effectiveness (Jones and Long 2013). In addition, while some studies are showing that online learning is better than in-class learning (Russell et al. 2016; Soffer and Nachmias 2018; Hoerunnisa et al. 2019), there are also studies that result in the opposite findings (Emerson and MacKay 2011; Carter 2012).

2.2 Online Lab Courses

Most undergraduate chemistry courses include in-class lectures, tutorials, and laboratory work. Almost all undergraduate science and engineering programs have mandatory lab courses because laboratory work provides unique opportunities for the students to get hands-on practical experience and enhance their learning process. According to Linn and Eylon (2011), supplementing traditional lessons with laboratory work constitutes approximately 50% of the total lesson, and doing so results in a significant increase in student learning outcomes (Merchant et al. 2012).

While lab work has become an essential component in chemistry education, COVID-19 has forced higher education institutions to make an urgent transition from physical labs to online labs. However, except for areas that can easily adapt to online learning, the use of technological tools in areas where practical experience is important, such as chemistry, has remained very limited (Tran et al. 2020; Valle-Suarez et al. 2020). Tran et al. (2020) identified the major barriers faced by instructors during this transition as student attendance synchronization, technological inequalities, assessments & post-lab activities, and experimental implementation. In addition, creating high-quality lab course content matching the learning objectives of the lab courses has become a challenging issue to overcome for the instructors (Buchberger et al. 2020). According to de Jong et al. (2013), inherent characteristics and tactile information physical labs offer lack in the case of online labs. On the other hand, several studies have shown that online labs could be equal to or even better than traditional labs (e.g., Brinson 2015; Makransky et al. 2016). There are also some studies that investigated the usage of online labs in engineering courses and showed promising results (e.g., Curry et al. 2016; Dixit et al. 2017).

Taking the above-mentioned findings into account, this study aims to address the following research questions:

RQ 1: What are the comparative perceptions of the students of the contributions of online learning and in-class learning modes in increasing their knowledge, laboratory skills, and social skills during the COVID-19 pandemic?
RQ 2: What are the comparative perceptions of the students of the online and traditional chemistry lab courses during the COVID-19 pandemic?

3 Methodology

3.1 Setting

This study was undertaken at ITU. ITU transitioned to a virtual setting and started using the Zoom platform on April 6, 2020. All courses were offered only online until the 2021–2022 Fall semester. The laboratory experiments in Chemistry Department were pre-made and video-recorded by the teaching assistants (TAs). Afterward, the TAs gave detailed information about the experiment and its steps and showed these recordings whenever they felt necessary on the Zoom platform during class hours. Students were allowed to ask questions and also took short quizzes and exams using an online exam platform called Ayva and a large-scale web-based electronic learning platform called Ninova while in Zoom class. Hybrid education was started in the 2021–2022 Fall and 2021–2022 Spring semesters, and all laboratory and compulsory courses were held in class during these semesters. This study aims to reveal the comparative perceptions of the students of the online and traditional chemistry lab courses, and their comparative evaluations of the contribution of online learning and in-class learning modes in increasing their knowledge, laboratory skills, and social skills.

3.2 Participants

The participants of this study were undergraduate students who did take chemistry lab courses online and in-class offered by the Chemistry Department at ITU. In the first half of June 2022, students were sent a collective e-mail message with a link to the questionnaire and a statement informing them that participation was voluntary and that all collected data would be kept confidential and anonymous.

3.3 Research Instrument

The questionnaire has 3 main parts. In the first part, information about the purpose of the study was given. In the second part, participants were asked to select or enter their demographic information regarding their age, gender, department, and year of study, and indicate whether they had previous experience with any online courses before the COVID-19 pandemic. In the third part, respondents were asked to compare online labs with traditional labs based on a total of 8 statements adapted from Li et al. (2020) and the contribution of these two education modes in increasing their knowledge, laboratory skills, and knowledge skills based on three statements adapted from Baczek et al. (2021), using the 5-point Likert scale with each statement rated on five anchors, (Strongly disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, and Strongly agree = 5).

A total of 58 responses were received and all analyses were conducted in IBM SPSS Statistics (Version 28.0).

4 Results

4.1 Participants' Characteristics

As seen in Table 1, participants mostly identified as female (72.4%), second-year students (44.8%), 21 to 22 years of age (56.9%), and in the Chemistry Department (36.2%). 63.8% reported that they had no previous learning experience before the COVID-19 era.

Table 1. Participants' demographic characteristics (N = 58)

Variables	n (%)
Gender	
Female	42 (72.4)
Male	16 (27.6)
Age (Years)	
19	3 (5.2)
20	14 (24.1)
1	21 (36.2)
22	12 (20.7)
23	3 (5.2)
24	4 (6.9)
25	1 (1.7)
Year in school	
1	6 (10.3)
2	26 (44.8)
3	20 (34.5)
4	6 (10.3)
Department	
Chemistry	21 (36.2)
Food engineering	10 (17.2)
Molecular biology & genetics	9 (15.5)
Environmental engineering	6 (10.3)
Metallurgical & materials engineering	5 (8.6)
Shipbuilding & ocean engineering	1 (1.7)
Geomatics engineering	1 (1.7)
Space engineering	1 (1.7)

(*continued*)

Table 1. (*continued*)

Variables	n (%)
Industrial product design	1 (1.7)
Previous online learning experience	
Yes	21 (36.2)
No	37 (63.8)

4.2 Comparative Perceptions of Students of the Online and Traditional Chemistry Lab Courses

The mean and standard deviation values of the responses of the students to the statements comparing online labs with traditional labs are shown in descending order by their mean in Table 2. The value of Cronbach's α was .91, indicating a high level of internal consistency and reliability for the 8 items. According to the results given in Table 2, among the 8 items, 'Online labs are better than traditional labs in terms of work safety and health' has the highest score of 2.74, while 'Online labs are better than traditional labs in terms of improving my ability to work in a team' has the lowest score of 1.64.

Table 2. Responses of the students to the statements comparing online labs with traditional labs

Item	Mean	S. D	t-values
Online labs are better than traditional labs in terms of work safety and health	2.74	1.38	−6.93*
Online labs are better than traditional labs in terms of instructor engagement and accessibility	2.24	1.28	−10.51*
Online labs are better than traditional labs in that I get experiment results quickly and repetitively	2.21	1.24	−11.02*
Online labs are better than traditional labs in terms of the accessibility of labs	2.03	1.11	−13.51*
Online labs are better than traditional labs in terms of completing my lab work efficiently	1.98	1.19	−12.89*
Online labs are better than traditional labs in terms of gaining hands-on experience	1.74	1.02	−16.89*
Online labs are better than traditional labs in terms of accessibility of group activities	1.69	1.08	−16.31*
Online labs are better than traditional labs in terms of improving my ability to work in a team	1.64	1.01	−17.93*

* $p < 0.01$

A one-sample t-test was used to assess in terms of what online labs are better than traditional labs. In our rating scheme, a score of four means that a student agrees with the statement that online labs are better than traditional labs on that particular item. Hence a score of four was selected as a cut-off point. Table 2 shows that online chemistry labs are too far away to be better than traditional chemistry labs on any of the items.

4.3 Comparative Perceptions of Students of Online Learning and In-Class Learning

Table 3 shows the mean and standard deviation values of the responses of the students to the statements comparing online learning with in-class learning in descending order by their mean. The value of Cronbach's α was .79 indicating an acceptable level of internal consistency and reliability for the 3 items. According to the results presented in Table 3, among the 3 items, 'Online learning is better than in-class learning in terms of increasing my knowledge' has the highest score of 2.55, while 'Online learning is better than in-class learning in terms of improving my social skills' has the lowest score of 1.78.

Table 3. Responses of the students to the statements comparing online learning with in-class learning

Item	Mean	S. D	t-values
Online learning is better than in-class learning in terms of increasing my knowledge	2.55	1.21	−9.18*
Online learning is better than in-class learning in terms of increasing my laboratory skills	1.83	1.16	−14.30*
Online learning is better than in-class learning in terms of increasing my social skills	1.78	1.01	−16.78*

* $p < 0.01$

A one-sample t-test was used to identify in terms of what online learning is better than in-class learning. In our rating scheme, a score of four means that a student agrees with the statement that online learning is better than in-class learning on that particular item. Hence a score of four was selected as a cut-off point. Table 3 shows that online learning is too far away to be better than in-class learning on any of the items.

5 Discussion and Conclusions

The COVID-19 pandemic has made it mandatory for higher education institutions all over the world to urgently switch to online education. But this urgent shift has been much more difficult, especially for science lecturers and students. This study aimed to reveal the comparative perceptions of the students of the online and physical chemistry lab courses, and their comparative perceptions of the contributions of online learning and in-class learning modes in increasing their knowledge, laboratory skills, and social skills during the COVID-19 pandemic.

Our results reveal that students have an overall preference for in-class learning relative to online learning in increasing their knowledge, laboratory skills, and social skills during the COVID-19 pandemic. This preference may be attributable to a significant decrease in interaction between the students and instructors and among the students in the case of online learning and to the fact that almost 64% of our participants had no previous online learning experience before the COVID-19 pandemic. Our results are in line with the findings of earlier studies (e.g., Emerson and MacKay 2011; Carter 2012; Kemp and Grieve 2014) and show that there is a need for studies that will focus on determining what does and does not work in online learning. Salta et al. (2022) stated that the interaction among participants in synchronous online learning may be improved by using live video streaming, screen sharing, and chat features. They also claimed that improving the communication and interaction performance among participants in asynchronous online learning may be possible by allowing them to use discussion forums and e-mail.

Over the last 15 years, there have several studies (e.g., Lim and Morris 2009; Poon 2013) that have shown that blended learning which is the combination of in-class and online learning is better than only in-class or online learning in enhancing student engagement and academic performance. Lately, some researchers such as Galway et al. (2014), Fautch (2015), and McCollum et al. (2017) suggested the use of flipped classroom concept which was first introduced by Bergmann and Sams (2012) who were both high school chemistry teachers to increase student engagement and collaboration skills. The flipped classroom is a type of blended learning and instructional strategy that flips traditional teaching methods. In the flipped classroom, most course content is taught in online mode while practical work requiring higher-order thinking is done through interaction with peers and instructors. However, in all these aforementioned blended learning types and online learning, effective online teaching is required and necessitates unique knowledge about how technology and pedagogical practices could be best integrated and then used in teaching chemistry-specific content.

Our results also indicated a negative perception among our participants toward online lab courses during the COVID-19 outbreak. The main reason for this negative perception may be the rapid and mandatory transition to online laboratory courses, as suggested by Watts et al. (2022). The results of this study also support the claims of some experts working in this field that practical skills in the field of chemistry can be acquired and comprehended much more quickly and effectively in real laboratories. In addition, online laboratory activities that have yielded successful results to date should be considered as a complement to classical laboratories, not a substitute. The TAs are at the center of the online laboratory courses in the Chemistry department of ITU. Therefore, as suggested by Buchberger et al. (2020), allowing TAs to communicate more with students without increasing the current load of the TAs, educating the TAs about the technologies they use, and making them understand the importance of uninterrupted and consistent communication may transform students' perceptions of these courses from the negative ones into positive ones.

The developments in technology in recent years have resulted in the development of highly functional and easy-to-use software, videos, animations, and simulations supported by virtual and augmented reality features, and these tools turned out to be successful in increasing students' and lecturers' satisfaction and performance in online chemistry lab courses (Nadelson et al. 2015; Jolley et al. 2016; Rennie et al. 2019; Pölloth et al. 2020; Wijenayaka and Iqbal 2021).

Although this study contributes to the existing literature in several ways, it has some limitations. The main limitation of our study is the small sample size of participants, and therefore, future studies should focus on recruiting a greater number of participants to see if similar results are obtained. In addition, as this study was conducted at only one university in Turkey, the representativeness of the sample is of actual concern. Thus, we can't generalize the findings of our study to all university students in Turkey. Another limitation is that the experiences and perceptions of students might not mirror the actual case after spending three semesters taking lab courses online. Conducting a similar study in the future might show different perspectives of the students in the same and different universities. Future studies should focus on blended learning rather than just online or in-class learning, taking into account studies showing that online learning produces better results when blended with in-class learning (Means et al. 2013; Sadeghi et al. 2014; Blissitt 2016).

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Digital Twins for Decision Making in Supply Chains

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Abstract. This paper studies the utilization of digital twins (DTs) as a decision support tool in supply chains (SCs) by providing a framework. DT is an emerging technology-based modeling approach reflecting a virtual representation of an object or system that can help organizations monitor operations, perform predictive analytics, and improve their processes. For instance, it may provide a digital replica of operations in a factory, communications network, or the flow of goods through an SC system. In this paper, by focusing on SC systems, we explore the critical decisions in SCs and their related data to track, to make the right decisions within DTs. We introduce six main functions in SCs and define frequent decisions that can be taken under those functions. After defining the required decisions, we also identify which data/information would help to make correct decisions within those DTs.

Keywords: Digital twin · Supply chain · Decision problems · Decision support

1 Introduction

Decision-making is a process of choosing one alternative from a set of alternatives to achieve the desired goal. This process requires *(i)* identification of alternatives, and *(ii)* evaluation of the level of satisfaction of needs by each alternative, which comprises the sequential activities of model building, data collection, analysis, and interpretation of analysis outcomes (Harris 1998). Decision support tools ensure this process is systematic and replicable.

In this study, our focus is on decision problems in SCs. In recent years, the most frequently confronted decision problems are related to disruptions in SCs. For instance, with the recent COVID-19 outbreak, serious disruptions took place in SCs in many countries. Hence, SC managers have started to question their SC management styles of the results of those disruptions (Alicke et al. 2021). While for years companies have focused on eliminating redundancy in sourcing to reduce costs and increase efficiency, the recent global pandemic has changed that sole perspective, and the importance of

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resilient SC designs has become one of the significant focus topics. According to a survey by McKinsey and Company which is employed for senior SC executives from across of industries and geographies, 93% of respondents declared that they intended to make their SCs far more flexible, agile, and resilient (Alicke et al. 2021). Another survey by Barclays (2021) which is applied to 700 US manufacturing professionals shows that 25% of professionals had to change their supply chains in response to the pandemic. A report from UK's Business Insights and Conditions Survey (BICS) shows that wholesale, retail, and manufacturing industries would like to rethink their SC management to overcome the bottlenecks they encountered during the global pandemic and the EU Brexit (Office for National Statistics 2022).

According to a Statista's report (Buchholz 2021), SC disruptions tend to increase again after the crisis in pandemics, especially in Europe and US. Due to those uncertainties and challenges in SCs, which are new in many aspects, it is well understood that past experiences cannot be relied upon to generate solutions. Hence, the big question is, how all those uncertainties and complex SC problems can be handled, particularly in terms of design, planning, and execution in the network.

An SC Digital Twin (DT) might be a solution for those challenges which is a versatile tool with extensive implementation potential in a wide range of decision-making problems. DT is a virtual replica of an object or system to help organizations to monitor operations, perform predictive analytics, and improve processes. While it could be a digital replica of operations in a factory, communications network, or the flow of goods through a supply chain system, it could also be a replica of a physical object such as an airplane, a spacecraft, a wind turbine, etc. A DT consists of three main components: an actual system, a detailed simulation model of that system (virtual system), and a data link in between (Jones et al. 2020).

Recent developments in the areas of the internet of things (IoT), big data, artificial intelligence (AI), and cloud computing technologies have enabled the effective realization of DTs for systems of concern. According to Gartner's Emerging Technologies and Trends Impact Radar 2022, DT technology will have a high impact on existing products and markets in 1–3 years (Gartner Insights 2021). SC systems can also benefit from DTs capabilities in many ways. According to DHL Logistics Trend Radar given in Fig. 1, it is foreseen that DT would be one of the emerging approaches within 5–10 years for Logistics systems (DHL Insights 2022).

Fig. 1. DHL logistics trend radar (source: DHL Insights 2022).

DT can provide an advantage for SCs by creating value in the following dimensions (Moshood et al. 2021):

Descriptive Value: Due to real-time data flow from the physical system, DT may provide immediate and real-time visualization of the system of concern. Thus, the real-time state of the SC system can be monitored, which provides visibility.

Analytical and Predictive Value: DT paves the way for conducting an enhanced what-if analysis on the simulation model, which might not be reasonable to apply directly to the real system. This capability can be utilized efficiently for complex problem-solving and optimization purposes.

Diagnostic Value: DT can process excessive data in SC systems. By applying big data analytics and machine learning algorithms embedded in DT, hidden patterns, complex relationships, and abnormalities can be identified.

Predictions on DTs' impact and discussion on the above values indicate that SCs may benefit from DTs in a variety of ways for decision support, monitoring, and training. Thus, research on the employment of DTs for decision problems of SCs worthwhile. As a first step, we investigate how DTs are used in different areas. A Survey of the literature indicates that DTs are primarily implemented in the "Manufacturing/Production" and "Maintenance" areas. DT implementation in SC-related areas is relatively rare (Errandonea et al. 2020; Kulaç et al. 2022). As we discuss above, SC resilience-related problems are widely considered and the development of robust decision support tools for these problems is still an ongoing effort. Combining these facts, research on DTs for decision support of SCs contributes to the area significantly.

Therefore, in this paper, we investigate how DTs could be utilized as a decision support tool for different decision-making processes in SCs. Accordingly, the main research question of the work can be summarized to be:

RQ: How do SC systems benefit from DT as a decision support tool?

The rest of this work is organized as follows. In Sect. 2, we outline different categories based-on decision problems in SCs. Then, we discuss the contribution of DTs on those decision problems in Sect. 3. Finally, we conclude the work in Sect. 4.

2 Decision-Making in Supply Chains

Decisions in SC systems can be grouped into three categories based on their period and impact level on systems. These categories are strategic, tactical, and operational (Ravindran 2016).

Strategic decisions are mainly related to the design of SC systems. They are usually considered for long time periods (e.g., for several years) and, as a result, they are subject to a high level of uncertainty. Strategic decisions generally have a greater impact on systems and require more resources than other decision types. Examples of strategic decisions for SCs are the number and locations of plants and warehouses, the choice of suppliers, and other partners.

Tactical decisions are made for a time horizon of moderate length (e.g., generally monthly, or quarterly decisions) and are subject to less uncertainty relative to strategic decisions. Examples of tactical decisions for SCs are production planning decisions (e.g., how much to produce and when?), transportation mode selection decisions, etc.

Operational decisions are short-term decisions (e.g., generally made on a daily/weekly basis). They involve a lower expenditure of funds and a lower level of uncertainty. Weekly or daily production schedule decisions, and setting due dates for customer orders are examples of operational level decisions in SCs.

The decision-making needs of organizations mostly depend on their organizational structures. In this study, we consider the functional organizational structure and its decision levels to classify the decision processes of SCs. We consider the following functional areas while defining the possible decision mechanisms within DTs:

- Planning
- Procurement
- Manufacturing
- Inventory
- Warehousing and Material Handling
- Transportation

We identify different decision problems that might contribute to the efficiency of SCs. We consider an already established SC system, where we ignore decision problems such as the initial number of plants and their locations in this study. In decision-making within DTs, data tracking is the most important process for correct decision-making. Therefore, DTs are typically built on a data-driven decision-making process structure (Provost and Fawcett 2013; Ivanov and Dolgui 2021). By tracking those data and correctly embedding the related intelligent decision-making algorithms in DTs, those decisions can be taken effectively. In this paper, along with the critical decisions in SCs, we provide a list of data types that could help in taking those decisions. Note that, data that has a fixed structure (e.g., warehouse dimensions, etc.) are not taken into consideration.

With the help of recent technological developments such as embedded sensors, RFID, and Industry 4.0 technologies, it is possible to track real-time data through end-to-end SCs. Consequently, DT enables real-time monitoring of the systems. High-fidelity models in DT enable thorough analysis of problems. Recent developments in big data analytics and machine learning techniques add more power to DT's capabilities. With the help of these capabilities, hidden patterns, correlations, and abnormalities can be explored. As a result, data tracking capability and possession of high-fidelity capable models make DT a powerful decision support tool. DT can track the past, monitor, and conduct analysis for the present, and predict the future of systems in concern. Establishing decision-making frameworks with relevant data tracking in DT facilitates solutions to decision problems for SCs. All those decision-making frameworks along with the required data to track within the DT are summarized in Fig. 2. The details of Fig. 2 layers are discussed below in sub-titles. In those sub-titles, we also discuss why those decisions are considered as well as what the challenges and required data tracking processes are.

2.1 Planning

A crucial tactical level problem in planning is to decide the amount and timing of production. Demand forecasting is the starting point of production planning efforts. It requires accurate data about demand and analysis of the data with appropriate models. Hence, this effort is challenging due to its nature. The recent COVID-19 pandemic and continuing global crisis have increased uncertainties in every stage of SCs (Association for Supply Chain Management 2021). Consequently, demand forecasting has become a challenging task. Similar circumstances are also valid for customer requirements which tend to be highly stochastic during disruptions. Another challenge in this decision area is to predict the availability of transportation lines, because of unpredicted congestions in ports/airports and fuel shortages. Moreover, wide-scale shortages of critical basic materials are still an ongoing issue due to the latest disruptions. Thus, forecasting the availability of materials becomes another challenging point in the planning of SCs.

Decisions on planning for sustainability require identifying recycling/remanufacturing/reusing and waste management capabilities of the system. This identification process requires real-time system state data. Also, a solution to this decision problem necessitates experimenting with different capability levels and observing system behaviors. Therefore, a data collection tool and a detailed representation of system behavior would be vital for this decision process.

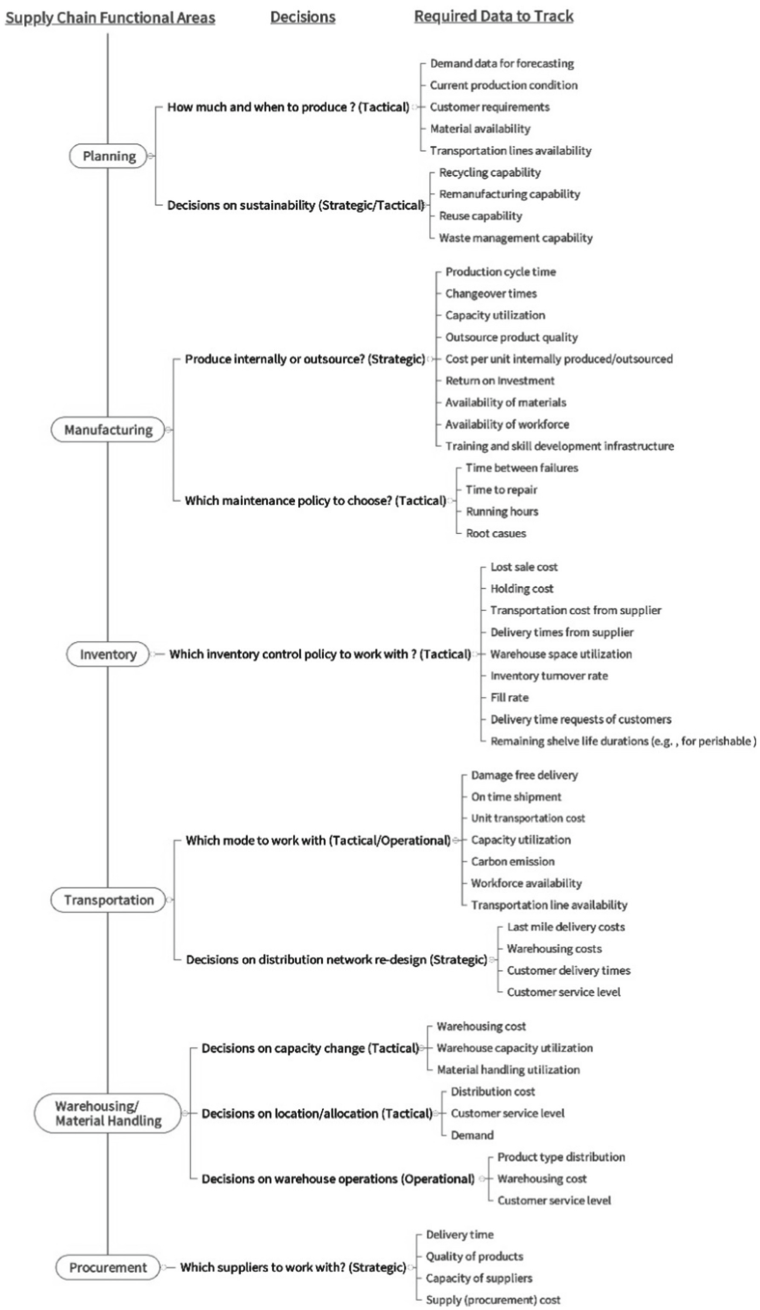

Fig. 2. Supply chain decision problems and data requirements.

2.2 Manufacturing

The main manufacturing decision is to choose between in-house manufacturing or outsourcing. As discussed earlier, supply chain disruptions have been among the biggest challenges for manufacturing, especially during the COVID-19 pandemic. As a result, shortages of critical basic materials and skilled labor create bottlenecks in manufacturing. One reason for the skilled labor shortage is the aging population. Senior workers are retiring, and their knowledge and experience leave with them. Difficulty in employee retention is another reason for labor shortage (Khan and Turowski 2016). Thus, training and skill development capability of SC system is becoming an important issue to overcome this challenge.

Other data requirements such as production cycle time, changeover times, and capacity utilization, which are listed in Fig. 2 are also vital for a data-driven decision process. Another challenge is deciding on maintenance policies for the shop floor, which have the potential to improve capacity utilization, and production cycle time and reduce production costs. This challenge necessitates real-time state data collection from the shop floor and algorithms to generate maintenance policies.

2.3 Inventory

Inventory control policy selection is a prominent strategic level decision for SC systems. This decision problem requires data such as inventory turnover rate, fill rate, lead times, customer requirements, and warehouse space utilization which are listed in Fig. 2. Limited visibility of inventory may result in insufficient customer satisfaction and increased inventory cost management. Improving end-to-end visibility in SCs can be realized by accession to necessary data (Moshood et al. 2021). Then, real-time data collection from SCs could be achieved for the solution of decision problems of concern. Uncertainties in transportation costs and customer delivery requests are some of the other challenges to deal with in inventory-related decisions, effectively.

2.4 Transportation

Distribution mode selection and distribution network re-design decisions are another set of decision problems considered under transportation problems (Engebrethsen and Dauzère-Pérès 2019; Yadav et al. 2022). Mode selection is a decision problem in choosing the best option, among the possible transportation methods (air, land, water, pipeline, cable, space, etc.). Transportation cost has a large share of the total cost of SCs. Hence, those modes can be changed dynamically in SC operations. Development of data-driven transportation algorithms taking into consideration, real-time transportation prices, customer expectations, delivery time requests, carbon emission amounts, etc. would be critical in this step.

Decision-making on distribution network re-design may be required when inefficiencies in the current distribution network are detected. This might be understood by tracking transportation cost-related data such as last-mile delivery costs, unit transportation costs, etc. as well as delivery-related data such as delivery times from suppliers, damage-free delivery, on-time shipment, capacity utilization of vehicles, etc. In addition, environmental concerns and regulations may necessitate the tracing of carbon emissions of assets (Chen and Wang 2016). By accomplishing end-to-end visibility in SC systems, accessibility and visibility to all those transportation-related data could be realized.

2.5 Warehousing/Material Handling

Decisions on warehousing capacity, location/allocation of supplier/demand changes, and decisions on warehouse operations are considered under the warehousing and material handling topic. Those decisions would require real-time data tracking of distribution and warehousing costs, warehouse capacities and their utilizations, material handling devices utilization, demand distribution as well as current customer service expectations, etc. Again, accomplishing end-to-end visibility would provide access to those data.

Decisions on warehouse operations would require product type distribution, warehousing cost, and customer service-related data. Warehouses generally have operations for receiving, put-away, storage, picking, sorting, packing, and shipping. Because of increased e-commerce usage, many warehouses involve in extensive return operations as well. Picking is the costliest operation in warehouses (Kembro et al. 2018). Product type distribution, warehousing cost, and customer service level might be the possible data requirements for that decision problem. Real-time data tracking from the SC system enables a detailed analysis of those operations. Thus, the main challenge for this problem is to construct visibility over the system.

2.6 Procurement

A leading strategical level decision problem in the procurement area is choosing which supplier/suppliers to work with. That decision would also play a significant contribution to SC resilience to alter disruptions. For instance, by predicting a possible disruption, a new supplier selection policy can be applied. Hence, it starts with identifying the right supplier, then continues with keeping track of the supplier performance which in return yields continual supplier management (Zimmer et al. 2016). This decision problem requires data about suppliers (e.g., delivery times, quality of products delivered, capacity, and cost). Limited visibility of the procurement process makes it challenging for companies to make decisions about their purchases and suppliers. Thus, lack of visibility through the SC system is an important issue to overcome in the procurement subject. Establishing visibility in the SC system provides easy access to information on delivery times of suppliers, quality of products delivered, and cost information.

3 DT for Decision Making Framework in SC Systems

With the help of DT, enterprises can access real-time data and information about internal and external processes, easily. It has been observed that organizations having business models involving real-time data monitoring, regular risk review, and incident management strategies implemented before the COVID-19 pandemic experienced fewer chronic disruptions in their SCs during the pandemic (Association for Supply Chain Management 2021).

End-to-end visibility of the SCs guarantees the collection of high-quality data from a real system. Thus, the data requirements that are listed in Fig. 2 would become critical in increasing the capabilities of DT. Then, current, and historical data can be used for decision problems defined in each functional area.

With the analytical abilities of DTs, different scenarios of actions can experiment for the SC system. For instance, various levels of shortages (e.g., material, workforce, energy, etc.) can be examined with respective impacts on SC systems to forecast future actions. Likewise, decision problems on sustainability, transportation mode selection, warehouse layout, and maintenance policies for shop floor can also be considered in decisions by experimenting with different cases. Due to its high-fidelity simulation model, DT also enables the analysis of different resolution levels of SC systems. This ability eliminates requirements for multiple models required for different resolution decision problems.

Due to skilled labor shortages, training, and skill development capability in SCs become a critical issue. Also, this capability is important for work safety purposes. A detailed simulation model by DT can also be used for training, skill development purposes, and work safety training.

With the help of DT big data analytics capabilities, hidden patterns, complex relationships, and abnormalities can be identified. This capability may provide early warnings for the disruptions ahead. Then, the SC system can take necessary precautions in advance. Also, for decision problems like the selection of maintenance policies in manufacturing and material handling areas, the diagnostic capabilities of DT provide necessary inputs to the SC system.

As a result, DT with its data-tracking and analysis capabilities can provide significant decision support for SC systems at different levels and functions.

4 Conclusion

Enhancing information technology and computational infrastructures brings about new powerful tools and methods across all areas. One such tool is DT. In this study, we focus on the implementation of DTs particularly on decision-making processes along the SC for which we identify the existence of room for development. Our goal is to shed a light on how DTs can be utilized as a decision support tool for different decision-making processes in SCs. To facilitate an efficient decision process in SCs, we present a decision-making framework with relevant decisions and data to track within DT. The decision-making framework is very much associated with the organizational structure and the level of decisions, i.e., strategical, tactical, or operational. We consider the functional organizational structure and all levels of decisions for different decision problems in SCs. We provide data requirements for each of these problems. We discuss detailed data tracking capability and possession of high-fidelity, as well as highly capable models of DTs while creating a powerful decision support tool in SCs. We also discuss the recent technological and IT developments which make it possible to realize DTs in SCs by integrating intelligent decision algorithms aiming to reduce the impacts of disruptions. This work is an initial step to implementing the body of knowledge on DTs in a real-life case for SC.

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Micro-fulfilment Centres in E-Grocery Deliveries

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Abstract. This paper studies micro-fulfilment centres (MFCs) as a response to rising e-grocery sales and customer expectations from decreased delivery time and cost requests. MFC is a business solution that allows orders to be picked and packed in a hyper-local facility. The study's aim is to provide an overview of this subject from two research questions: i) how MFCs affect the last-mile delivery challenges? and ii) what design decisions are critical in building MFCs? While we evaluate the advantages and disadvantages of centralised versus decentralised warehousing strategies in the first question, we discuss the critical decisions in designing MFCs in the second question. In that, we discuss location and technology selection decisions as well as other warehousing design criteria. Further, this study provides future research directions at the end of this study.

Keywords: E-commerce · Micro-fulfilment centre · Sustainability · Last-mile delivery · Urban distribution centre

1 Introduction: E-commerce and E-grocery Increase

E-commerce has been growing rapidly in the past years. Online sales accounted for 7% of the total retail sales worldwide in 2016 (Arslan et al. 2021), and it is declared to be reaching a penetration of 13.8% in 2019 (Statista 2022). By the COVID-19 pandemic, although restrictions have reduced the economic activities in most countries and sectors, e-commerce sales have increased as a result of many businesses going online. Hence, the COVID-19 pandemic acted as a catalyst for the online market, accelerating the growth for 4 to 6 years, by causing consumers to spend most of their time on the internet (Forbes 2020). It is estimated that the global e-commerce market will reach more than $6,388 billion by 2024, with an annual growth of about 13.5% (Zennaro et al. 2022).

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According to NielsenIQ's Global New Shopper Normal Study, before the COVID-19 pandemic, 9% of global consumers were regularly purchasing online. As precautions are taken to slow down the spread of the virus, the number of online consumers has massively increased reaching 27% of global consumers (Nielsen 2020). In a survey study, it is observed that 44% of global consumers stated that they were shopping online each week, with 23% declaring shopping online several times each week (Nielsen 2020).

An increase in e-grocery purchasing also played a significant role in the increase of e-commerce. It is well known that due to the restrictions during COVID-19, many consumers purchased groceries online, resulting in a rise in the traffic of online purchasing (Contentsquare 2020).

Although part of the shift in consumer spending towards online grocery may be thought to be temporary, a significant portion is expected to remain after the pandemic, with many previously sceptical customers that are now inclined to change their grocery shopping behaviour in favour of e-commerce (Seghezzi et al. 2022). The McKinsey Consumer Pulse survey which is conducted worldwide shows that roughly three-quarters of people using digital platforms for shopping during the pandemic state that they would continue buying online, even when the situation would return to normality (McKinsey 2020).

That growth in online purchasing paves the way for retailers to reshape their distribution strategies to cope with their omnichannel interaction with final customers to fulfil their orders (Arslan et al. 2021; Chopra 2018).

2 Delivery-Time Requests Are Decreasing

Increase in e-commerce has affected customer expectations towards shorter delivery times and cost requests. The 2020 Flexe Omnichannel Consumer Survey (Flexe 2020) found that 85% of consumers look elsewhere for better alternatives when the delivery time is longer than their expectations. One of the two main reasons for dropping the shopping cart is that the delivery speed was not sufficient. Moreover, these considerations are even more relevant for the groceries sector where speed of delivery is a crucial factor. Indeed, one of the fastest-growing segments in grocery is instant delivery, where consumers expect to receive the products within 15 to 30 min (McKinsey 2022). Many major grocery retailers now offer some form of same-day delivery service. For instance, Amazon Prime Now, Waitrose Rapid Delivery, Ocado Zoom or Walmart Express Delivery are services that offer one- or two-hour delivery windows (Dethlefs et al. 2022).

Customers increasingly accustomed to rapid deliveries have created a demand for this type of fulfilment. Grocery customers often expect quick deliveries because they generally would like to consume products at short notice, while they are willing to wait longer for other types of products (Dethlefs et al. 2022).

According to Fabric's Retail Report (2022), consumer expectations on short delivery requests are one of the three biggest challenges that the retail industry faces today, together with a lack of fulfilment capacity and last-mile delivery costs. Indeed, in the last two years retailers lost an average of 22% of sales due to insufficient fulfilment capacity and they are expected the issue to get worsen, with lost sales that can reach a figure near 30% during 2022.

Supply chains need to seek new solutions to address those global trends and the associated challenges. One of the solutions to alter those challenges might be to follow an MFC logistics model in the distribution network which we discuss it in the following sections.

The concepts presented in this paper are taken from a few scientific articles discussing the MFCs topic within the current literature. Since this topic is rarely discussed in the literature and it is an emerging phenomenon in the e-grocery area recently, we aim to provide an overview on this subject (Hübner et al. 2022; Seghezzi et al. 2022). Since it is expected that the growth of e-grocery will continue, new solution models for progressive penetration of omnichannel strategies are required (Kellermayr-Scheucher et al. 2021). We discuss centralized versus decentralized fulfilment centre models in the following section before discussing the details of MFCs.

3 Centralized Versus Decentralized Fulfilment Centres

In modern supply chains, retailers can usually opt for two types of strategies, namely centralized or decentralized warehousing (Schmitt et al. 2015). In the former, retailers manage their inventories in a single location, in a large central warehouse serving an entire region. Instead, the decentralized strategy utilises multiple strategic locations to store inventories closer to final customers. Each configuration has different strengths and weaknesses.

Centralized warehousing involves lower operating costs, higher product availability and more efficient inventory management (Chopra 2018). This last advantage is given by the risk pooling effect achieved in the central warehouse, allowing to reduce demand uncertainty and therefore inventory costs (Schmitt et al. 2015). However, a centralized strategy leads to vulnerability to disruptions, longer lead time in last-mile delivery and high shipping costs due to longer outbound distances in the last-mile delivery (Chopra 2018). Instead, decentralized warehousing may benefit from shorter lead times, lower shipping costs and better customer service and order fulfilment, thanks to the proximity to final customers. Drawbacks mainly refer to high operating costs and less efficient inventory management than the centralized version. Following on, we discuss the role of MFCs in those two concepts.

4 Micro-fulfilment Centres (MFCs) and Benefits

MFCs are defined to be highly automated logistics facilities located in large urban areas and cities, to become closer to the end customers (Kellermayr-Scheucher et al. 2021). Therefore, those centres, are also referred to be urban fulfilment centres (UFCs) which can perform a large range of activities from storage of products to order picking and last-mile distribution. The urban MFC can provide direct delivery of orders from online retail companies to the final customer. These logistics hubs require between 30–50 employees, a space between 1000 and 3000 square metres and serve in a radius of 5 km (Freichel et al. 2019). Due to their distributed location strategy, MFCs can be seen as a decentralised fulfilment strategy for inventory management and last-mile delivery.

One of the main characteristics of these centres is that most of the activities are performed autonomously, by means of automated storage and retrieval systems according to a "goods-to-person" principle instead of the "person-to-goods" one, which is applied in many conventional logistics centres. This means that the goods are moved towards the operator to be picked up, instead of an operator moving the item to pick it up. The MFC concept tries to combine the advantages of the efficiency of a big and automated warehouse with the advantages of small logistics facilities in terms of proximity to the customers to be served and the possibility for them to pick up products directly in the store. The high level of automation allows for achieving better space utilisation. A conventional warehouse or distribution centre could take up to 300 thousand square feet, while an MFC takes up to 10 thousand square feet on average (Kellermayr-Scheucher et al. 2021). Many grocers such as Walmart, Tesco and Albertsons have already applied MFCs (Scriven 2021).

According to Scriven (2021) in 2019 and 2020, while there were 16 and 29 MFCs, respectively, it is forecasted that over 2,100 MFCs would have been installed globally by 2025.

The main advantages of MFCs can be summarized below (Kellermayr-Scheucher et al. 2021):

- picking activity costs and times are significantly reduced with the help of automated systems;
- increased accuracy in the order fulfilment by reducing the number of wrong deliveries, again through automated picking systems;
- last-mile delivery time and costs are low due to the proximity to the final customer;
- decreased leasing and operating costs due to low space requirements;
- increased efficiency in inventory management (e.g., more SKUs per square foot);
- better goods return flow management by also focusing on more return possibilities in e-purchasing;
- better sustainability performances from both decreased energy consumption and carbon emission based on lower last-mile delivery distances.

5 Research Questions

As already mentioned, one of the main features of MFCs is the high level of automation, which is the enabler for greater performance, lower processing time and consequently saving on costs. The main technology solution adopted in MFCs is automated storage and retrieval systems (AS/RS) where automated order-picking robots collect the orders from their storage racks (Koçak et al. 2021). Once it is well designed in terms of technology, warehouse capacity, location, inventory optimization, etc., MFCs may provide great solutions for e-groceries from multi-objective perspectives: increased customer satisfaction, decreased energy consumption, carbon emissions and costs.

In this work, we aim to provide an overview of MFCs by discussing the relevant studies in literature from their benefits and design perspectives. According to that, we explore the below research questions (RQs).

RQ1: How MFCs affect the last-mile delivery challenges?

RQ2: What design decisions are critical in building MFCs?

In RQ1, we research the potential benefits of MFCs on last-mile delivery challenges. In RQ2, we research the critical design decisions in building MFCs to realize the RQ1 benefits. In the following section, we summarize the works according to RQ1 and RQ2.

6 Role of MFCs in Last-Mile Delivery

As mentioned above, MFCs are very small logistics hubs located next to urban areas, devoted to e-commerce orders, and typically characterised by a high automation level (Seghezzi et al. 2022). They can provide benefits for last-mile delivery compared to other types of distribution centres. The advantages that they bring can be summarized in the following three categories.

- ***Delivery time benefits***

  Last-mile delivery is the final step of the delivery process when a product is moved from a logistics hub to the destination. It is a critical process shaping the customer experience (Kim et al. 2021). Indeed, it is the interface between the retailer and the final customer. As mentioned, customer expectations in terms of punctuality and delivery speed are the most challenging issues for retailers (Mangiaracina et al. 2019).

  MFCs are positioned in urban areas closer to the final customer. In this way, it is possible to deliver the products faster with respect to other types of distribution and thus enable short delivery times, like same-day delivery (Kellermayr-Scheucher et al. 2021).

  The work of Arslan et al. (2021) shows that distribution from a tier of UFCs provides an increase in profitability compared to the shipment from a central warehouse. Indeed, the latter shows limitations in terms of potential demand satisfaction, mainly with the increase in the proportion of orders requiring a shorter response time, while UFCs make it possible to deliver to end customers when ordering online within a few hours (Kellermayr-Scheucher et al. 2021).
- ***Cost benefits***

  Last-mile fulfilment is the least efficient and most expensive part of the entire logistics process because of the challenging target service levels and due to the high level of dispersal of destinations and the small dimension of orders (Mangiaracina et al. 2019; Kim et al. 2021). For instance, the biggest challenge in designing a successful business model with omnichannel grocery retailing is the high cost and complexity of fulfilment for groceries bought online (Hübner et al. 2016). MFCs can provide a high level of automation saving on labour costs and reducing operational costs such as heating and lighting (Azadeh et al. 2019). Moreover, automation allows for an increase in the picking speed and so to reduce picking costs that represent a relevant portion of logistics costs (Hübner et al. 2016). It is estimated that order picking accounts for 50%–55% of the operating costs which is done for searching and retrieving items, and travelling, which can account for 80% of the time needed to fulfil orders (Bozer and Aldarondo 2018).

  MFCs also reduce transportation costs since the products are stored in urban areas near the final customers. Indeed, in decentralized fulfilment centres, the transportation costs from storage to the customer are generally lower as the distance to a customer's home is shorter (Hübner et al. 2016).

- ***Sustainability benefits***

  The continuing boom in e-commerce gives rise to questions about the sustainability of home delivery services for online purchases (Janjevic and Winkenbach 2020). Last-mile delivery impacts on environmental and social spheres as it causes road congestion and air pollution (Kim et al. 2021). MFCs may bring an advantage here since they allow reductions of the total distance travelled to deliver the products and moreover, they can be coupled with the usage of more sustainable modes of transport such as light electric vans and cargo bikes (Kellermayr-Scheucher et al. 2021; Arrieta-Prieto et al. 2022). The study of Kim et al. (2021) highlights that a tier of hyperconnected UFCs can reduce CO_2 emissions in comparison to a dedicated UFC.

7 Critical Decisions in MFCs

While designing MFCs, different perspectives can be considered: location selection and technology selection as well as some other perspectives referred to as warehouse design, here.

- ***Location selection***

  As already discussed, MFCs are positioned within large urban areas for more proximity to the end customers. Their exact positions can be selected by taking into consideration a facility location problem together with a vehicle routing problem (Arrieta-Prieto et al. 2022).

  Location selection would impact the type of vehicles utilized for last-mile distribution, and hence the sustainability (Janjevic et al. 2020). Also, deciding on the number of MFCs within a region is relevant as it would influence delivery times and product availability. Therefore, while selecting the location of MFCs, a well-developed optimization model taking into consideration multiple parameters is critical.
- ***Technology selection***

  Automation would be necessary in order to meet recent customer order profiles such as small order sizes with shortened delivery time requirements (Boysen et al. 2019). The decisions regarding the level of automation and the type of it would be critical to take. The drivers for the automation level decisions are investment cost, space requirement and flexibility needed (Boysen et al. 2019). One of the most common solutions might be automated storage and retrieval systems (AS/RSs) (Koçak et al. 2021). Shuttle systems are estimated to be the most utilized technology for MFCs followed by ultra-high density storage systems (Scriven 2021).
- ***Warehouse design***

  The main decisions here are concerned with the product portfolio to match the demand in the area and the size of the warehouse (Kellermayr-Scheucher et al. 2021). Jin et al. (2019) study an integrated algorithm to select products in such warehouses. Regarding the capacity, usually many days of safety stock are kept in inventories regardless of the holding cost, since the main goal is to avoid stock-out and provide the customer with the best experience (Jin et al. 2019).

As a result, before implementing MFC strategies in businesses, applying algorithms to find optimal solutions for the above three decisions would be critical.

8 Conclusion

This paper presents MFC as a response to the rising challenges in e-commerce and specifically in e-grocery. Recently, customer order expectations have changed towards more decreased delivery time requests with low costs. A distributed warehousing concept of MFCs may offer significant advantages for that purpose. We investigate the MFC strategy from two research questions, one of which seeks how MFCs affect the last-mile delivery challenges, and the other seeks what design decisions would be critical in building MFCs.

For the first research question, we evaluate the problem from centralized versus decentralized warehousing strategies. We also provide the advantages and disadvantages of those two strategies. In the second research question, we discuss the critical decisions in the design of MFCs. In that, we discuss location and technology selection decisions as well as other warehousing design decisions.

As future work, the effect of MFCs on total cost, transportation cost and sustainability subjects can be studied. Based on different demand distributions, a simulation study, providing those three outcomes under different demand points and distributions would be worthwhile exploring.

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A Comparison Between Linear and Non-linear Combinations of Priority Rules for Solving Flexible Job Shop Scheduling Problem

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Abstract. Priority rules (PRs) have gained importance in the literature since they are suitable for solving especially large-scale scheduling problems in the industry. There are different types of PRs, of which composite PRs (CPRs), i.e., combinations of multiple rules, are known to have better performance in general. In this study, a basis for the generation of CPRs from linear and non-linear combinations of different PRs is defined and a comparison is made between these two approaches. Genetic algorithm and particle swarm optimization are operated for linear combination, and gene expression programming is used for non-linear combination, whose details are given. The employed benchmarks are from the flexible job shop scheduling problem, but the algorithms can also be employed to solve different scheduling problems. Along with the rules obtained based on the two approaches, a comparison is made between the famous simple PRs (SPRs) in the literature in terms of solution quality and time. The results show that usually, the non-linear combination provides better results. Since there is no process for rule extraction for SPRs, their computation time is very low. Both the used benchmarks and source codes are made available to the readers.

Keywords: Flexible job shop scheduling · Priority rules · Gene expression programming · Genetic algorithm · Particle swarm optimization

1 Introduction

Scheduling problems have long been the focus of researchers. One of the most important reasons for this is the serious application of these problems in the industry. For instance, there are many examples of the flexible job shop scheduling problem in the press working and chemical industries (Pawar and Bhosale 2022; Rakovitis et al. 2022). Because of their high complexity, the exact methods proposed for scheduling problems are not suitable to solve large-scale real-life problems. Unlike these, priority rules (PRs), which solve scheduling problems in polynomial time, are proper for solving dynamic, stochastic, and large-scale problems (Ozturk et al. 2019; Pawar and Bhosale 2022; Rakovitis et al. 2022;

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Teymourifar 2015; Teymourifar 2021; Teymourifar and Ozturk 2018a; Teymourifar and Ozturk 2018b; Teymourifar et al. 2018a; Teymourifar et al. 2018b; Teymourifar et al. 2020).

PRs can be categorized based on the features they use. If a PR makes decisions only based on a feature of the work or environment, it is called a simple PR (SPR). Usually, classic PRs are in this category. In the literature, there are other types of PRs consisting of SPRs, which are called Composite PRs (CPRs) (Ozturk et al. 2019). These types of PRs generally have better performance as they use multiple rules for decision-making. But the manner that SPRs are combined remarkably affects the performance of the resulting rule. In recent years, serious work has been done on the derivation of PRs, especially using evolutionary algorithms (Teymourifar et al. 2020). In this study, unlike the previous one, a comparison is made between CPRs resulting from linear or non-linear combinations of SPRs. For the first time in the literature, genetic algorithm (GA) and particle swarm optimization (PSO) is used for the linear combination of SPRs. Furthermore, gene expression programming (GEP) is employed for the non-linear combination of SPRs. All used source codes in the study are shared with readers. They can be easily revised and employed to solve other scheduling problems.

In the next parts of the study, first, the problem is defined and solution approaches are explained. After presenting the experimental results, the conclusion and future studies are discussed.

2 Problem Definition

In this study, the problem is the flexible job shop scheduling problem (FJSSP), which has two general phases machine assignment and process sequencing. Due to flexibility, unlike the job shop scheduling problem (JSSP), jobs can direct on multiple routes.

The assumptions of the problem can be summarized as follows: (i) each job has one or more operations, (ii) assignable machines and the corresponding processing times on them are predefined, (iii) jobs are independent of each other, (iv) there is no interruption during the processes (v) each machine can perform at most one operation at a time, (vi) the setup times of the machines are negligible, (vii) each machine can operate with maximum performance independent of other machines, and there is no maintenance time (Rakovitis et al. 2022; Teymourifar et al. 2018b).

The objective function of the problem is defined as $min\ F = \frac{C_{max}+W_{max}+W_t+Fl}{4}$, where

C_{max}: Maximum completion time of machines (makespan).
W_{max}: Maximum machine workload.
W_t: Total workload of machines.
Fl: Mean flow time.

3 Solution Approaches

There are studies about to solve this problem with mathematical modeling and meta-heuristics (Teymourifar et al. 2018b) but unlike them, we solve it with PRs, and we use new approaches to derive PRs. We use a simulation model to solve the problem, details of which are given by Teymourifar et al. (2020).

The simulation model is able to solve different kinds of scheduling problems. Since the model is capable of solving stochastic problems, it is called a simulation model, but the problem in this study is static. The general stages of the solution are as follows: when each operation is released, one of the assignable machines is selected and assigned using the least waiting time (LWT) heuristic (Ozturk et al. 2019). For each released operation, LWT calculates the sum of the waiting time as the sum of processing time and waiting time in the queue of each possible machine. It assigns that operation to the machine that provides the minimum value of waiting times. This stage is called machine assignment. If the machine that an operation is assigned to, is in the free state, it starts the process, but if not, it waits in the queue of the machine. As soon as the machine is in the free state, if more than one job is waiting in its queue, one of them is selected with a PR and the process is started. Thus, the operation sequencing also takes place.

GA, PSO, and GEP have an evolutionary process. At each iteration, the individuals and particles of the population are formed. Every individual in the GA and every particle in the PSO actually contains the required weights for the linear combination of PRs. Details of these two algorithms can be found in reference 1.

In GEP, each individual is the genotype of a CPR, and the mathematical expression is obtained as a result of decoding. With each obtained CPR, the scheduling problem is solved once and thus objective functions are acquired. Then, by sorting the population, new generations are created with operators such as selection, crossover, and mutation. The stopping criterion of the algorithm is the achievement of the maximum iteration number. It should be noted that the initial population is generated randomly.

The formation of individuals in each iteration and the calculation of the relevant objective function are shown in Fig. 1.

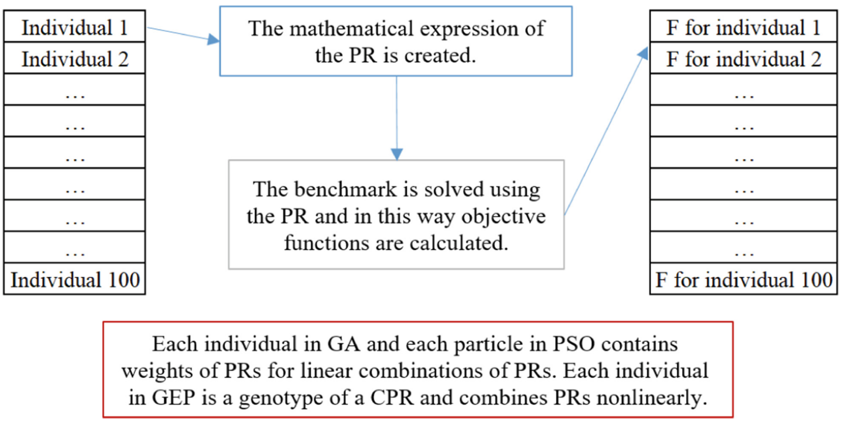

Fig. 1. Creation of CPRs and calculation of objective functions in each iteration of GA, PSO, and GEP.

Some of the commonly used features in PRs are given in Table 1 with their explanations. SPRs that use these features are presented in Table 2. We compare their performance with CPRs resulting from evolutionary processes (Teymourifar et al. 2020). In Table 2, Z_i indicates the decision value assigned to the job i in the relevant rule, so that the job with the minimum value has the highest priority. Thus, operation sequencing is done. In Tables 1 and 2, i is the index of jobs and j is the index of operations while m is the index of machines.

Table 1. Used notation (Teymourifar et al. 2020).

Notation	Description
O_{ij}	The j-th operation of job i
r_{ij}	Release time of O_{ij}
p_{ijm}	Processing time of O_{ij} on machine m
n_i	Total operation number of job i
ren_i	Remaining operation number of job i
P_i	Total processing time of job i
Re_i	Remaining processing time of job i

Table 2. Employed SPRs (Teymourifar et al. 2020).

SPR	Z_i
FIFO	r_{ij}
SPT	p_{ijm}
LnOps	n_i
LRnOps	ren_i
LTWRK	P_i
LRWRK	

4 Experimental Results

The described algorithms in the previous section have been implemented in MATLAB R2022a. We employ a system with an Intel Core i5 processor, 2.4 GHz with 12 GB of RAM. We choose the MK set as the benchmark.

In GEP, the population number, the maximum number of iterations, and the rates of crossover, and mutation are respectively defined as 100, 100, 1, and 0.4. Also, GEP has specific parameters such as the size of the head, sets of elements, and functions, whose value is selected as 5, 6, and 5 respectively. In fact, the set of elements consists of the SPRs presented in Table 2, and the operations required for their non-linear combination (+, −, *, /, $\sqrt{}$) form the set of functions. Details on this can be found in (Teymourifar et al. 2020). GA uses default options for selection, crossover, and mutation operators. We also use the options of *MaxStallGenerations* and *MaxGenerations*. The first one checks the number of generations in the GA without improvement and if there is no progress during 500 iterations, it stops. The maximum number of generations in GA is checked using *MaxGenerations*, which is set equal to 1000. Similar values and options are operated for the PSO. The value of the weights of SPRs is gained as a result of a continuous search in the range [−10, 10] in GA and PSO. It is observed that similar ratios are found when different intervals are used instead. Other options for both algorithms are the defaults set in the toolbox of global optimization in MATLAB.

The evolved rules are listed in Table 3, where, LC1, LC2, and NLC are the rules derived by GA, PSO, and GEP, respectively. LC1 and LC2 are linear combinations of SPRs while NLC is the result of a non-linear combination. Rule LC3, which is not listed in Table 3, is as follows for all benchmarks:

LC3: *FIFO* + *SPT* + *LnOps* + *LRnOps* + *LTWRK* + *LRWRK*. This rule is not evolved within any evolutionary process, and it is defined by assigning equal weights to all rules and is used only for comparison purposes.

Table 3. Extracted rules for each benchmark.

	PR	Z_i
MK1	LC1	−4.28 * FIFO + 8.09 * SPT + 8.90 * LnOps + 7.21 * LRnOps − 0.70 * LTWRK − 1.77 * LRWRK
	LC2	−8.87 * FIFO + 4.87 * SPT + 10 * LnOps + 10 * LRnOps − 3.88 * LTWRK − 0.38 * LRWRK
	NLC	SPT * FIFO
MK2	LC1	−2.26 * FIFO + 1.01 * SPT + 6.66 * LnOps − 0.66 * LRnOps + 4.13 * LTWRK − 0.91 * LRWRK
	LC2	−5.40 * FIFO + 5.29 * SPT − 9.91 * LnOps − 9.03 * LRnOps + 9.52 * LTWRK − 0.23 * LRWRK
	NLC	((LnOps/LRnOps) * (LTWRK * LRWRK))
MK3	LC1	1.19 * FIFO − 4.46 * SPT − 9.73 * LnOps + 1.66 * LRnOps − 8.29 * LTWRK + 9.21 * LRWRK
	LC2	0.91 * FIFO + 3.48 * SPT − 3.94 * LnOps + 8.94 * LRnOps − 8.57 * LTWRK + 9.95 * LRWRK
	NLC	((LnOps/LRnOps) * (LTWRK * LRWRK))

(*continued*)

Table 3. (*continued*)

	PR	Z_i
MK4	LC1	$-3.25 * FIFO + 3.33 * SPT - 1.15 * LnOps - 3.36 * LRnOps + 7.89 * LTWRK + 2.37 * LRWRK$
	LC2	$-4.13 * FIFO + 10 * SPT - 5.14 * LnOps - 6.53 * LRnOps + 10 * LTWRK + 1.79 * LRWRK$
	NLC	$LTWRK + SPT$
MK5	LC1	$-7.92 * FIFO - 6.34 * SPT - LnOps - 6.45 * LRnOps - 4.98 * LTWRK - 0.40 * LRWRK$
	LC2	$3.09 * FIFO + 5.57 * SPT + 10 * LnOps + 5.31 * LRnOps + 7.67 * LTWRK + 5.41 * LRWRK$
	NLC	$(LRnOps/LRWRK) - FIFO$
MK6	LC1	$-6.85 * FIFO + 1.74 * SPT - 8.62 * LnOps + 9.78 * LRnOps - 3.42 * LTWRK + 2.10 * LRWRK$
	LC2	$10 * FIFO + 2.24 * SPT + 1.35 * LnOps + 8.93 * LRnOps + 10 * LTWRK + 0.13 * LRWRK$
	NLC	$(\sqrt{(FIFO + LRnOps)/FIFO)}/LRnOps$
MK7	LC1	$1.50 * FIFO + 9.66 * SPT + 4.83 * LnOps - 1.08 * LRnOps - 4.84 * LTWRK + 3.88 * LRWRK$
	LC2	$-10 * FIFO + 7.16 * SPT + 8.87 * LnOps + 0.38 * LRnOps + 2.48 * LTWRK + 0.50 * LRWRK$
	NLC	$(\sqrt{(FIFO + LRnOps)/FIFO)}/LRnOps$
MK8	LC1	$-5.17 * FIFO + 2.98 * SPT + 0.88 * LnOps - 8.20 * LRnOps - 5.91 * LTWRK + 4.59 * LRWRK$
	LC2	$-6.79 * FIFO - 6.46 * SPT + 7.13 * LnOps + 0.71 * LRnOps + 6.22 * LTWRK + 0.03 * LRWRK$
	NLC	$\left(\frac{LRWRK}{LnOps}\right) * \sqrt{LRnOps}$
MK9	LC1	$-0.28 * FIFO + 6.36 * SPT + 8.32 * LnOps + 1.49 * LRnOps + 7.3 * LTWRK + 0.03 * LRWRK$
	LC2	$7.11 * FIFO + 5.18 * SPT + 3.29 * LnOps - 9.84 * LRnOps + 0.56 * LTWRK + 6.25 * LRWRK$
	NLC	$((LnOps/LTWRK) * LnOps)/SPT$
MK10	LC1	$-7.59 * FIFO + 2.34 * SPT - 2.26 * LnOps - 5.82 * LRnOps - 7.75 * LTWRK - 3.55 * LRWRK$
	LC2	$-7.27 * FIFO + 9.32 * SPT - 8 * LnOps - 4.06 * LRnOps - 3.60 * LTWRK - 9.83 * LRWRK$
	NLC	$((LnOps/LTWRK) * LnOps)/SPT$

As seen in Table 3, the same NLC rule is obtained for some benchmarks. The results are presented in Table 4, where the best results are bolded. In Table 3, T is the computation time in seconds.

Table 4. Obtained results for all Benchmark examples

Benchmark	PR	C_{max}	W_t	W_{max}	FL	F	T
MK1	FIFO	90	163	88	59.8	100.20	0.16
	SPT	92	170	88	53.6	100.90	0.07
	LnOps	105	170	100	60.1	108.78	0.04
	LRnOps	117	174	106	61.1	114.53	0.06
	LTWRK	105	165	94	52.6	104.15	0.04
	LRWRK	91	168	88	54.2	100.30	0.04
	LC1	75	160	**70**	41.9	86.73	121.08
	LC2	75	160	**70**	42.1	86.78	27.47
	LC3	100	168	94	59.4	105.35	0.06
	NLC	**72**	**153**	**70**	**44.1**	**84.78**	61.36
MK2	FIFO	74	152	72	56.5	88.63	0.02
	SPT	78	150	67	42.2	84.30	0.02
	LnOps	77	153	73	52	88.75	0.02
	LRnOps	77	149	69	45.1	85.03	0.02
	LTWRK	71	151	67	41.2	82.55	0.02
	LRWRK	77	152	71	43.6	85.90	0.02
	LC1	69	147	59	38	78.25	127.12
	LC2	64	147	59	37.4	76.85	24.25
	LC3	71	151	67	43.1	83.02	0.05
	NLC	**49**	**140**	**45**	**32.2**	**66.55**	125.66
MK3	FIFO	446	884	432	354.13	529.03	0.14
	SPT	436	880	423	255.86	498.71	0.08
	LnOps	496	896	459	258.87	527.47	0.05
	LRnOps	469	872	432	249.27	505.57	0.05
	LTWRK	435	875	406	239.13	488.78	0.05
	LRWRK	430	869	404	229.4	483.1	0.05
	LC1	390	855	369	223.87	459.47	511.14
	LC2	390	858	369	224.93	460.48	61.7

(*continued*)

Table 4. (*continued*)

Benchmark	PR	C_{max}	W_t	W_{max}	FL	F	T
	LC3	423	873	409	275	495	0.06
	NLC	**343**	**812**	**330**	**194.07**	**419.77**	170.85
MK4	FIFO	191	328	188	113.07	205.02	0.03
	SPT	192	328	188	98.87	201.72	0.03
	LnOps	197	332	188	86.87	200.97	0.03
	LRnOps	197	328	188	89.4	200.6	0.03
	LTWRK	197	328	188	82.87	198.97	0.03
	LRWRK	197	332	188	89.07	201.52	0.03
	LC1	190	330	**181**	**80.13**	195.28	265.33
	LC2	**189**	330	**181**	80.47	**195.12**	84.75
	LC3	197	330	188	93.47	202.12	0.05
	NLC	196	**324**	188	82.8	197.70	127.41
MK5	FIFO	306	690	304	243.6	385.9	0.04
	SPT	273	690	254	169.93	346.73	0.03
	LnOps	296	693	276	160.73	356.43	0.03
	LRnOps	297	698	295	162.6	363.15	0.03
	LTWRK	302	698	262	154.87	354.22	0.03
	LRWRK	339	695	285	170.87	372.47	0.03
	LC1	241	692	**217**	163.73	328.43	298.96
	LC2	**236**	692	234	146	327.00	44.81
	LC3	277	694	243	159.33	343.33	0.05
	NLC	247	**672**	239	**133.8**	**322.95**	246.05
MK6	FIFO	133	352	125	122.5	183.13	0.03
	SPT	144	365	110	95.6	178.65	0.04
	LnOps	141	364	107	94.1	176.52	0.03
	LRnOps	196	364	167	122.5	212.37	0.03
	LTWRK	182	359	146	121.4	202.1	0.03
	LRWRK	152	368	128	99.6	186.9	0.05
	LC1	113	347	100	79.4	159.85	409.54
	LC2	**104**	342	100	91.1	159.28	52.34
	LC3	114	354	**99**	83.8	162.70	0.06
	NLC	112	**330**	100	**76.3**	**154.58**	234.43

(*continued*)

Table 4. (*continued*)

Benchmark	PR	C_{max}	W_t	W_{max}	FL	F	T
MK7	FIFO	308	736	304	219.65	391.91	0.02
	SPT	281	729	264	144.45	354.61	0.02
	LnOps	296	757	283	156.7	373.17	0.02
	LRnOps	336	746	313	173.45	392.11	0.03
	LTWRK	263	729	248	151.15	347.79	0.02
	LRWRK	280	729	258	155.95	355.74	0.03
	LC1	237	705	**215**	137.75	323.69	298.95
	LC2	253	713	224	130.85	330.21	74.48
	LC3	285	741	278	189.75	373.44	0.05
	NLC	**226**	**649**	217	**117.35**	**302.34**	149.48
MK8	FIFO	644	2540	640	469.8	1073.45	0.04
	SPT	649	2529	616	423.8	1054.45	0.04
	LnOps	778	2528	641	382.6	1082.4	0.04
	LRnOps	771	2543	665	393.1	1093.02	0.07
	LTWRK	751	2526	637	393.55	1076.89	0.04
	LRWRK	741	2538	623	382.7	1071.17	0.06
	LC1	**602**	2506	590	371.65	1017.41	633.53
	LC2	626	2520	**581**	372.7	1024.93	205.83
	LC3	730	2570	639	425.1	1091.02	0.09
	NLC	611	**2484**	587	**351.35**	**1008.34**	523.23
MK9	FIFO	599	2419	573	469.15	1015.04	0.04
	SPT	569	2393	496	377.95	958.99	0.05
	LnOps	613	2391	499	361.15	966.03	0.05
	LRnOps	652	2364	502	369.7	971.92	0.05
	LTWRK	600	2363	474	338.2	943.8	0.05
	LRWRK	608	2384	512	339.25	960.81	0.06
	LC1	543	2304	430	309.7	896.68	676.89
	LC2	504	2331	**427**	333.15	898.79	108.31
	LC3	617	2403	528	372.05	980.01	0.09
	NLC	**473**	**2210**	454	**292.45**	**857.36**	542.65
MK10	FIFO	580	1965	576	433.35	888.58	0.05
	SPT	574	1972	531	328.3	851.32	0.05

(*continued*)

Table 4. (*continued*)

Benchmark	PR	C_{max}	W_t	W_{max}	*FL*	*F*	*T*
	LnOps	547	1932	511	290.55	820.13	0.05
	LRnOps	592	1975	532	315.9	853.72	0.05
	LTWRK	539	1978	509	308.2	833.55	0.05
	LRWRK	623	1975	581	339.15	879.54	0.07
	LC1	419	1984	371	284.55	764.64	813.43
	LC2	421	1951	404	298.8	768.70	255.32
	LC3	**354**	**1847**	**334**	**225.05**	**690.01**	0.09
	NLC	546	1982	516	330.2	843.55	657.28

As seen from Table 4, in general, the rules obtained as the non-linear combinations of SPRs with GEP give better results, although in some objective functions and benchmarks it is possible to get good results with CPRs resulting from the linear combination of rules. One noteworthy point is that computation times with SPRs are almost zero, though the quality of the results is not very high.

The convergence of GEP for solving MK1 is given in Fig. 2. As seen in Fig. 2, it is smooth, though not perfectly stable.

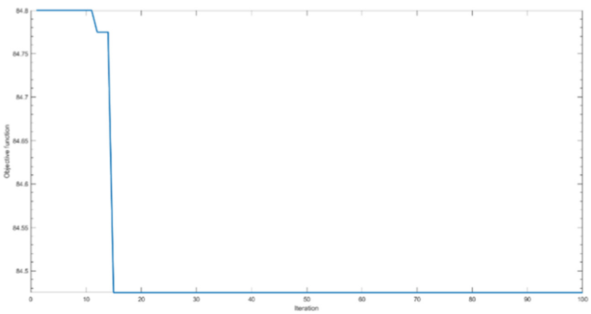

Fig. 2. Convergence of GEP for solving MK1

Gantt chart for the solution achieved for MK1 by GEP is given in Fig. 3.

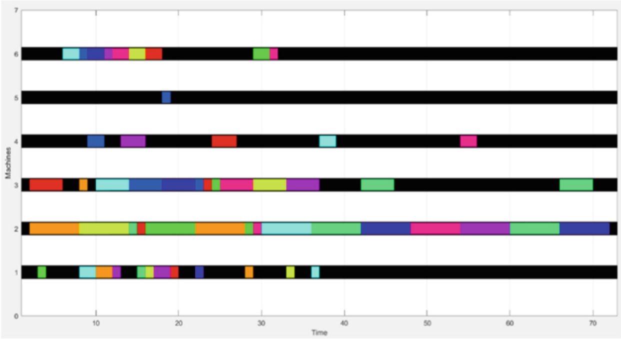

Fig. 3. Gantt chart for the solution acquired for MK1 by GEP.

5 Conclusion and Future Works

In this study, the importance of PRs in solving scheduling problems, especially in industry, and the fact that CPRs generally provide better results than SPRs were emphasized. Unlike the other studies in the literature, two basic approaches to generating CPRs, which are the linear and non-linear combination of PRs and the performance of resulting rules, were investigated. GA and PSO were used for the linear combination of PRs while GEP was employed for their non-linear combination. Novel algorithms were designed for this aim and some details were given.

The used benchmarks were from FJSSP, whereas the algorithms can be operated for other types of problems, as well. According to the acquired results, it was observed that the non-linear combination of PRs provided better results. But since CPRs were extracted in an evolutionary process, computation time was longer than for SPRs. Obviously, this mentioned time was for generating the rules and once a rule was obtained, the solution time with it was close to zero like SPRs.

One limitation of the study was that the applied GA, PSO, and GEP were not very efficient, which was evident from the convergence of algorithms during the solution process for some benchmarks. In future studies, it is planned to carry out studies on making algorithms more effective. Furthermore, although the importance of PRs in solving large-scale scheduling problems was emphasized, the used benchmarks were actually small size. In future studies, it is planned to carry out more comprehensive analysis on larger size benchmarks, based on statistical experimental design.

Although GEP is commonly used for the non-linear combination of PRs, algorithms such as GA and PSO can also be utilized with a special design for this purpose, which is also targeted for future work.

In addition, in this study, different rules were derived for each benchmark, though in future studies, fewer but a more robust rules will be evolved. In fact, based on the philosophy of using PRs, they should be robust to be applicable in several environments. For this aim, it is necessary to make the algorithms more effective, also enlarging the benchmarks. In this case, though, the evolutionary process will probably be longer.

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Supporting Information

All codes are accessible to readers via the following public link on GitHub: https://github.com/aydinteymurifar/Linear-Dispatching-Rules.

Appendix

Abbreviations

CPR Composite Priority Rule

FIFO First In First Out

GA Genetic Algorithm

GEP Gene Expression Programming

GP Genetic Programming

LnOp Least Operation Number

LRnOp Least Remaining Operation Number

LRWK Least Remaining Work Content

LTWK Least Total Work Content

LWT Least Waiting Time

PR Priority Rule

PSO Particle Swarm Optimization

SPR Simple Priority Rule

SPT Shortest Processing Time

LC CPR obtained with linear combination of SPRs

NLC CPR obtained with non-linear combination of SPRs

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A Comparison Between Two Definitions of Idle Time in Offline Scheduling of Flexible Job Shop Problem

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Abstract. Calculating idle time (IDT) based on different definitions for solving flexible job shop scheduling problems (FJSSPs), may lead to dissimilar results. This is valid for both offline and online scheduling. Therefore, it is important to clarify the description of IDT. In this study, the differences between offline and online scheduling concepts are first explained. The advantages and disadvantages of these two approaches are analyzed in detail. The details of an offline scheduling method are illustrated through a step-by-step example, which is solved manually to be elucidative. Two definitions for IDT are then given over the waiting of the operations and machines, and an FJSSP is solved offline with a priority rule defined based on them. The differences in the results of the two definitions are demonstrated through the illustrative example. In addition, a source code is written in MATLAB for offline scheduling, with which some benchmarks are solved. Details of benchmarks are presented and the results are discussed.

Keywords: Offline scheduling · Idle time · Flexible job shop scheduling · Priority rules

1 Introduction

The Flexible Job Shop Scheduling Problem (FJSSP) has been studied by many researchers in recent years and various methods have been proposed for its solution. The use of priority rules (PRs) is one of them that, unlike methods based on mathematical modeling, can solve the problem in polynomial time. Moreover, PRs are robust, meaning they can be applied in almost all environments. However, if a PR is not specifically designed for an environment, the results may not be good. Consequently, in recent years, several attempts have been made to derive environment-specific PRs (Ozturk et al. 2019; Rakovitis et al. 2022; Teymourifar 2015; Teymourifar and Ozturk 2018a; Teymourifar and Ozturk 2018b; Teymourifar et al. 2018a; Teymourifar et al. 2018b; Teymourifar et al. 2020).

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PRs can solve scheduling problems in both offline and online manners. There are examples of both approaches in the literature (Zhang et al. 2017; Teymourifar et al. 2018b). In offline methods, in general, the order of operations and assignments of machines are formed without advancing in time. Whereas, in online methods, the problem is solved by moving forward in time. It should be noted that we use the word "online" for the naming of a solution method and not for a problem. With an online approach, it is possible to solve both static and dynamic problems. In particular, online methods are suitable for solving stochastic problems, which set up an important category in dynamic problems. As real-life scheduling problems are mostly dynamic or even stochastic, online approaches may be more appropriate for solving scheduling problems, especially in the industry. However, offline solutions commonly have a lower computational load, which can be considered an advantage for them.

In this study, we solve FJSSP using PRs, based on the offline approach. Unlike many studies available in the literature, we describe the solution step-by-step. This study mostly focuses on two different definitions for idle time (IDT) in offline solutions and discusses how they can lead to dissimilar results. Although this issue has not been addressed in previous studies, it is an important point. Therefore, it is thought that this study contributes to the literature, especially due to the detailed explanation of the solution methods, the definition of IDT, and examples.

In the next part of the study, the definition of the problem and the solution method are presented with illustrative instances. Then, the used benchmarks and the obtained solutions are presented in the experimental results section. Conclusion and future works form the last part of the study.

2 Problem Definition and Solution Approaches

The problem of this study is an FJSSP, in which there are some independent jobs, and each of them has one or more operations. There is a constraint relevant to the order of operations of each job. Assignable machines and the related processing times on them are known beforehand. There are no setup times for the machines. The problem consists of two general stages, which are machine assignment and process sequencing. Different from the job shop scheduling problem (JSSP), jobs can forward on different routes (Teymourifar et al. 2018b).

The objective function of the problem is makespan ($C_{\max}$), which is the maximum completion time of machines.

An illustrative example is given to explain the stages of offline scheduling. The information of the benchmark used for this purpose is given in Fig. 1. In the example, there are three jobs that are denoted by J_1, J_2, and J_3. Each of them consists of operations. For example, J_1 has three operations, symbolized by O_{11}, O_{12}, and O_{13}, which are respectively the first, second, and third operations of the job. As shown in Fig. 1, O11 can only be processed on the third machine, which is shown as M_3. The corresponding processing time is nine. O_{12} can be processed either on M_1 or M_2. Processing times are one on M_2, and ten on M_1.

The instance shown in Fig. 1 is solved with the shortest processing time (SPT) rule, in which the operation with the minimum processing time is selected at each stage. Although IDT is the focus of this study, SPT is employed in this example to show the applicability of other PRs in the method.

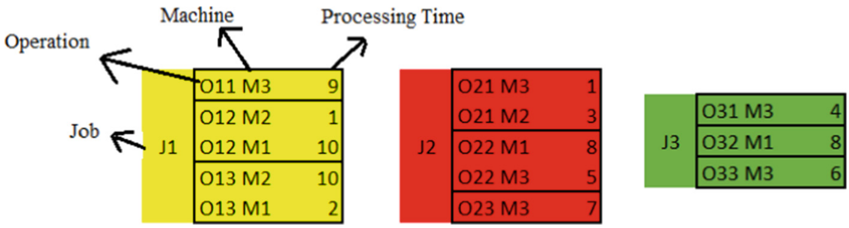

Fig. 1. The benchmark to solve with the SPT rule (Zhang et al. 2017).

The stages of offline scheduling with the SPT rule are given in Fig. 2. As seen, only the first operations of jobs are released in the first stage. Other operations are released after their previous operations. For example, O_{12} is released after O_{11}. Among the operations released in step 1, the lowest processing time is for O_{21} on M_3, which is marked with a blue circle. Thus, the first place in the order of operations is determined. After O_{21}, the next operation of J_2, which is O_{22}, is released as appears in Step 2, in which O_{31} is selected. The process of offline scheduling continues until the order of all operations is determined.

Fig. 2. Stages of offline scheduling with SPT rule.

The order of operations and machine assignment information obtained from the offline scheduling with the SPT rule is shown in Fig. 3.

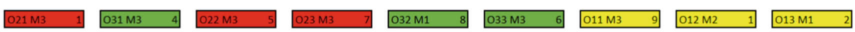

Fig. 3. Order of operations and machine assignment information acquired from the offline scheduling with SPT rule.

The Gantt chart formed based on the order given in Fig. 3 is drawn in Fig. 4. However, as seen, if this order is followed exactly, then some gaps appear. For example, once O31 finishes, O32 can immediately start processing on M1. However, in the Gantt chart of Fig. 4, it starts after O23 to fit the order. It should be noted that what occurs here is a gap, not an IDT, and a left shift can be applied to fill it. The black arrow in Fig. 4 indicates the possible left shit. Here, the left shift means to move an operation to the earliest time that it can start, without violating the order on the assigned machine. Obviously, in this case, the overall order may be violated. For example, in Fig. 3, O23 is before O32, but with the left shift, this order is violated. It is clear that in this type of left shift, the order of operations in the same job must be followed. For example, O32 cannot start before O31. Also, the order of jobs on the same machine should not be disturbed. For example, O11 cannot be shifted before O33. It should be noted that the last-mentioned rule is only valid for the solution method of this study, and different left shifts can be operated in other problems.

The computational load of the explained process can be high because gaps are determined at each stage, possible local shifts are evaluated and the appropriate one is applied. This process repeats until it is not possible to apply any local shift. For example, in Fig. 4, after O_{32} is shifted to the left, it is possible to perform a similar movement for O_{33}. The Gantt chart obtained at the end of this process is shown in Fig. 5.

Fig. 4. Gantt chart obtained from offline scheduling with SPT rule.

Fig. 5. A revised version of the Gantt chart gained from offline scheduling with the SPT rule.

To reduce the computational load mentioned in the previous paragraph, during offline scheduling, for each operation, we list the values of the finish time of the previous operation on the job and on the machine, respectively indicated by PO and PM. Then the start time of each operation is calculated as Maximum (PM, PO). For example, since the PM and PO values for O_{32} are zero and five, respectively, its start time is calculated as Maximum $(0, 5) = 5$. Thus, there is no need to apply left shifts.

In the previous example, the meaning of the gap and its difference from IDT was explained. Again, Fig. 5 is used to describe IDT, which is the focus of this article. The finish time of O_{21} is one, and the release time of O_{22} is also one. However, since this operation starts after O_{31} on M_3, the start time is five. If we calculate IDT over the waiting time of the operations, it is equal to four (i.e. *starting time of* O_{22} – *finish time of* $O_{21} = 5 - 1 = 4$) for O_{22}. Nevertheless, if we calculate IDT based on the waiting time of M_3, it equals zero (i.e. *starting time of* O_{22} – *finish time of* $O_{31} = 5 - 5 = 0$). These are operation - and machine-based definitions of IDT, respectively. An example is given to illustrate how these two definitions cause different results, the information of which is given in Fig. 6. This instance is solved with the minimum IDT (MIDT) rule, in which, at each stage, the operation that causes the lowest IDT is selected.

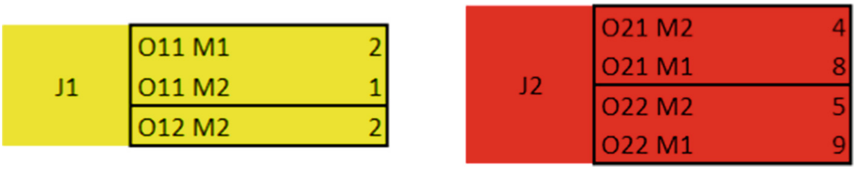

Fig. 6. Benchmark solved by MIDT rule (Zhang et al. 2017).

To solve the example, both definitions for IDT described earlier are utilized. The solution steps according to the operation-based IDT are given in Fig. 7. Unlike Fig. 2, in this figure, the value on the right side of each rectangle is the operation-based IDT, not processing time. As in Step 1, if the values of IDT are equal, the selection is done randomly.

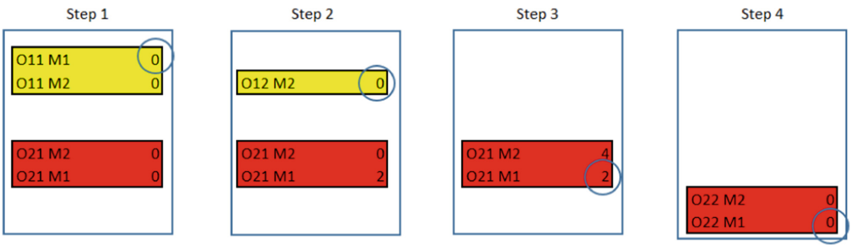

Fig. 7. Solution stages according to the operation-based IDT.

The solution steps according to the machine-based IDT are given in Fig. 8, which is similar to Fig. 7 but unlike Fig. 2, the values to the right side of the rectangles are machine-based IDTs, not processing times.

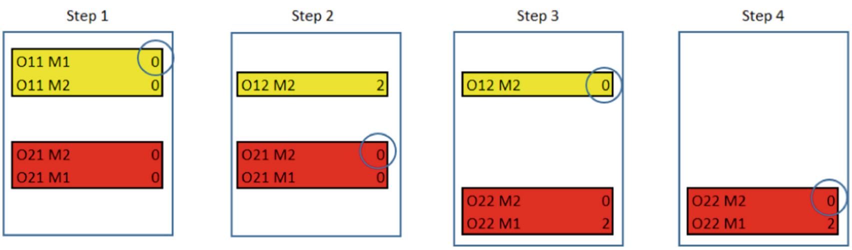

Fig. 8. Solution stages according to the machine-based IDT.

The Gantt chart of the solution according to the operation-based IDT is presented in Fig. 9, where the horizontal axis shows the time while the vertical axis displays machines.

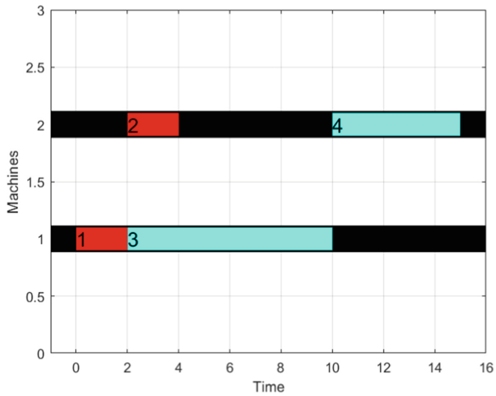

Fig. 9. Gantt chart of the solution according to the operation-based IDT.

The Gantt chart of the solution according to the machine-based IDT is shown in Fig. 10.

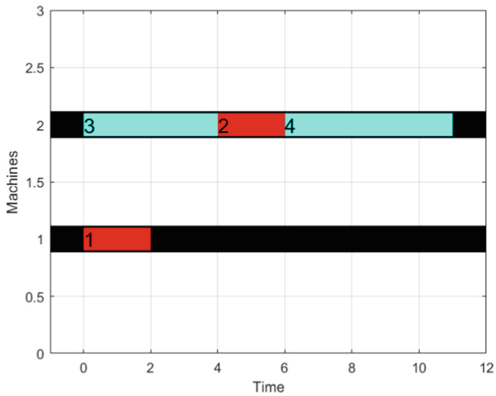

Fig. 10. Gantt chart of the solution according to the machine-based IDT.

Although online scheduling is not the main subject of this study, for comparison, the benchmark in Fig. 6 is also solved based on the online approach. The resulting Gantt chart is shown in Fig. 11. As seen, the result of online scheduling for this example is exactly the same as in Fig. 10. However, this may not be valid for different benchmarks.

It should be mentioned that, unlike offline scheduling, the online one goes forward in time, during the solution process. In this approach, FJSSP is divided into two stages, which are machine assignment and operation sequencing. Each operation is assigned to a machine according to a PR, once it is released. This step is called machine assignment. If the machine is in the free state at the time of assignment, the operation starts to process. If the machine is not free, the operation waits on the waiting list of the machine, and as soon as the machine is free, an operation is selected from the waiting list according to a PR. This stage is called operation sequencing. The computational load of this approach is higher than the offline one, as many situations are checked during the solution process. However, as an advantage, it is capable to solve dynamic and stochastic problems (Ozturk et al. 2019).

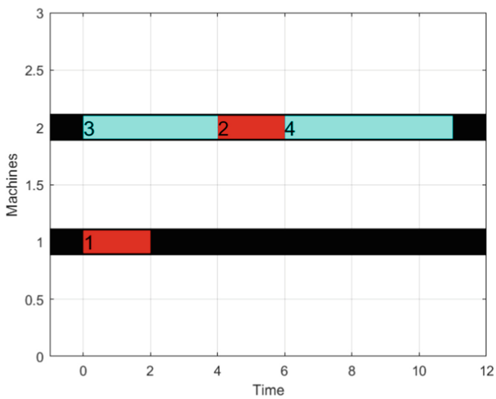

Fig. 11. Gantt chart of the solution acquired by online scheduling.

3 Experimental Results

The algorithm of the described steps in the previous section for both definitions of IDT has been implemented in MATLAB R2022a. We employ a system with an Intel Core i5 processor, 2.4 GHz with 12 GB of RAM.

The used benchmarks are given in Fig. 8, which are modified versions of the ones from the literature (Zhang et al. 2017). There is information about energy consumption in the original ones, which is eliminated since the objective function of this study is not related to energy. Benchmark 3 is not given in Fig. 12 since is as in Fig. 6.

The gotten results are given in Table 1, wherein if one of the definitions achieves a better outcome, it is bolded. For all results, the computation time is less than one second.

As Table 1 shows, the two definitions cause the same result in five benchmarks, while in four examples, the one that defines IDT based on machines' waiting times, yields better results. It should be noted that the generalization of this outcome requires more investigation based on more objective functions. However, these results prove that at least sometimes different results can be brought based on these two definitions. This matter has been neglected in many studies.

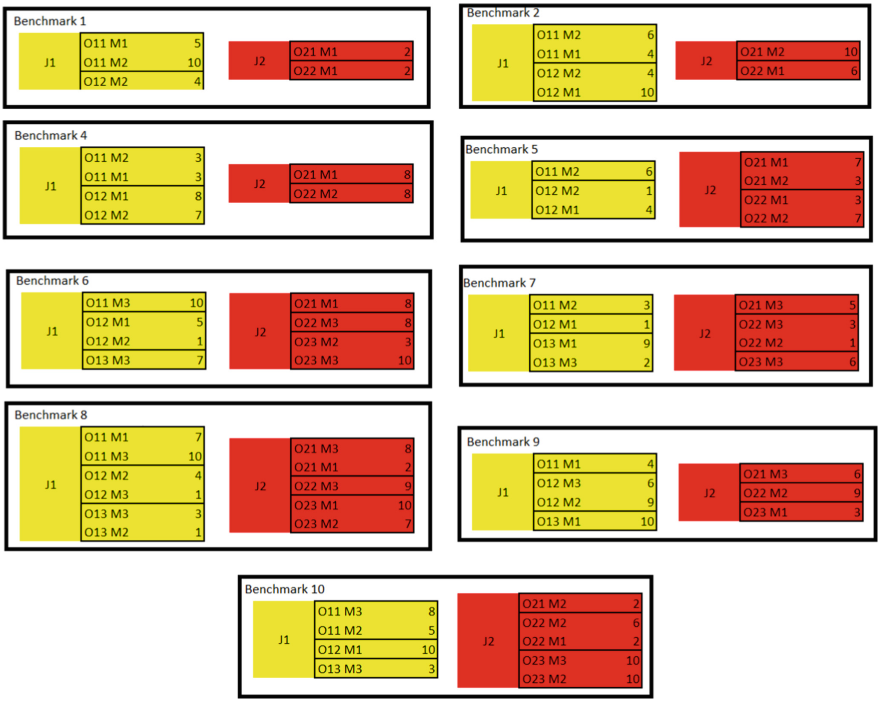

Fig. 12. Benchmarks of the experimental results (Zhang et al. 2017).

Table 1. Obtained results for all benchmark examples

Benchmark	C_{max}	
	Operation-based definition	Machine-based definition
1	9	9
2	26	26
3	15	**11**
4	27	**18**
5	10	10
6	**34**	35
7	14	14
8	33	**31**
9	28	**25**
10	21	21

4 Conclusion and Future Works

In this study, we used the offline solution approach for solving FJSSPs and we discussed its differences, advantages, and disadvantages from online methods. Based on the offline approach, using a PR, the solution process was explained step by step, with illustrative examples. Then, we focused on the definition of IDT, which needed to be clarified especially during offline solutions. For this aim, solutions were made through the operation - and machine-based definition of IDT. The results and differences were discussed. Along with manual solutions, a source code had been written for solving the problem in MATLAB, which is shared with readers via a public link. Since there are no explanatory studies on this topic, it is thought that this study contributes to the literature.

It was observed that the machine-based definition of IDT generally provided the same results as the operation-based one. However, in some benchmarks, it caused better results. In this way, it was proven that different results can occur with the operation - and machine-based definitions for IDT. In addition, it should be noted that, in general, in visual analysis and Gantt charts, IDT is calculated based on the waiting times of machines.

This study was mainly focused on the offline scheduling method and the concept of IDT, but it also had its limits, for example, the benchmarks were small-size. Moreover, the objective function in this study was only makespan. The results of the online methods were not included unless an example. Considering these shortcomings, it is planned to carry out more comprehensive studies in the future.

Integrating the solution method with evolutionary algorithms (Teymourifar 2021) is another goal for future studies.

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Supporting Information

All codes are accessible to readers via the following public link on GitHub:
https://github.com/aydinteymurifar/Offline-Scheduling.

Appendix

Abbreviations

IDT Idle Time

MIDT Minimum Idle Time

PM Previous Operation on the Assigned Machine

PO Previous Operation of the Related Job

PR Priority Rule

SPT Shortest Processing Time

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A Comparative Analysis of Apriori and FP-Growth Algorithms for Market Basket Analysis Using Multi-level Association Rule Mining

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Abstract. Nowadays, many companies have massive amounts of data. Data mining is essential to gain business insights from large amounts of data. Market basket analysis is a data mining technique that analyzes customer buying behavior by discovering relationships between pairs of products purchased together. This analysis helps companies to design a better strategy for business decisions such as marketing and campaign management, store layout optimization, and inventory control. FP-Growth and Apriori are two widely used algorithms for market basket analysis. In this study, Apriori and FP-Growth algorithms are applied for market basket analysis with real-life data from an FMCG retailer. Furthermore, the performance of these algorithms is compared using multilevel association rules mining. Numerical results showed that the FP-Growth has greater performance than Apriori in terms of run time and memory for all levels of product groups. On the other hand, compared to FP-Growth, Apriori is better in terms of generating good candidates. At this point, a hybrid approach can be developed that minimizes the disadvantages of both algorithms.

Keywords: Market basket analysis · Apriori · FP-growth · Association rule mining

1 Introduction

Nowadays, many companies have massive amounts of data stored in their databases and different resources. However, it is critical for companies to extract useful insights from this massive data. At this point, data mining algorithms offer important opportunities to extract useful information from data. For example, in a retail chain, analysis of customer transaction data can be used to determine customer purchasing patterns and to optimize store layout. To do this, companies apply different data mining methodologies such as association rule mining and sequential pattern mining.

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Market basket analysis is a way to discover customers' purchasing behaviors by gaining insight into items purchased together. It gives an idea about the items which are most likely to be seen together in a customer's basket. This analysis can be used to organize shelves and promote and increase sales by applying promotions to cross-sales. Apriori and FP-Growth are two widely used algorithms for market basket analysis. This paper aims to present the performance of Apriori and FP-Growth algorithms for multi-level association rule mining.

The organization of the rest of the paper is as follows: In the second section, a literature review about market basket analysis and association rule mining is presented. In the third section, association rules mining and Apriori and FP-Growth algorithms are briefly explained. In the fourth section, the application of the market basket analysis is performed with the real-life data obtained from a retail chain. Finally, the findings and conclusions are presented in the last section.

2 Literature Review

Association rule mining is one of the most important functions of data mining. At this point, association rule mining algorithms are widely used for market basket analysis in retail. Association rule mining is a base step for revealing associations between items of (Dorf and Bishop 2011). Agrawal et al. (1993) explain the application of the association rule by calculating support and confidence and determining minimum support and confidence values in their article Mining Association Rules between Sets of Items in Large Databases. In this way, it reveals how much an item is purchased with another item (support) and how much the other item is likely to be bought (confidence).

Many research studies have been done about different applications of market basket analysis. Apriori and FP-Growth algorithms are two of the most common algorithms used for market basket analysis in the literature (Kumar and Rukmani 2010; Mythili and Shanavas 2013; Singh et al. 2014; Garg and Gulia 2015; Khan et al. 2017; Ilham et al. 2018; Hossain et al. 2019; Aldino et al. 2021). Kumar and Rukmani (2010) suggested that although the Apriori algorithm is easy to implement when it comes to memory utilization and execution time, it has disadvantages compared to FP-Growth, especially with larger datasets. However, FP-Growth does not perform well in terms of generating good candidates. Consistent with these findings, Mythili and Shavanas (2013) indicated that Apriori requires larger memory and more time to implement than FP-Growth. According to Singh et al. (2014) divide and conquer strategy makes FP-Growth faster than Apriori. Apriori algorithm also scans the dataset multiple times to generate candidates whereas FP-Growth scans two times (Garg and Gulia 2015). That's why the studies suggest that the disadvantages of the algorithms can be minimized by combining the results of Apriori and FP-Growth algorithms.

3 Methodology

In this section, the concept of association rule mining is introduced and Apriori and the FP-growth algorithms are discussed.

3.1 Association Rule Mining

Association rule mining was first introduced by Agrawal et al. (1993). A mathematical statement of the association rule mining can be summarized as follows (Han and Kamber 2006).

Let *I* be an itemset where *I* contain $\{I_1, I_2, \ldots, I_m\}$. Assume that *D*, the task-relevant data, consists of a collection of database transactions *T*, each of which *T* is a nonempty itemset with the property $T \subseteq I$. Each transaction has a unique identifier known as a *TID. A* is a set of items. If $A > T$, a transaction *T* is said to include *A*. An implication of the type $A \Rightarrow B$, where $A \subset I$, $B \subset I$, $A \neq \emptyset$, $B \neq \emptyset$, *and* $A \cap B = \emptyset$ is an association rule. In the transaction set D with **support**s, where s is the proportion of transactions in D that include the rule union of sets *A and B,* the rule $A \Rightarrow B$ holds.

In the transaction set *D*, the rule $A \Rightarrow B$ has a **confidence** level of c, where c is the proportion of transactions in *D* that contain both *A* and *B*. This is considered to be $P(B|A)$, the conditional probability. These equations can be defined as follows:

$$support(A \Rightarrow B) = \mathrm{P}(A \cup B) \text{ and} \tag{1}$$

$$confidence(A \Rightarrow B) = P(B|A) = \frac{Support(A \cup B)}{Support(A)} = \frac{Support\ count(A \cup B)}{Support\ count(A)} \tag{2}$$

To find patterns (relationships, structures) in the data, association rule machine learning is utilized. The most common uses of association analysis in data science are applications. Another name for it is recommendation systems. Online recommendation systems refer to clients by saying things like "people bought this product too" and "the ones who bought this item also bought this item". These are the situations that have come up the most often in studies on data science and data mining in e-commerce.

Boolean rules that include Support and Confidence are used to express association rules. The percentage of transactions in an extremely large data set that adheres to the norm is called support. The likelihood that *Y* is a real subject to *X* or P (Y|X) is referred to as confidence.

Association rule mining is typically divided into two distinct processes. The first one is, to identify all frequent item sets, which are those that occur at least as frequently as the proposed minimum Support count. And the second one is, to create robust association rules from the frequent Itemset, making sure the rules match the basic requirements for Support and Confidence.

Both the antecedent (if) and the consequent (then) are parts of an association rule. An item found in data is called an antecedent, and an item found alongside the antecedent is called a consequent.

Each rule with high support and confidence values may not be important sometimes. In this case, the "Lift" value is calculated to measure the difference and importance of the obtained rules.

The calculation of lift between A and B can be calculated as follows:

$$lift(\mathrm{A, B}) = \frac{\mathrm{P(A \cup B)}}{P(A)P(B)} = \frac{Confidence(A \rightarrow B)}{Support(B)} \tag{3}$$

3.2 Apriori Algorithm

The Apriori Algorithm is one of the most important collections of Association rules used in association analysis. It is one of the first and the best algorithms for mining all common itemsets and was developed by Agrawal et al. in 1993.

The Apriori algorithm concept is to make several passes over the database. To efficiently count candidate k-itemsets, it employs a breadth-first search and a tree structure. Apriori consists of two steps which are merging and pruning as described below.

The **joining** step creates the (K + 1) itemset from these K-itemsets, by linking each item with itself.

In the **prune** step, count each item in the database by scanning it. If they do not have the necessary minimum support because they are deemed to be infrequent. This procedure is used to make the candidate itemsets smaller.

The basic idea behind the Apriori algorithm is simple. An item set is deemed a frequent item set when its support value surpasses a specific limit. First, the support criterion is established; only elements that are more relevant than the support threshold is then examined.

The below assumptions are made by the Apriori Algorithm.

- A frequent itemset must have frequent subsets.
- An infrequent item collection must have infrequent subsets.
- Set a support threshold level.
- Step 1: The minimum level of assistance and reliability should be determined, together with the amount of transactional database support.
- Step 2: Select all of the supports that are higher than the default or predetermined support value in the transaction.
- Step 3: Look for all rules in these subgroups that are more precise than the cutoff or baseline level.
- Step 4: The rules should be arranged in ascending strength.

3.3 FP-Growth Algorithm

The FP-Growth algorithm is an improvement on the Apriori approach in that it addresses some of its shortcomings. To receive frequent itemsets in Apriori, a generated candidate is necessary. However, the FP-Growth generate candidate technique is not implemented since it searches for frequent itemsets using the idea of tree development. The FP-Growth algorithm is faster than the Apriori approach because of this (Mythili and Shanavas 2013).

The data structure utilized in the FP-Growth algorithm is a tree known as the FP-Tree. The FP-growth method may directly extract frequent Itemset from the FP-Tree using the FP-Tree. By producing data tree structures, also known as FP-Trees, the FP-Growth algorithm will be used to frequently excavate itemsets.

The steps for building the FP-tree are as follows:

a) Perform a single transaction database *D* scan. Gather *F*, the group of frequent items, together with the support numbers for each. As *L*, the list of frequently occurring items, sort F in support count decreasing order.

b) A root is made for an FP tree and labeled "null". Do the following for each transaction *Trans* in *D*. Choose and put the frequent itemsets in *Trans* based on the order in *L*. Let [p|P], where *p* is the initial member and *P* is the rest of the list, represent the sorted frequent item list in *Trans*. This is carried out like this; If T has a child N which is the list's first element, then N's count should be increased by 1. If not, a new node N should be created, with its count set to 1, its parent link set to T, and its node-link set to other nodes that share the same item name via the node-link structure (Han and Kamber 2006).

4 Application

In this section, the application steps of the market basket analysis performed with data from a retail store are presented.

4.1 Data Preprocessing

For the study, transaction data was used from a store of a retail company in Turkey. The dataset consists of one month's purchases for this particular store. Purchases with one type of product were eliminated in the first place. Certain product categories, such as nylon bags, and seasonal products, were also excluded from the data. Algorithms were operated for 109186 unique invoices which include 4856 distinct product items; 538 distinct subcategories; and 180 distinct main categories. There are 477276 transaction lines for these unique invoices.

The sample data in Table 1 represents the row data which includes the invoice number of the transaction, product code, sub-category, main category, and how many products were bought in that transaction (count).

Table 1. Sample dataset for market basket analysis

	Invoice	Product_Id	Sub_Category	Main_Category	Count
1	Inv_1	product_9876	sub_5	main_5	2
2	Inv_1	product_409	sub_8	main_3	1
3	Inv_2	product_389	sub_47	main_9	1
4	Inv_3	product_1578	sub_67	main_11	3
5	Inv_3	product_489	sub_78	main_1	1
6	Inv_3	product_34	sub_21	main_5	1
…	…	…	…	…	…
427773	Inv_109185	product_1024	sub_11	main_15	4
427274	Inv_109185	product_467	sub_49	main_4	1
477275	Inv_109186	product_456	sub_23	main_1	1
477276	Inv_109186	product_579	sub_61	main_7	1

In this study, the Apriori and FP-Growth algorithms are coded in Python 3.9.10 using a few packages (Networkx, Pandas, Matplotlib, and Mlxtend). All calculations and tests are performed on Intel(R) core(TM) i5 2.42 GHz CPU with 8 GB RAM. The dataset should be in one-hot encoded form, i.e., in the form of "0" or "1", to use the Apriori module from the "mlxtend" package. The data frame was transformed into a one-hot encoded data frame as shown in Table 2.

Table 2. One-hot encoding structure

Invoice_Number	Product_1	Product_2	Product_3	...	Product_4783	Product_4794
Inv_1	0	1	0	...	0	1
Inv_2	0	0	0	...	0	0
Inv_3	1	0	0	...	0	0
Inv_4	0	1	0	...	0	0
...	...	...	...	...	...	...
Inv_109184	0	1	0	...	1	0
Inv_109185	0	0	1	...	0	0
Inv_109186	1	0	0	...	1	0

4.2 Data Processing

Some parameter values are necessary for the apriori class to execute. The one-hot encoded data frame from which we aim to extract rules is the first parameter. The second one is the minimum support parameter. The items with support values greater than the value indicated by the parameter are selected using this parameter. Next, the use of the colnames argument, if True, substitutes column names for column indices in the produced DataFrame. As we set the minimum support to 0.001 we had 3445 item sets. To examine more meaningful associations, Apriori and FP-Growth algorithms were applied for three-level: main category, subcategory, and product item. Table 3 demonstrates the minimum support and confidence values used for the different levels.

Table 3. Support and confidence values of product levels

	Support	Confidence
Main category	0.005	0.5
Sub category	0.003	0.5
Product item	0.001	0.3

For the levels of the product item, subcategory, and main category, the results of the association rule are shown in Table 4, Table 5, and Table 6, respectively. As a result of association rule mining algorithms, there are 20 rules for product item categories (Table 4).

Table 4. The results of the association rule based on the product item

Rule	Antecedents	Consequents	Support	Confidence	Lift	Leverage	Conviction
rule_1	product_14	product_26	0.0015	0.4271	127.416	0.0015	1.7396
rule_2	product_36	product_4	0.0011	0.4169	65.8827	0.0011	1.8326
rule_3	product_67	product_6	0.0010	0.4682	50.6205	0.0010	1.7042
rule_4	product_790	product_85	0.0016	0.3527	36.3690	0.0018	1.8632
rule_5	product_903	product_ 6	0.0021	0.3338	36.0861	0.0020	1.5300
rule_6	product_109	product_ 11	0.0028	0.6198	35.8251	0.0027	1.4871
rule_7	product_124	product_6	0.0012	0.3010	32.5472	0.0012	1.5847
...	...	...	...	...	...	...	...
rule_19	product_456	product_69	0.0010	0.3394	1.4813	0.0009	1.4813
rule_20	product_57	product_69	0.0011	0.3019	1.4017	0.0010	1.4017

As seen in Table 5, as a result of the application of the algorithms, 10 association rules are obtained for the sub-categories.

Table 5. The results of the association rule based on the sub-category

Rule	Antecedents	Consequents	Support	Confidence	Lift	Leverage	Conviction
rule_1	sub_1	sub_2	0.0100	0.6642	19.5017	0.0095	2.8769
rule_2	sub_3	sub_2	0.0066	0.5041	14.8018	0.0062	1.9481
rule_3	sub_4	sub_5	0.0032	0.7306	5.5453	0.0026	3.2239
rule_4	sub_6	sub_5	0.0037	0.6082	4.6161	0.0029	2.2162
...	...	...	...	...	...	...	...
rule_9	sub_10	sub_5	0.0051	0.5136	3.8984	0.0038	1.7853
rule_10	sub_11	sub_5	0.0038	0.5017	3.8082	0.0028	1.7427

As seen in Table 6, 11 association rules are obtained for the main categories.

Table 6. The results of the association rule based on the main category

Rule	Antecedents	Consequents	Support	Confidence	Lift	Leverage	Conviction
rule_1	main_1	main_2	0.0069	0.5128	3.9309	0.0051	1.7848
rule_2	main_3	main_4	0.0074	0.6609	3.0311	0.0049	2.3064
rule_3	main_5	main_4	0.0069	0.6468	2.9662	0.0046	2.2139
rule_4	main_6	main_4	0.0073	0.6454	2.9601	0.0048	2.2057
…	…	…	…	…	…	…	…
rule_10	main_13	main_4	0.0169	0.5285	2.4240	0.0099	1.6587
rule_11	main_14	main_4	0.0063	0.5265	2.4245	0.0037	1.6514

5 Conclusions

Figure 1 represents the associations among the top ten product relationships based on lift values according to the results of the algorithms. The highest lift value is between Product_14 and Product_26.

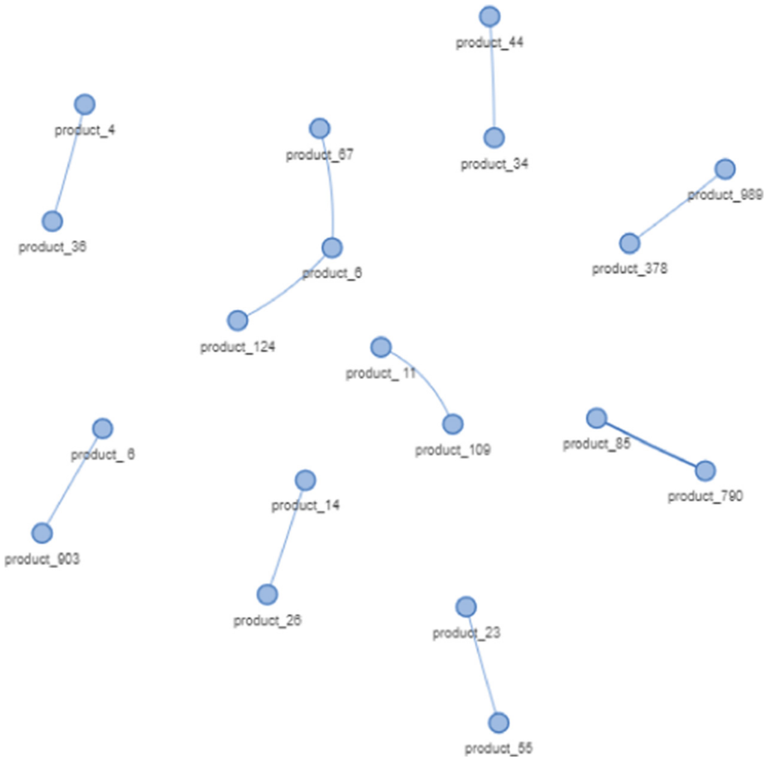

Fig. 1. The network graph of the associations among the top ten product items

Figure 2 presents the execution time comparison of Apriori and FP-Growth algorithms for different levels of product groups. To see the differences in run times, the logarithm of the execution times is shown in the figure on the right.

To compare the performance of the Apriori and FP-Growth algorithms, 10 replications were made and the mean (M) and standard deviation (SD) of the run times of the algorithms were calculated.

The results revealed that execution times of apriori algorithm in main category ($M = 1.61$, $SD = 0.06$), subcategory ($M = 4.30$, $SD = 0.76$), and product item ($M = 53.55$, $SD = 6.31$) are higher than execution times of FP-Growth algorithm in main category ($M = 1.38$, $SD = 0.04$), subcategory ($M = 2.14$, $SD = 0.24$), and product item ($M = 20.76$, $SD = 4.49$) (Fig. 2). Numerical results showed that FP-Growth algorithm runs faster than the Apriori algorithm.

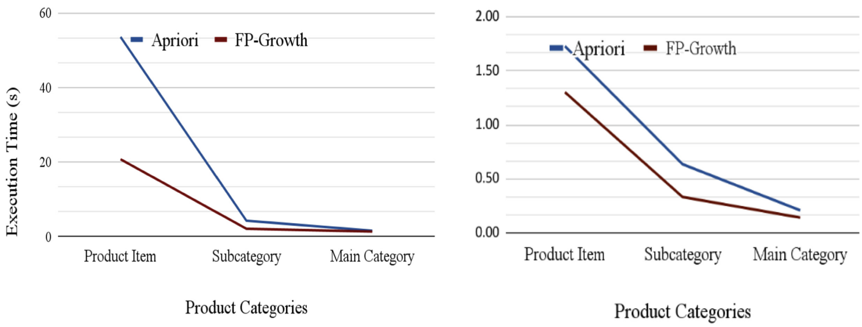

Fig. 2. A comparative analysis of run-times of Apriori and FP-Growth algorithms for multi-level association rules

The fact that Apriori examined the material more than once to produce candidate itemsets was the main cause of the lengthy processing time. Therefore, the execution time grows exponentially as the data gets bigger and more complex. Since FP-Growth uses the "divide and conquer" method, the entire database is only scanned twice. As a result, the FP-Growth requires less time to execute and Apriori uses large memory space. That's why consistent with prior studies, the results indicated that the FP-Growth algorithm outperforms the Apriori algorithm.

Because of the limitations in the implementation of the algorithms, the algorithms are performed in data within a limited time and space. In future studies, different strategies and algorithms can be used with larger data sizes. Future studies can also integrate FP-Tree with the Apriori candidate generation approach to overcome the drawbacks of both Apriori and FP-growth. Further studies are required to examine and analyze customer buying behavior. Furthermore, in future studies, it is aimed to use association rules mining and sequential pattern mining algorithms for decisions such as store layout optimization and product recommendation system design.

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Supplier Selection with Fuzzy TOPSIS- A Case Study on a Pharmacy in Izmir

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Abstract. Multi-criteria supplier selection problems are widely studied problems in the OR literature. Various criteria are inspected during the evaluation process. Although, selecting the appropriate criteria is not cumbersome, deciding on the weights of each criterion and performance weights for the suppliers is not easy. The difficulty arises due to fuzziness in the evaluation process. This fuzziness can be handled by some fuzzy methods due to its fuzzy nature. In this study, the aim is to show an appropriate selection of suppliers for a pharmacy located in Turkey by using the fuzzy TOPSIS method. The motivation behind selecting a pharmacy to conduct a case study is the significance of medicine supply, especially after Covid-19. In the case study, the fuzzy TOPSIS method is implemented on 4 suppliers from the pharmaceutical industry based on 11 selection criteria. Evaluations of 6 decision-makers who work in the pharmaceutical industry are gathered. Then, results are reported and conclusions, as well as future directions, are mentioned.

Keywords: Supplier selection · Multi-criteria supplier selection · Fuzzy TOPSIS · Pharmacy · Healthcare

1 Introduction

Supply chain applications are among the most important issues that have taken great attention since the beginning of the 1990s. One of the problems involved in the supply chain is the supplier selection problem which has a great impact on corporate performance. The aim of the supplier selection problem is to find the right supply chain partners under some restrictions and criteria (Chang et al. 2011). Although supplier selection problem is related to various sectors, consideration of supplier selection problem plays a vital role in the health sector where the reduction in cost and increase in quality are indispensable. The increase in costs compared to the customer price index in the last years has caused an increase in the efforts to reduce costs in this sector. Nonetheless, some concerns about reducing costs in the health sector may also influence the quality and performance of the service (Lambert et al. 2006). Especially with the effect of the recent Covid-19 pandemic, cost problems related to the health sector have gained a great

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deal of attention one more time. Consequently, supplier selection problem involving cost and quality criteria has emerged in the health sector.

In today's business life, low cost and high-quality output are almost impossible to achieve together without satisfactory suppliers since these two factors are often conflicting. Considering this fact, an important purchasing decision is the selection of an eligible supplier group and the maintenance of supply chain relations. Supplier selection is a difficult decision since the decision process necessitates the consideration of many criteria (Weber et al. 1991). Suppliers are obstacles for businesses due to the increase in costs. The success of good supply chain management is highly related to the selection of the right supplier. According to Saen (2007), the supplier selection process is an important step in purchasing process because it influences the costs and provides a competitive advantage in the market. As a result, it is important for businesses to be able to consider their suppliers as their partners (Cousins & Menguc). Hence, evaluation of supplier performance becomes more critical for supply chain management (Dickson 1996).

Like in other service sectors, the supply chain management of medical equipment and consumer goods in the health sector involves plenty of uncertainty. An important challenge in the health sector is the evaluation and choice of suppliers (Bahadori 2017). With the recent turn of attention to the health sector, sectoral improvement efforts have grown. One of the most important stakeholders of the health sector is pharmacies that provide quality drug supplies to patients. According to Bağcı and Atasever (2020) pharmacists play an active role in disease screening, disease prevention, improvement of drug compliance and monitoring of chronic diseases, etc. In order to provide the right number of drugs at right time to patients, pharmacies should work with drug suppliers who can deliver drugs correctly and also in a short time. Considering this fact, an efficient supplier selection is vital for pharmacies as well. Selection of the wrong supplier may result in increasing prices, decreasing service quality, quality problems, and distrust of the health sector. With the recent outbreak of the Covid-19 pandemic, the appropriateness and dependability of pharmacies as institutions from which people get prescribed medicines, personal care products, and many supplements have become more vital. In light of the aforementioned veracity, the ultimate goal of the study is to select the best supplier for a pharmacy among all possible alternatives.

Due to the aforementioned significance of the pharmacies and their supplier selection decisions in today's environment (i.e., post-pandemic conditions), this study emphasizes the supplier selection decision process in pharmacies. Since real-life decisions mostly include fuzziness, fuzzy TOPSIS methodology is selected as an appropriate technique to be utilized in this setting.

This paper is organized as follows; in Sect. 2, the problem definition is given, then in Sect. 3, the literature review for the multi-criteria supplier selection is presented. After that, in Sect. 4 fuzzy TOPSIS and criteria for the problem are defined, then in Sect. 5, case study & numerical results are given. Finally, in Sect. 6, conclusions and future works are mentioned.

2 Problem Definition

The supplier selection decision is very significant in every sector. If the best possible supplier is selected for any company (i.e. vendor), then the company approaches its profit maximization or cost minimization goals. However, there are various criteria to be evaluated during the multi-criteria supplier selection process. Quality, reliability, durability, maintainability, availability, on-time delivery, environmental-friendly, accessibility, flexibility, accident history, technology, reputation, communication, payment conditions, and cost are some of the various criteria that can be considered while selecting the best suppliers. Although some of these criteria can be selected for the supplier selection decision-making process easily by considering the sector of the company, the evaluation phase is not very easy. The difficulty of evaluating of the criteria comes from the vagueness of the evaluations. For instance, when the quality of a supplier is evaluated by a decision-maker, linguistic variables such that "quality is high" or "quality is low" are commonly used. This fuzziness can be handled by converting these linguistic variables into fuzzy numbers and then making numerical evaluations accordingly. Triangular fuzzy numbers are mostly utilized to convert linguistic terms into numbers. Fuzzy numbers (i.e., fuzzy values) are used for both criteria weight and performance evaluation of suppliers. These fuzzy numbers are generally represented as (a, b, c) where a, b, c correspond to crisp numbers of an evaluation scale. Then closeness coefficients are ranked and the highest preference is related to the supplier with the closeness coefficient value closer to 1 and the lowest preference is related to the supplier with the closeness coefficient value closer to 0 (Haddad et al. 2021).

Besides the fuzziness in the evaluation of criteria, when deciding the best supplier, the sector of the vendor is quite important. Especially after Covid-19, the healthcare sector and pharmacies have become the most significant sectors. Therefore, pharmacies should consider multi-criteria supplier selection as a significant issue and make their decisions accordingly so that they can meet the demand of the patients while maximizing profits or minimizing costs at the same time.

3 Literature Review

There are various articles about supplier selection problems and the Fuzzy TOPSIS method independently. In this part, the literature review is conducted on supplier selection problems that consider fuzzy TOPSIS as a solution method. Reviewed articles are explained in separate paragraphs below.

Wang et al. (2009) propose the fuzzy hierarchical TOPSIS method to solve the multi-criteria supplier selection problem. The fuzzy hierarchical TOPSIS method is an extended and improved version of the classical fuzzy TOPSIS method that has been introduced by Chen et al. (2000). This improved version of the fuzzy TOPSIS method results in more accurate criteria weights. Based on the results, it is observed that the newly introduced method is consistent with the fuzzy TOPSIS method (Wang et al. 2009).

Zouggari and Benyoucef (2012) present a hybrid method that is a fusion of the fuzzy AHP and fuzzy TOPSIS procedures. According to the hybrid method, initially, fuzzy

TOPSIS is used to select suppliers based on four classes that are performance strategy, quality of service, innovation, and risk. Next, the simulation-based fuzzy TOPSIS is utilized to allocate the selected suppliers based on their orders. In this study, a plain numerical example is presented and solved. The applicability of the proposed hybrid method is proven by the outcomes of the numerical example (Zouggari and Benyoucef 2012).

Liao and Kao (2011) utilize the integration of Fuzzy TOPSIS and multi-choice goal programming (MCGP) methods as a solution method for multi-criteria supplier se-lection problems. The integrated method is demonstrated by solving a numerical example in a watch firm. Results of the numerical example show that this hybrid method is beneficial to demonstrate vague evaluations of decision-makers to define various evaluation levels for multi-criteria supplier selection problems such that "the more/higher is better" for the profit criteria (Liao and Kao 2011).

Junior et al. (2014) compares the performance of Fuzzy AHP and Fuzzy TOPSIS for multi-criteria supplier selection problems. Based on the results of this comparative study, fuzzy TOPSIS is found to be superior to Fuzzy AHP for the supplier selection problem due to its adaptation to the problem when there are changes in the alternatives, criteria, the number of criteria, and alternative suppliers (Junior et al. 2014).

Rouyendegh and Saputro (2014) use Fuzzy TOPSIS and Multi-choice Goal Programming (MCGP) for selecting suppliers and assigning the orders to the selected suppliers. A case study is conducted on the fertilizer production company. There are 17 criteria for deciding the best supplier for the corresponding company. In the case study, multi-choice aspiration levels are considered. The outcomes of the case study show that the integrated methods are superior to the conventional fuzzy TOPSIS method while deciding the order quantity. Moreover, it is proven that the selection of the best supplier improves the robustness of the supply chain of a company (Rouyendegh and Saputro 2014).

Junior et al. (2016) introduces a new approach that combines two Fuzzy TOPSIS models to categorize suppliers into four groups based on their performance evaluations. This new method utilizes performance metrics of the Supply Chain Operations Reference (SCOR) model for evaluating suppliers based on cost and delivery performances. It is observed that combining the Fuzzy TOPSIS with the SCOR leads to some advantages over other approaches to solve multi-criteria supplier selection problems. Some of these advantages are the agility of the decision process, the unlimited number of alternatives that can be evaluated at the same time, and the applicability of the ranking reversal whenever necessary (Junior et al. 2016).

Kannan et al. (2014) proposes a framework by using a Fuzzy TOPSIS method to select among green suppliers for a Brazilian electronics company. Furthermore, the effect of the preferences of the decision-makers for the selected Green Supply Chain Management (GSCM) practices for the selection of green suppliers is evaluated. Based on the results of the study conducted on the corresponding electronics company, four criteria are selected to be the most significant among others (Kannan et al. 2014).

Nag and Helal (2016) perform multi-criteria decision-making for supplier selection by using the fuzzy TOPSIS method. In this study, 7 criteria that affect the supplier selection decision are considered. A case study is conducted on the pharmaceutical distributor in Kuwait that is in contact with multiple suppliers in Europe. Based on the outcomes of the case study, the multi-criteria supplier selection by utilizing the Fuzzy TOPSIS method is proven to be appropriate for handling uncertainty (Nag and Helal 2016).

Haddad et al. (2021) show the effectiveness and applicability of the fuzzy TOPSIS method on multi-criteria supplier selection in real-life applications. A case study is conducted on the oil and gas industry to exhibit the benefits of utilizing fuzzy TOPSIS for multi-criteria supplier selection. As an outcome of the case study, it is observed that, once the appropriate linguistic variables are determined, and fuzzy values are assigned to the corresponding linguistic term scale, the Fuzzy TOPSIS method works properly to overcome uncertainty in the decision-making process for the multi-criteria supplier selection (Haddad et al. 2021).

Shiraz et al. (2014) includes the subjective opinions or evaluations of the employees in the multi-criteria decision-making process of an automobile company. The main reason for including the subjective opinions of the employees is to enable the selection of suppliers based on well-defined criteria. In this context, the fuzzy TOPSIS method is utilized to perform real-life decision-making processes in multi-criteria supplier selection problems. Based on the detailed analysis that is performed in the study, past data for the business, warranties, geographical region, warranties, and delivery are observed to be the significant criteria for the supplier selection decision-making process for the automobile company (Shiraz et al. 2014).

Shahraki et al. (2011) demonstrate the necessity to use the Fuzzy TOPSIS method to overcome situations in which it is difficult to quantify performance indices during the supplier selection process. According to the outcomes of the study, the Fuzzy TOPSIS method is found to be a flexible method that covers both qualitative and quantitative factors in the supplier selection process, and therefore applicable for multi-criteria supplier selection problems in the fuzzy environment (Shahraki et al. 2011).

Latpate (2015) introduces a modified method that is a fusion of the Fuzzy TOPSIS and Linear Programming model for supplier selection in the supply chain. After implementing the proposed method for supplier selection, it is seen that the modified Fuzzy TOPSIS method is suitable to cope with the fuzzy environment. The better closeness of the coefficients is achieved by using this fusion fuzzy method (Latpate 2015).

Yayla et al. (2012) prove the appropriateness of the Fuzzy TOPSIS method for the multi-criteria supplier selection. A case study is conducted on a Turkey-based company in the garment industry. 3 basic suppliers of this company are evaluated by using the fuzzy TOPSIS method. Based on the literature review and the decision-maker's evaluations, quality, delivery time, cost, flexibility, and geographical location are determined to be the criteria while using the fuzzy TOPSIS method. Supplier alternatives' closeness index values are considered and the best supplier among all alternatives is selected accordingly. As an outcome of the case study in the Garment industry, it is proven that the Fuzzy TOPSIS method is effective for determining the suppliers in the supply chain (Yayla et al. 2012).

Izadikhah (2012) proposes Atanassov's interval-valued intuitionistic fuzzy numbers extension of Fuzzy TOPSIS for supplier selection. As an outcome of the numerical example, the proposed method is found to be very flexible that can be used to decide to outrank the order of suppliers as well as rate the suppliers and decision-makers (Izadikhah 2012).

Kılıç (2012) considers the fuzzy TOPSIS method for supplier selection due to the vagueness of the real-life environment. A case study is conducted on a filter company to verify the quality of the fuzzy TOPSIS method for the multi-criteria supplier selection problem. Four criteria are considered in the case study that are quality, cost, delivery time, and institutionalization. After that, the most suitable supplier is selected based on these criteria by using the Fuzzy TOPSIS method. The outcomes of the case study prove the applicability of the fuzzy TOPSIS method for the multi-criteria supplier selection problems (Kılıç 2012).

Kumar et al. (2018) use the fuzzy TOPSIS method to deal with the uncertain environment during the supplier selection process. A model for a steel manufacturing unit that is located in India is proposed to exhibit the application of the fuzzy TOPSIS method for the multi-criteria supplier selection problem. Based on the Fuzzy TOPSIS multi-criteria model, information about the various challenges in the firm is provided, then the area for implementation of performances is determined. These result in better knowledge about the supplier selection process in a vague environment. Then by utilizing the method, the most and least preferred suppliers are determined properly (Kumar et al. 2018).

Özbek (2015) develops a supplier selection model and used the Fuzzy TOPSIS model to solve this model. A case study is conducted on a medium scaled company that produces aluminum profiles. Four criteria that are quality, price, delivery performance, service, and past performance are evaluated by the decision-makers. As an outcome of the numerical example, all of the supplier alternatives are found to be suitable but one of them is found to be the most appropriate (Özbek 2015).

Ayvaz et al. (2015) present the Fuzzy TOPSIS method to select appropriate sup-plier under vagueness. This method is applied to a company in the banking sector. Based on the numerical example, one supplier is selected to be best among all by appropriate application of the fuzzy TOPSIS method (Ayvaz et al. 2015).

Javad et al. (2020) selects suppliers of Khuzestan Steel Company. Suppliers are ranked based on their green innovation abilities. There are 38 criteria for the evaluation and order allocation of the suppliers. After all of the suppliers are evaluated based on the corresponding criteria, top suppliers are selected by utilizing the best-worst and the fuzzy TOPSIS method. Among 11 suppliers, 2 are selected to be the best suppliers in terms of green innovation criteria. After that, the sensitivity analysis is performed to show the robustness of the model and as a result of this analysis, the robustness of the model is proven (Javad et al. 2020).

Büyüközkan and Çifçi (2012) propose a framework to evaluate green suppliers. Both quantitative and qualitative factors are considered. A case study is implemented at Ford Otosan. Based on the case study, it is observed that the fuzzy TOPSIS method is an efficient way to select the best suppliers (Büyüközkan and Çifçi 2012).

There are also some studies that are relevant to the ranking which is significant for the fuzzy TOPSIS method. For instance, Cetintav et al. used ranked set sampling (RSS) in their study as a handful tool for the information about the ranks of the units (Cetintav et al. 2017). Moreover, they worked on the improvement of RSS which is fuzzy-weighted ranked set sampling (FwRSS) to cope with the unpredictability while ranking (Çetintav et al. 2016).

4 Fuzzy TOPSIS and Criteria Definition

As mentioned before, fuzzy TOPSIS is used as a methodology to solve the multi-criteria supplier selection problem in this study. Before mentioning the implementation and numerical results, the fuzzy TOPSIS method and 11 criteria that are used in this study are explained in this section.

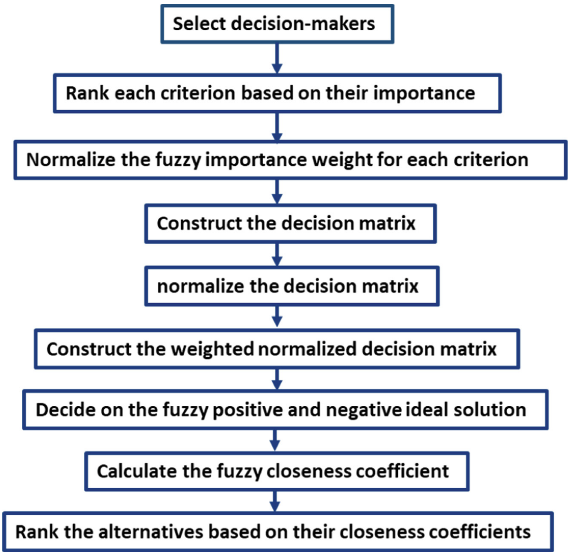

Fig. 1. Fuzzy TOPSIS

4.1 Fuzzy TOPSIS

The main idea of the Fuzzy TOPSIS is that the best candidate among all alternatives must have the shortest distance from the positive ideal solution and whereas farthest distance from the negative ideal solution (Kahraman 2008).

The positive ideal solution is described as the solution maximizing the benefit criteria and minimizing the cost criteria while the negative ideal solution does vice versa. Based on this information, the aim of the method is to choose the best alternative among all candidates' ones which is closest to the positive ideal solution. The basic steps of the traditional Fuzzy TOPSIS technique have been demonstrated in Fig. 1.

4.2 Criteria

Criteria are parameters of the Fuzzy TOPSIS approach whose determination is of paramount importance. Most of Multi-Criteria Decision-Making Problems, often have incongruous dimensions that result in some problems in the evaluation process. To eschew this problem, the utilization of fuzzy systems embedded with the TOPSIS technique is necessary for better assessments. Considering this fact, each criterion is evaluated using linguistic terms which are converted into fuzzy numbers with triangular distributions. In this study, 11 different criteria are determined after performing a brainstorming with those who are involved in this sector. These criteria are recapitulated as follows:

Quality: The quality of the products that are delivered by the suppliers is evaluated. For instance, the packaging, and expiration date are significant factors under this criterion.
Cost Advantage: If one supplier gives promotions more frequently than others, this can be regarded as a cost advantage since, in the healthcare sector, the cost of the medicines should be the same for all suppliers legally.
On-time delivery: The delivery performance of the suppliers is evaluated by this criterion. If the medicines are supplied on time, then this criterion is strong.
Flexibility: This criterion measures if there is confusion about the type or amount of the medicines, and how flexible is the supplier to provide the demanded medicine.
Dependability: This criterion measures whether the pharmacy employees trust the supplier or not.
Payment conditions: If suppliers facilitate pharmacies' ability to make payments. (i.e., by installments).
Environmental-friendly: This criterion measures how suppliers react to the environment. For instance, if they use environmentally friendly bags, or use motorcycles instead of cars, they get high points for this criterion.
Reputation: This shows how much popularity or experience gained from a supplier in the sector.
Accident history: If there are damages to the medicines or workers of a supplier make a car accident, then this supplier gets low points for this criterion.
Communication: Communication of a supplier with pharmacy employees or pharmacists is evaluated by this criterion.
Technology: This criterion shows the automation degree of a supplier.

5 Case Study and Numerical Results

In this case study, we consider 4 candidate pharmacy suppliers located in different regions of Izmir. To evaluate these suppliers, there are 11 criteria, namely quality, cost advantage, on-time delivery, flexibility, dependability, payment conditions, environmental-friendly, reputation, accident history, communication, and technology are employed to determine the best supplier among all candidates' ones.

In order to make a pertinent choice, the Fuzzy TOPSIS method is used, where 4 suppliers are evaluated based on 11 different criteria. During the assessment process, six experts who work at pharmacies are selected to form a committee and make a final decision. Decision-makers evaluated each criterion weight by using linguistic ranks such that "Very Low, Low, Medium, High, Very High". These ranks are then converted into corresponding triangular membership values that range between 0 and 1 (See Table 1 and Fig. 2).

Table 1. Rank and membership function values

Rank	Sub-criteria grade	Membership function
Very Low (VL)	1	(0.00, 0.10, 0.25)
Low (L)	2	(0.15, 0.30, 0.45)
Medium (M)	3	(0.35, 0.50, 0.65)
High (H)	4	(0.55, 0.70, 0.85)
Very High (VH)	5	(0.75, 0.90, 1.00)

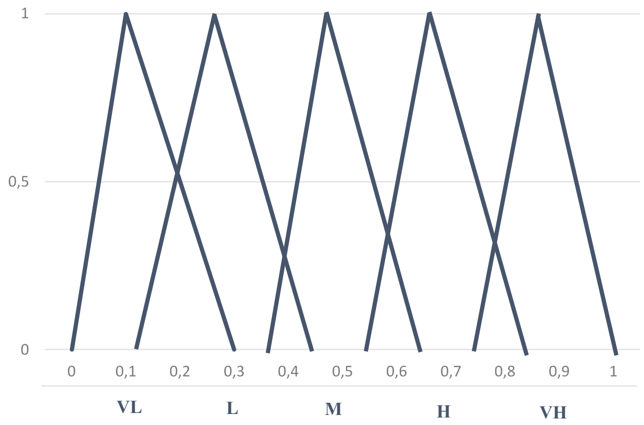

Fig. 2. Graphical representation of membership function values

Each supplier is also evaluated based on each criterion by using the same rank scale and corresponding membership function value. Then, the triangular membership value for each criterion is obtained by taking the average of values stated by 6 decision-makers. After that, these values are normalized by dividing each value for a specific criterion by the max value of that criterion. Then, normalized values are multiplied by the weights of the criteria previously. After obtaining the weighted and normalized decision matrix, distances from the positive ideal solution and negative ideal solution are calculated for each supplier regarding all criteria. Finally, the closeness coefficient index is calculated for each supplier. As a result, Supplier 1 is found to be the best supplier among the 4 suppliers since it has the smallest closeness coefficient value (See Table 2). It can be observed from the table that the ranking of the suppliers is S1-S3-S2-S4 when their closeness coefficient values are considered.

Table 2. Suppliers and closeness coefficient values

Supplier	A+	A−	Cci
S1	4,4235	7,3708	0,3751
S2	5,4536	6,2149	0,4674
S3	5,1109	6,6035	0,4363
S4	5,9607	5,6657	0,5127

6 Conclusion and Future Work

In conclusion, fuzzy TOPSIS is an effective method to select the best supplier among alternatives. Based on the results of the case study, it is observed that Supplier 1 is the best supplier among 4 candidate suppliers when evaluated by 6 decision-makers based on 11 criteria.

Although this case study is an introduction to the wise supplier selection for the pharmacies in Turkey, the study can be implemented on a vast number of suppliers in the same sector by more than 6 decision-makers. Fuzzy methods other than fuzzy TOPSIS can also be applied to the same problem and the results can be compared with the outcomes of this study. In another direction for future research, the location of a new pharmacy can be decided by applying multi-objective optimization of the same problem.

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Supplier Selection with Fuzzy Analytical Hierarchy Process

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Abstract. Today, competition is increasing rapidly due to developments in technology. Firms should follow new methods in the process of the product from the producer to the consumer (Supply Chain) to maintain their place in the competition. For the continuation of a successful Supply Chain, long-term cooperation based on mutual trust and cooperation should be established between the supplier and the customer. Purchasing timely and quality raw materials from suppliers is the first step of this chain. If one of the supplier links is broken, the entire chain will be broken. As a result, business decisions on supplier selection are critical. The difficulty of supplier selection is complicated by several competing considerations. Cost, quality, design capability, manufacturing competence, technical capability, technological capability, performance history, managerial capability, degree of collaboration, financial performance, and closeness are only a few of these considerations. In this instance, multi-purpose decision-making methodologies should be applied rather than traditional supplier selection analyses. One of the Multi-Criteria Decision Making strategies that aid the decision maker is the Fuzzy Analytical Hierarchy Process. This study started by examining the factors affecting supplier selection. The literature review focused on Fuzzy AHP applications. Criteria suitable for the examined company were determined and the process was started by creating matrixes. Finally, the best supplier was determined.

Keywords: Fuzzy AHP · Quality · Selection · Supplier

1 Introduction

In today's world, where globalization and technological developments accelerate rapidly, the understanding of competition between businesses has started to increase. Businesses that follow innovation and technology are at the forefront of the competition. Businesses are targeting fundamental, long-term, strategic improvements apart from superficial, short-term improvements. The concept of the supply chain, which is very important for businesses and is considered a complex structure, also comes to the fore at this point (Benyoucef, L., Ding, H., & Xie, X. 2003). Supply chain management is defined as an important system for businesses to respond to competition and meet customers' demands and expectations. The general functions of the concept of procurement are as follows:

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to determine the requirements of the business, to determine and select a supplier that can meet the requirements, to determine the issues related to product delivery, and to monitor the delivery-related transactions. One of the first and most important steps of the supply chain is the supply of the production input and where the inputs will be obtained. Extensive research on potential suppliers is required. Suppliers' general and technical criteria need to be evaluated. There are many criteria to consider when choosing among suppliers. These criteria are cost (price), quality (suitability of the product for use), design ability (different thicknesses and lengths), manufacturing ability, technical ability (sophistication of measuring devices), technological ability, performance history (low return rates), management ability, cooperation degree, financial performance, proximity, and possession of the required documentation (such as ISO 9000, DIN, TSE, etc.). In this study, it is investigated which supplier would be better to work with the Fuzzy Ahp method in supplier selection.

2 Problem Definition

In this study, the evaluations of a metal factory in Izmir in the selection of suppliers were examined. This business includes pipe bending, welding, and CNC departments. One of the most important first and common steps for all these departments is supplier selection (Taherdoost, H., & Brard, A. 2019). In this context, the company has been working with companies from which it has purchased raw materials since its establishment. With the uncertainties brought by the covid epidemic and the exchange of dollar rate, the company wants to work with this supplier to find the best among the suppliers it has worked with before and to bring profit in financial terms. Some of the priority criteria determined by the Quality Department are as follows; quality (availability of raw materials), proximity (availability of location), price (comparison of costs with other suppliers), on-time delivery (to avoid delays in delivery times to the customer), and quality documentation status. An evaluation will be made among 5 suppliers. In the Problem Definition part, firstly, a few criteria determined by the quality department of the company are mentioned. Then, general information about Fuzzy AHP will be given.

First, the focus will be on the quality criterion. If the steps of the incoming raw material in the incoming quality department are examined:

- First, conformity is checked against general acceptance rules (other than quality level). These are general acceptance conditions such as quantity, time, etc.
- Compliance with the specified specifications (thickness and diameter for pipes) is determined by inspection and analysis and written on the quality control record forms.
- The codes (identities) of the raw materials were determined by the ERP system and the previous work of the input quality specialist (Included in the quality registration form.).
- Inspection and analysis results are evaluated and decided by the entrance quality department. The decision alternatives to be made in this regard are as follows;

    - Incoming raw material or material is accepted.
    - Inadmissible.

- The suspicious situation is seen and a 100% sorting examination is performed. (One-by-one measurement is performed.)
- Faulty ones are returned to be corrected or replaced.
- Even if it is unacceptable according to the specification, it is accepted as temporary. (Customer approval is essential.)

The data were analyzed by looking at the return and deviation rates of the company in previous years. Due to the privacy policy of the business, the supplier does not share their names and rates. The return rate for the quality criteria is listed as follows, from the best supplier to the worst supplier; supplier 3, supplier 2, supplier 5, supplier 4, and supplier 1.

Secondly, the focus is on the proximity criterion. Proximity affects the movement of products from one place to another in the supply chain, their efficiency, stock, and facilities. Proximity is an important point in increasing the responsiveness of the transported product by using different transportation methods and reducing stock holding costs. Firms want to minimize transportation costs due to the sudden changes in the covid epidemic and the dollar exchange rate. The order of the suppliers that the company wants to choose from the closest to the farthest is as follows; supplier 1, supplier 3, supplier 4, supplier 5, and supplier 2.

Thirdly, the importance of price in supplier selection will be examined. Production cost is the cost required by businesses to procure raw materials and convert those raw materials into final products. Considering the costs of the enterprise, a large proportion of it is seen as the cost of raw materials. In this respect, the criticality of supplier selection is revealed again. By choosing the right supplier, businesses that minimize raw material costs can ensure their sustainability. In addition, choosing the right supplier also affects production and post-production costs. Faulty and unsuitable products from the supplier cause quality problems and thus increase quality costs. As an example, the formation of cracks in pipe end shaping, which occurs frequently in the enterprise, in cases where the raw material quality is not suitable can be given (Kahraman, C., Cebeci, U., & Ulukan, Z. 2003). The order of suppliers according to the prices of various raw materials is as follows: supplier 2, supplier 3, supplier 4, supplier 5, and supplier 1 (closest to farthest).

As another supplier evaluation criterion, the on-time delivery criterion was considered. Delivery time is the key point for product and service agreements. Suppliers are obliged to deliver their products at the right time, in the right quantity, quickly, and reliably. Companies that do not deliver on time and cannot meet the deadline may have to pay a line stop allowance to their customers. In addition, companies may not be able to cover this cost and fall behind in the competition, and businesses may have to close in different situations. On the other hand, suppliers should have delivery flexibility in addition to on-time delivery. Delivery flexibility is concerned with whether the changes that may occur in the order quantity or the urgent product requests of the enterprises can be met by the suppliers. By quickly responding to the requests of the customers and providing delivery flexibility, relations with the customers are developed. When the suppliers are evaluated for the on-time delivery criterion, the suppliers are ranked as follows, from the best supplier to the worst supplier: supplier 4, supplier 3, supplier 2, supplier 1, and supplier 5.

Finally, the status of quality certificates is considered a criterion. These days when technology competition is most important, the concept of standardizing quality has emerged. Many organizations have various quality certificates showing that they meet the standards and quality accepted around the world. Especially supplier organizations that have ISO 9001 Quality Management System Certificates stand out for their customers. Having this certificate is proof that the supplier has adopted a policy of continuous improvement and a certain quality standard. In this case, suppliers with this certificate will have an advantage over their other competitors. Documenting processes, workflows, and application instructions are one of the biggest advantages of this document. On the other hand, one of the most important quality documents of the company is material certificates. According to the status of having ISO 9001 Quality Management System Certificate and sending the material certificate, the suppliers are ranked as follows: supplier 2, supplier 3, supplier 4, supplier 1, and supplier 5.

Secondly, before looking at fuzzy AHP definitions and applications, the concept of fuzzy logic will be examined. Fuzzy logic first entered the literature with the study titled "Fuzzy sets" published by Dr. Lütfi Askerzade Zadeh in 1965 (Ogrodnik, K. 2019). Fuzzy logic is especially difficult to understand and very complex, based on interpretation. It is useful in processes that rely on the fact of decision-making. Contrary to classical logic, in fuzzy logic, the truth values of certain propositions can take values as "1", "0" and "between zero and one" as true, false, and uncertain, respectively. With fuzzy logic applications, the alternatives that are in the classical logic principles and that indicate certainty are stretched, so that the alternatives are multiplied through models that also cover more uncertain situations, and the variables are graded in the light of certain rules (Wang, Y. M., Luo, Y., & Hua, Z. 2008).

It is aimed to solve complex and multidimensional problems related to variables that are uncertain, contradictory, and ambiguous and to make them manageable. Values that seem difficult to understand can provide mathematical models based on strong probabilities and predictions in non-linear situations where it is not possible to reach precise inputs because they are used in data delays. Since fuzzy logic is close to human logic, decisions taken using techniques that take this logic into account are more accurate. Since the weights of the criteria are taken as a certain range to decide the fuzzy AHP, it provides a more comfortable movement in the decisions. Because the analytic hierarchical process, which is one of the multi-criteria decision-making approaches, is not entirely adequate for making decisions in the face of uncertainty, a fuzzy analytic hierarchy process has been discovered by combining fuzzy logic with AHP. It is done by experts in the field at the decision-making stage, so there is a risk of subjectivity in the evaluation of the decision-making process, but this problem is avoided with the Fuzzy AHP (Çetintav, Ulutagay, Gürler and Demirel 2016a, 2016b). In most cases, a decision-maker will find an intermittent evaluation more credible than a precise value evaluation. Supplier selection for the company will be done during the research.

3 Literature Review

The information results on the themes and subheadings mentioned in this study were gathered from a variety of sources. The literature review began by investigating general concepts of the Fuzzy Analytical Hierarchical Process. The continuation of the literature review focused on implementations of AHP. As it is seen in the research that similar policies meet on common ground in implementations.

Companies should manage supply chain management more effectively because there is a hard competitive situation in the world. This study focuses on leather apparel companies. According to the company's expectations and criteria, managers must choose the most suitable suppliers. This choice is a critical decision issue in supply chain management. In the content of this study, firstly a Turkish leather apparel company was chosen. Then, this study focuses on a field survey about leather supply with purchasing managers of this company. To analyze the data, Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) methods are used. Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) approaches are used to choose the best provider. Furthermore, certain conclusions and recommendations for the firm and industry were presented in advance (Ofluoğlu, Nilay, Mutlu, and Atilgan 2017).

According to Vahidnia, Alesheikh, Alimohammadi, and Bassir (2008) because Analytical Hierarchy Process (AHP) is a multi-criteria decision-making process, AHP is particularly useful in challenges of a spatial character or that are GIS-based. Besides, this research focus on some points which are stages of the AHP, implementation of AHP, defects and abilities OF AHP, concepts of fuzziness, uncertainty, and ambiguity in expert decision-making. The research conclusions show a clear priority vector from the triangular fuzzy comparison matrix of Chang's fuzzy range analysis method and the cut-based approach of fuzzy AHP.

According to Putra et al. (2018), gem evaluation options require excellent ability to select and investigate the type of gem to be replaced. The variety of gemstones and buyers is an obstacle in itself if the information and people's ability to analyze the nature of the gemstone is negligible. The decision-making method used is the Fuzzy Analytic Hierarchy Process (FAHP) strategy, which is widely used in various disciplines. FAHP can easily adapt to many decision problems. This study proposes a decision-making system that uses the FAHP algorithm to analyze gem quality.

Abadi et al. (2018), focus on the process of selecting notebook brands among consumers in their study. Thanks to Fuzzy AHP (Analytical Hierarchy Process) to assist decision support system in the option of Notebook from decision support systems framed to aggrandizement all decision-process through assigning problems, choosing proper data, and defining the approaches were used to appraise the selection of options in the decision-making process.

The Analytical Hierarchy Process (AHP) could be a multi-criteria decision-making approach (MCDMA) that can be utilized to unravel complex choice issues. This ponders pointed to utilizing these objective applications to construct suppliers' choice demonstrate, utilizing competitive needs "quality, taken a toll, conveyance and adaptability" as an assessment and determination criteria. In the light of what the consider has concluded, the analyst prescribed the need of utilizing the Analytical Hierarchy process in making choices of selecting providers, particularly in chemical businesses segment, and other mechanical divisions as well, due to what this approach has of focal points and highlights for making complex choices (Hajar 2016).

One of the most important activities in supply chain management is supplier selection (SCM). Choosing the ideal supplier is a challenge for most small and medium-sized enterprises (SMEs) that use traditional approaches. A mixed multiple-criteria decision-making (MCDM) approach has been proposed to identify suppliers. This proposed system coordinates the Delphi method as a data acquisition tool with the analytic hierarchy process (AHP) as an MCDM strategy for information review. Both were used to select a successful supplier. This extension applies a Delphi strategy that allows specialists to choose most criteria and compares the trade-offs between available options according to most criteria. The criteria chosen were cost, transit time, online positioning, churn rate, and adaptability. Using the AHP approach, the criteria weights were acceptable at this point (Al Hazza, Abdelwahed, and Sidek 2022).

Design optimization is important in the improvement of efficient engineering products because using engineering judgment in the design and production of quality products is inevitable. Systems can show lots of failures because of lacking significant design criteria and lacking forecasting of their associated significance in the design and development of engineering. For vital design criteria of an engineering product need to be determined and their various level of importance (i.e. weights) defined using powerful engineering tools, Analytical Hierarchy Process (AHP) methodology was used (Nwaoha and Ashiedu 2015).

Supplier Evaluation is of expanding significance for companies and encourages trade advancement due to the truth that companies are concentrating on their center competencies. Following that, a prominent supplier assessment comprises all inside offices and their input approximately the supplier's execution to get an entire picture of the supplier's potential. This means that distinctive individuals are assessing suppliers due to their obligation which needs requires an organized handle for supplier assessment. Precisely this part is captured by AHP which guarantees that every single assessment for a supplier is embroiled within the add-up to picture assessment. The commonsense utilization of AHP in supplier assessment and determination is displayed with an expanded commerce illustration of Henkel in Germany upgraded by current trade patterns like hazard administration and the advantage to recognize best-in-class suppliers out of the supplier portfolio in a comparative approach (Politis, Klumpp, Celebi 2010).

4 Modeling and Solution Methodology

The steps of the Fuzzy Analytical Hierarchy Process are listed below (Polat, T.K., & Kaçmaz):

- As in the AHP method, determining the main and, if any, sub-criteria, with the support of experts and creation of the hierarchical model,
- Determination of pairwise comparisons of main and sub-criteria and the corresponding fuzzy numbers for these comparisons,
- Calculation of fuzzy importance weights of sub-criteria,
- Evaluation of alternatives using linguistic variables of each sub-criterion,
- Multiplying the fuzzy weights of the sub-criteria with the fuzzy evaluations of the alternatives and adding them to find the total score of each alternative,

- Clarifying the total scores of the alternatives.

Step 1. According to Saaty Scale Table 1, decision-maker class with criteria (suppliers) according to linguistic terms (Ayhan 2013).

Table 1. Saaty scale

Saaty scale	Definition		Fuzzy Triangular Scale		
1	Equally important	(Eq. Imp.)	(1,	1,	1)
3	Weakly important	(W. Imp)	(2,	3,	4)
5	Fairly important	(F. Imp.)	(4,	5,	6)
7	Strongly important	(S. Imp.)	(6,	7,	8)
9	Absolutely important	(A. Imp.)	(9,	9,	9)

The pairwise addition matrix is indicated in Eq. 1, where $\tilde{f}_{ij}^{k}$ demonstrates the k^{th} decision-maker's prediction of k i the criterion over j^{th} criterion, via fuzzy triangular numbers.

$$\tilde{M}^{k} = \begin{pmatrix} \tilde{f}_{11}^{k} \cdots \tilde{f}_{1n}^{k} \\ \tilde{f}_{21}^{k} \cdots \tilde{f}_{2n}^{k} \\ \tilde{f}_{n1}^{k} \cdots \tilde{f}_{nn}^{k} \end{pmatrix} \quad (1)$$

Step 2. If there is more than one decision maker, predilections of each decision maker $(\tilde{f}_{ij}^{k})$ are averaged and $(\tilde{f}_{ij}^{n})$ is computed as in the Eq. 2.

$$\tilde{f_{iJ}} = \frac{\sum_{k=1}^{k} \tilde{f}_{ij}^{k}}{k} \quad (2)$$

Step 3. Thanks to averaged predilections, pair wise addition matrix is updated as demonstrated in Eq. 3.

$$\tilde{M} = \begin{pmatrix} \widetilde{f_{11}} \cdots \tilde{f}_{1n} \\ \cdots \\ \widetilde{f_{n1}} \cdots \tilde{f}_{nn} \end{pmatrix} \quad (3)$$

Step 4. The geometric mean of fuzzy comparison values of each criterion is computed as demonstrated in Eq. 4. $\tilde{t}_i$ still symbolizes triangular values.

$$\tilde{t}_i = \left(\prod_{j=1}^{n} \tilde{f}_{ij} \right)^{1/n} \quad i = 1, 2, \ldots, n \quad (4)$$

Step 5. The fuzzy weight for each criterion can be found in Eq. 5 by integrating the following three substeps.

Step 5a. Calculate the vector collection of each.
Step 5b. Calculate the (−1) power of collection vector. Change the fuzzy triangular number, to make it in an increasing order.
Step 5c. In order to calculate the fuzzy weight of criterion i ($\tilde{w}_i$), multiply each $\tilde{t}_i$ with this reverse vector.

$$\begin{aligned}\widetilde{w}_i &= \widetilde{t}_i \otimes (\widetilde{t}_1 \quad \oplus \ldots\ldots\ldots \widetilde{t}_2)^{-1} \\ &= (lw_i, mw_i, uw_i)\end{aligned} \quad (5)$$

Step 6. Due to the fact that $\tilde{w}_i$ are still fuzzy triangular numbers, it needs to be defuzzy by the proposed centroid method.

$$\tilde{S}_i = \frac{lw_i + mw_i + uw_i}{3} \quad (6)$$

Step 7. $\tilde{S}_i$ is a non-fuzzy number but it needs to be normalized by following Eq. 7.

$$\widetilde{K}_i = \tilde{S}_i / \sum\nolimits_{i=1}^{n} \tilde{S}_i \quad (7)$$

Normalized weights for both the criteria and the alternatives are determined using these seven methods. Then generate the score for each choice by multiplying it by the criteria associated with the weight of each choice. Based on these results, the decision maker recommends the option with the highest score.

Excel program was used for calculations and operations. First, 5 evaluation criteria were evaluated with each other according to the Saaty Scale. You can see the calculated geometric averages in Table 2. In Table 3, the fuzzy weights of the criteria examined for the company were found. Values are normalized.

Table 2. Criteria with geometric mean

Quality	Geometric Mean		
	2.1689	2.5365	2.8619
Proximity	1	1.3099	1.6054
Price	0.8027	1	1.4309
On-time Delivery	0.5296	0.6443	0.8218
Quality Document Status	0.4013	0.4670	0.5743
Total	4.9026	5.9579	7.2946
Inverse	0.2039	0.1678	0.1370
Increasing Order	0.1370	0.1678	0.2039

Table 3. Fuzzy weights

Quality	Fuzzy Weight			(Average)	Normalized
	0.2973	0.4257	0.5837	0.4356	0.4135
Proximity	0.1370	0.2198	0.3274	0.2281	0.2165
Price	0.1100	0.1678	0.2918	0.1899	0.1803
On-time Delivery	0.0726	0.1081	0.1676	0.1161	0.1102
Quality Document Status	0.0550	0.0783	0.1171	0.0835	0.0792
Total				1.0533	1

5 Result and Discussion

Table 4 and Table 5 fuzzy AHP steps were applied according to criteria and suppliers. The order of suppliers to be selected by the firm according to the fuzzy AHP is as follows: supplier 1, supplier 2, supplier 3, supplier 4, and supplier 5. According to the result, the best supplier was determined as 1. According to the results, the best supplier 1 was determined, but when the purchase rates of the company in the previous year are examined, it has been observed that the highest number of suppliers has been worked with 3 so far.

Table 4. Weights according to criteria and suppliers

	Weights	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Quality	0.4135	0.3945	0.3258	0.1886	0.0622	0.0286
Proximity	0.2165	0.5841	0.1563	0.1486	0.0804	0.0303
Price	0.1803	0.3606	0.3858	0.1516	0.0707	0.0310
On-time Delivery	0.1102	0.4061	0.2659	0.1819	0.1191	0.0267
Quality Document Status	0.0792	0.3846	0.3726	0.1532	0.0610	0.0283

Table 5. Results

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Quality	0.1631	0.1347	0.0780	0.0257	0.0118
Proximity	0.1265	0.0338	0.0321	0.0174	0.0065
Price	0.0650	0.0695	0.0273	0.0127	0.0056

(*continued*)

Table 5. (*continued*)

	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
On-time Delivery	0.0447	0.0293	0.0200	0.0131	0.0029
Quality Document Status	0.0304	0.0295	0.0121	0.0048	0.0022
Sum	0.4299	0.2970	0.1697	0.0739	0.0292

6 Conclusion

In this study, firstly general information about the company is given. While examining the general information about the company, the stages of the company in the supply chain were observed. The focus is on supplier selection, which is one of the most important. Subsequently, the literature search continued. The first step of the literature research, started by examining the supplier selection criteria, which are important for companies. Considering the literature research, after examining many different criteria, the firm's quality department focused on 5 criteria (quality, proximity, on-time delivery, price, and quality document status). Afterward, the literature research focused on the fuzzy AHP part. Fuzzy AHP has been used in supplier selection because it is a method that determines the best for all criteria, transforms verbal uncertainty into numerical data, and determines the best alternative in the light of these numerical data. Applied to fuzzy AHP steps. Necessary calculations were made in the Excel program for the criteria examined. As a result of the calculations, the best supplier was determined as the 1st supplier.

For future studies, it is aimed to create a simulation by combining the Arena (Rockwell Arena) software with the evaluation criteria in other parts of the production and extending the fuzzy logic of the data type I am working with. Arena (Rockwell Arena) software will be a good evaluation tool in conjunction with fuzzy AHP as it allows comparisons for various scenarios in different production areas.

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Determining Graduate Level University Selection Criteria Weights by Using Type-2 Fuzzy AHP

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Abstract. University selection is a process where a person is affected by universities' education, culture, and other perspectives during their student years. While university selection consists of many criteria, graduate-level university selection is another concern since the applicant has experience with at least one university and the reason for application is somewhat different. Therefore, it is important to construct an analysis for the graduate level and define the most important criteria in the selection process. In this study, graduate-level university selection is discussed to explore the criteria with the highest priority to understanding the selection process. To achieve this objective, Type-2 Fuzzy AHP is used to construct the decision model and determine the criteria weights along with students to compare the criteria. The results show that professor quality, education quality, and professor choice are the highest-ranking criteria for graduate-level applications.

Keywords: University selection · Type-2 fuzzy sets · Analytic hierarchy process · AHP

1 Introduction

A person's career and life are determined by their education up to some degree. While the selection of primary school and high school may not be a choice, university selection is highly dependent on personal choice and one's choice builds upon various criteria. Although university selection also differs depending on the country's education system, it is important to recognize university education in different degrees. While an undergraduate degree can be pursued for different reasons, the main reason is mostly for getting a profession. Graduate-level education includes masters and Ph.D. degrees. Having a bachelor's degree in a similar field is mandatory for graduate applications. Therefore, an applicant for the graduate level already has experience in university selection and application processes. The objective of graduate-level university selection can be distinguished from other levels of school selection as it can be likely for academic purposes or, job seniority.

Having various criteria for university selection produces MCDM (Multiple Criteria Decision Making) problems. At first, it is important to determine the graduate-level

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university selection criteria, then using an MCDM method each criteria weight should be calculated. Better solutions can be obtained by using Fuzzy Logic in MCDM problems because fuzzy logic is efficient in linguistic variables. There are also extensions for fuzzy logic that can also be integrated with MCDM methods. In this study, the graduate-level university selection problem will be examined using the Type-2 Fuzzy AHP method where AHP is a frequently used method for decision making in the determination of criteria weights and Type-2 Fuzzy AHP is an extension of AHP.

This paper is sectioned as follows: a literature review of university selection criteria, methodology of Type-2 Fuzzy AHP, a numerical application explaining the decision model, and conclusions of the study.

2 Literature Review

The majority of the studies done in the university selection process handle undergraduate-level university selection. According to the literature review, there are no studies about graduate-level university selection criteria yet. Therefore, similar topics like undergraduate level university selection, major selection, and course selection literature are reviewed.

Undergraduate university selection can be analyzed from various perspectives as it may result in different outcomes because of factors like the country's education system, university application system, student demography, university departments, etc.

The selection criteria of a person can change over time. As the person gains more knowledge and experience about the topic, meaning that there can be different criteria or criteria weights among students in different grades. Strasser et al. (2002) studies the university major selection problem by examining university students from different grades, from freshmen to senior grade. According to Strasser et al. (2002)'s work, when selecting a major, seniors were more consistent than sophomores. Akkaş (2018) studies university selection criteria using high-school students from different grades and finds that prep grade students prioritize university selection, profession, and socio-demographic features respectively, but a year later once they become 9th-grade students, their priority changes to profession choice, university selection and socio-demographic features correspondingly which is similar to 12th-grade students.

Akkaş (2018) studies university selection criteria using a survey to identify the criteria and applies the Fuzzy Analytical Hierarchy Process. Out of many Fuzzy AHP techniques, Akkaş (2018) uses Buckey's method in weights of criteria and alternatives. Strasser et al. (2002) use previous studies but also survey the determination of criteria again using the AHP method. Bedir et al. (2016) apply AHP to postgraduate course selection problems to obtain weights of the alternative courses.

Akkaş (2018) categorizes selection criteria into three main categories as university selection, profession choice, and socio-demographic features with 33 sub-criteria overall. According to the research, under the criteria named university selection Akkaş (2018) uses 12 sub-criteria which all come from past research. Those criteria are: university's name/popularity, scholarship opportunities, type of the university, education language, taking courses from different departments, quota in the university department, technological facilities, cultural activities, connection with foreign universities, academic staff, university ranks in the entrance exams and social life in university (Akkaş 2018).

For the selection of a university, criteria like a foreign language, foreign connection, scholarship, popularity, and entrance score are found to be significant by Kılıç and Ayhan (2011). According to the research, it is found that the impact of the factors social and cultural properties, rank of the university considering its score, education language, popularity, and academic staff are in descending weights (Kılıç and Ayhan 2011). According to the Friedman analysis conducted by Ağaoğlu and Yurtkoru (2014), state universities, low tuition, and the reputation of the university have the highest importance in the selection process.

Mishra and Gupta (2021) study the selection criteria of private universities and colleges in Oman using undergrad students as a sample group. Location, reputation, and image, academic programs, academic staff quality, accreditation of the university, employment circumstances, foreign partner universities, advertisement of the university, career objectives, and lastly financial scope are determined as the most important criteria affecting the selection process of higher education institutes.

3 Methodology

The steps of Interval Type-2 Fuzzy AHP proposed by (Kahraman et al. 2014) are explained as follows:

Step 1. A decision model is developed based on the literature review and pairwise comparison matrices are constructed.

Step 2. The pairwise comparison matrices are transformed into Type-2 fuzzy matrices by using the linguistic scale given in Table 1.

Table 1. Definition and interval type-2 fuzzy scales of the linguistic variables (Kahraman et al. 2014)

Linguistic variables	Triangular interval type-2 fuzzy scales	Trapezoidal interval type-2 fuzzy scales
Absolutely Strong (AS)	(7.5,9,10.5;1) (8.5,9,9.5;0.9)	(7,8,9,9;1,1) (7.2,8.2,8.8,8.9;0.8,0.8)
Very Strong (VS)	(5.5,7,8.5;1) (6.5,7,7.5;0.9)	(5,6,8,9;1,1) (5.2,6.2,7.8,8.8;0.8,0.8)
Fairly Strong (FS)	(3.5,5,6.5;1) (4.5,5,5.5;0.9)	(3,4,6,7;1,1) (3.2,4.2,5.8,6.8;0.8,0.8)
Slightly Strong (SS)	(1.5,3,4.5;1) (2.5,3,3.5;0.9)	(1,2,4,5;1,1) (1.2,2.2,3.8,4.8;0.8,0.8)
Exactly Equal €	(1,1,1;1) (1,1,1;1)	(1,1,1,1;1,1) (1,1,1,1;1,1)
If factor I has one of the above linguistic variables assigned to it when compared with factor j, then j has the reciprocal value when compared with i	Reciprocals of above	Reciprocals of above

$$\tilde{\tilde{A}} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \ldots \tilde{\tilde{a}}_{1n} \\ \tilde{\tilde{a}}_{21} & 1 & \ldots \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\tilde{a}}_{n1} & \tilde{\tilde{a}}_{n2} & \ldots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \ldots \tilde{\tilde{a}}_{1n} \\ 1/\tilde{\tilde{a}}_{21} & 1 & \ldots \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{\tilde{a}}_{n1} & 1/\tilde{\tilde{a}}_{2n} & \ldots & 1 \end{bmatrix} \tag{1}$$

where

$$1/\tilde{\tilde{a}} = \left(\begin{array}{c} \left(\frac{1}{a_{14}^U}, \frac{1}{a_{13}^U}, \frac{1}{12}, \frac{1}{a_{11}^U};\ H_1\left(a_{12}^U\right), H_1\left(a_{13}^U\right) \right), \\ \left(\frac{1}{a_{24}^L}, \frac{1}{a_{23}^L}, \frac{1}{a_{22}^L}, \frac{1}{a_{21}^L};\ H_1\left(a_{22}^L\right), H_1\left(a_{23}^L\right) \right) \end{array} \right)$$

Step 3. The consistency of each fuzzy pairwise comparison matrix is examined.

Step 4. The geometric mean of each row is calculated. The geometric mean of each row $\tilde{\tilde{r}}_i$ is calculated as follows;

$$\tilde{\tilde{r}}_i = \left[\tilde{\tilde{a}}_{i1} \otimes \ldots \otimes \tilde{\tilde{a}}_{in}\right]^{\frac{1}{n}} \tag{2}$$

where

$$\sqrt[n]{\tilde{\tilde{a}}_{ij}} = \left(\left(\sqrt[n]{a_{ij1}^U}, \sqrt[n]{a_{ij2}^U}, \sqrt[n]{a_{ij3}^U}, \sqrt[n]{a_{ij4}^U}; H_1^u\left(a_{ij}\right), H_2^u\left(a_{ij}\right)\right),\right.$$
$$\left.\left(\sqrt[n]{a_{ij1}^L}, \sqrt[n]{a_{ij2}^L}, \sqrt[n]{a_{ij3}^L}, \sqrt[n]{a_{ij4}^L}; H_1^L\left(a_{ij}\right), H_2^L\left(a_{ij}\right)\right)\right)$$

Step 5. The fuzzy weight of the i$^{\text{th}}$ criterion is calculated as follows;

$$\tilde{\tilde{w}}_i = \frac{\tilde{\tilde{r}}_i}{\left[\tilde{\tilde{r}}_1 \oplus \ldots \oplus \tilde{\tilde{r}}_i \oplus \ldots \oplus \tilde{\tilde{r}}_n\right]} \tag{3}$$

where

$$\frac{\tilde{\tilde{a}}_{ij}}{\tilde{\tilde{b}}_{ij}} = \left(\frac{a_1^U}{b_4^U}, \frac{a_2^U}{b_3^U}, \frac{a_3^U}{b_2^U}, \frac{a_4^U}{b_1^U}, \min(H_1^U(a), H_1^U(b)\right), \min(H_2^U(a), H_2^U(b)))$$
$$\left(\frac{a_1^L}{b_4^L}, \frac{a_2^L}{b_3^L}, \frac{a_3^L}{b_2^L}, \frac{a_4^L}{b_1^L}, \min(H_1^L(a), H_1^L(b)\right), \min(H_2^L(a), H_2^L(b)))$$

Step 6. The steps are applied to each level of the decision matrix and the global weight of an alternative ($\tilde{\tilde{U}}_i$) is calculated by using Eq. 4.

$$\tilde{\tilde{U}}_i = \sum_{j=1}^{n} \tilde{\tilde{w}}c_j \otimes \tilde{\tilde{w}}a_{ij} \tag{4}$$

where $\tilde{\tilde{w}}c_j$ represents the weight of j^{th} criterion and $\tilde{\tilde{w}}a_{ij}$ is the weight of alternative i with respect to criterion j.

Step 7. The classical AHP method's procedure is applied to determine the best alternative.

4 Numerical Application

4.1 Decision Model

In accordance with previous research done on university selection criteria, it is also important to recognize the purpose of this study as it investigates another level of education. Therefore, literature cannot be the only source for criteria selection. Hence, an interview is formed to collect criteria from graduate-level Industrial Engineering students who study in universities located in Turkey. Criteria with the highest frequency are selected and categorized as 5 main, and 14 sub-criteria can be observed in Fig. 1.

According to initial research, 5 main criteria formed are Off-campus Opportunities, In-Campus Opportunities, Popularity, Research, and Education. And their sub-criteria are as follows: Housing, Transportation; Library, Social Life, Scholarship; University Ranking, Recommendation; Research Area, Professor Choice, R&D Opportunities, Publication/Conference Opportunities; Course Contents, Education Quality, and Professor Quality.

After determining the criteria, a questionnaire is conducted on five graduate-level Industrial Engineering students located in Istanbul. Additionally, by using the previous studies it can be understood that AHP is a commonly used methodology in academic selection problems. A questionnaire is implemented in the AHP structure as one should make multiple dual comparisons of main criteria as well as sub-criteria of each category. Trapezoidal fuzzy numbers are used in comparison matrices. This comparison results in criteria weights showing the relative importance of each main and sub-criteria.

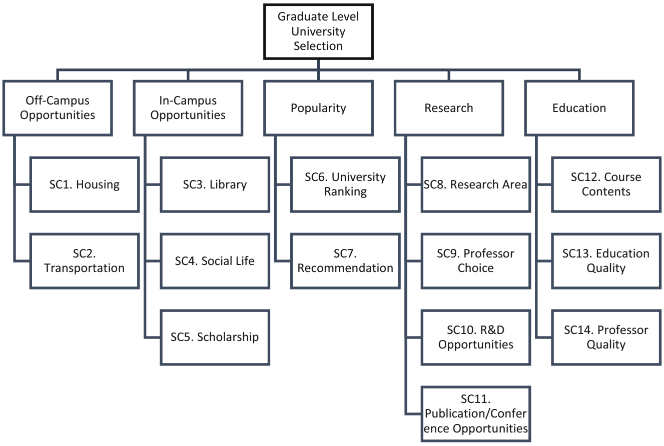

Fig. 1. Hierarchy of graduate-level university selection problem

4.2 Application

Step 1: Pairwise comparison matrices of both main and sub-criteria using linguistic scale are constructed as in Table 2 and Table 3.

Table 2. Pairwise comparison matrix for main criteria of student 1

	O	I	P	R	E
O	E	TFS	TW	TA	TA
I	FS	E	W	TVS	TVS
P	W	TW	E	TFS	TFS
R	A	VS	FS	E	E
E	A	VS	FS	TE	E

Table 3. Pairwise comparison matrix for sub-criteria Education(E) of student 1

E	C1	C2	C3
C1	E	TVS	TFS
C2	VS	E	FS
C3	FS	TFS	E

Step 2: Consistency ratios of pairwise comparison matrices for each student are checked. It has been found that both consistency ratios are under 0.1.

Step 3: Equation 2 is used to calculate the geometric means for each pairwise comparison matrix along with data in Table 4. Trapezoidal fuzzy numbers are used in the process. Geometric means of main criteria Off-Campus Opportunities (O) are calculated as follows:

$$\tilde{\tilde{r}}_1 = [\tilde{\tilde{a}}_{11} \otimes \tilde{\tilde{a}}_{12} \otimes \tilde{\tilde{a}}_{13} \otimes \tilde{\tilde{a}}_{14} \otimes \tilde{\tilde{a}}_{15}]^{\frac{1}{5}}$$

$$= [(1,1,1,1;1,1)(1,1,1,1;1,1)$$
$$\otimes (0.14,0.16,0.25,0.33;1,1)(0.14,0.17,0.23,0.31;0.8,0.8)$$
$$\otimes (0.2,0.25,0.5,1;1,1)\ (0.20,0.26,0.45,0.83;0.8,0.8)$$
$$\otimes (0.11,0.11,0.125,0.14;1,1)\ (0.11,0.11,0.12,0.13;0.8,0.8)$$
$$\otimes (0.11,0.11,0.125,0.14;1,1)(0.11,0.11,0.12,0.13;0.8,0.8)]^{\frac{1}{5}}$$
$$= (0.203, 0.219, 0.287, 0.368;\ 1, 1)\ (0.207, 0.225, 0.276, 0.346;\ 0.8, 0.8)$$

Step 4: Main and sub-criteria priority weights are calculated using Eq. 3. Priority weights of the main criteria in Table 2 are calculated using geometric means computed in Step 3 as Table 5.

Using data in Table 5, priority weights of Off-Campus Opportunities (O) for student 1 can be calculated as follows:

Table 4. Pairwise comparisons for the main criteria of student 1

	O	I	P	R	E
O	(1,1,1,1;1,1) (1,1,1,1;1,1)	(0.14,0.16,0.25,0.33;1,1) (0.14,0.17,0.23,0.31;0.8,0.8)	(0.2,0.25,0.5,1;1,1) (0.20,0.26,0.45,0.83;0.8,0.8)	(0.11,0.11,0.125,0.14;1,1) (0.11,0.11,0.12,0.13;0.8,0.8)	(0.11,0.11,0.125,0.14;1,1) (0.11,0.11,0.12,0.13;0.8,0.8)
I	(3,4,6,7;1,1) (3.2,4.2,5.8,6.8;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(1,2,4,5;1,1) (1.2,2.2,3.8,4.8;0.8,0.8)	(0.11,0.125,0.16,0.2;1,1) (0.11,0.12,0.16,0.19;0.8,0.8)	(0.11,0.125,0.16,0.2;1,1) (0.11,0.12,0.16,0.19;0.8,0.8)
P	(1,2,4,5;1,1) (1.2,2.2,3.8,4.8;0.8,0.8)	(0.2,0.25,0.5,1;1,1) (0.2,0.26,0.45,0.83;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(0.14,0.16,0.25,0.33;1,1,0.14) (0.17,0.23,0.31;0.8,0.8)	(0.14,0.16,0.25,0.33;1,1) (0.14,0.17,0.23,0.31;0.8,0.8)
R	(7,8,9,9;1,1) (7.2,8.2,8.8,8.9;0.8,0.8)	(5,6,8,9;1,1) (5.2,6.2,7.8,8.8;0.8,0.8)	(3,4,6,7;1,1) (3.2,4.2,5.8,6.8;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(1,1,1,1;1,1) (1,1,1,1;1,1)
E	(7,8,9,9;1,1) (7.2,8.2,8.8,8.9;0.8,0.8)	(5,6,8,9;1,1) (5.2,6.2,7.8,8.8;0.8,0.8)	(3,4,6,7;1,1) (3.2,4.2,5.8,6.8;0.8,0.8)	(1,1,1,1;1,1) (1,1,1,1;1,1)	(1,1,1,1;1,1) (1,1,1,1;1,1)

Table 5. Geometric means of pairwise comparison matrix for the main criteria of student 1

O	(0.203, 0.219, 0.287, 0.368; 1, 1) (0.207, 0.225, 0.276, 0.346; 0.8, 0.8)
I	(0.517, 0.659, 0.922, 1.069; 1, 1) (0.548, 0.685, 0.894, 1.038; 0.8, 0.8)
P	(0.332, 0.425, 0.659, 0.889; 1, 1) (0.352, 0.443, 0.628, 0.828; 0.8, 0.8)
R	(2.536, 2.861, 3.365, 3.553; 1, 1) (2.604, 2.923, 3.311, 3.509; 0.8, 0.8)
E	(2.536, 2.861, 3.365, 3.553; 1, 1) (2.604, 2.923, 3.311, 3.509; 0.8, 0.8)

$$\begin{aligned}
\tilde{\tilde{w}}_1 &= \tilde{\tilde{r}}_1 \otimes [\tilde{\tilde{r}}_1 \oplus \ldots \oplus \tilde{\tilde{r}}_i \oplus \ldots \oplus \tilde{\tilde{r}}_5]^{-1} \\
&= (0.203, 0.219, 0.287, 0.368;\ 1, 1)(0.207, 0.225, 0.276, 0.346;\ 0.8, 0.8) \\
&\otimes [(0.203, 0.219, 0.287, 0.368;\ 1, 1)(0.207, 0.225, 0.276, 0.346;\ 0.8, 0.8) \\
&\oplus (0.517, 0.659, 0.922, 1.069;\ 1, 1)(0.548, 0.685, 0.894, 1.038;\ 0.8, 0.8) \\
&\oplus (0.332, 0.425, 0.659, 0.889;\ 1, 1)(0.352, 0.443, 0.628, 0.828;\ 0.8, 0.8) \\
&\oplus (2.536, 2.861, 3.365, 3.553;\ 1, 1)(2.604, 2.923, 3.311, 3.509;\ 0.8, 0.8) \\
&\oplus (2.536, 2.861, 3.365, 3.553;\ 1, 1)(2.604, 2.923, 3.311, 3.509;\ 0.8, 0.8)]^{-1} \\
&= (0.022, 0.026, 0.041, 0.060; 1, 1)(0.022, 0.027, 0.038, 0.055; 0.8, 0.8)
\end{aligned}$$

Same calculation steps are followed for each main and sub-criteria shown in Table 6.

Table 6. Type-2 fuzzy weights of main and subcriteria according to student 1

Priority weights	
with respect to the main criteria	
O	(0.022,0.026,0.041,0.060;1,1) (0.022,0.027,0.038,0.055;0.8,0.8)
I	(0.055,0.077,0.131;1,1) (0.059,0.081,0.124,0.164;0.8,0.8)
P	(0.035,0.049,0.094;1,1) (0.038,0.053,0.087;0.8,0.8)
R	(0.268, 0.332, 0.478, 0.580; 1, 1) (0.282, 0.347, 0.459, 0.555;0.8, 0.8)
E	(0.268, 0.332, 0.478, 0.580; 1, 1) (0.282, 0.347, 0.459, 0.555; 0.8, 0.8)

(*continued*)

Table 6. (*continued*)

Priority weights	
with respect to O	
SC1	(0.5, 0.5, 0.5, 0.5; 1, 1) (0.5, 0.5, 0.5, 0.5, 1, 1)
SC2	(0.5, 0.5, 0.5, 0.5, 1, 1) (0.5, 0.5, 0.5, 0.5, 1, 1)
with respect to I	
SC3	(0.048,0.064,0.120,0.187;1,1) (0.051,0.068,0.0111,0.169;0.8,0.8)
SC4	(0.148, 0.211, 0.436, 0.747; 1, 1) (0.160, 0.226, 0.401, 0.655; 0.8, 0.8)
SC5	(0.254, 0.423, 0.873, 1.278; 1, 1) (0.287, 0.459, 0.814, 1.175; 0.8, 0.8)
with respect to P	
SC6	(0.5, 0.5, 0.5, 0.5; 1, 1) (0.5, 0.5, 0.5, 0.5, 1, 1)
SC7	(0.5, 0.5, 0.5, 0.5, 1, 1) (0.5, 0.5, 0.5, 0.5, 1, 1)
with respect to R	
SC8	(0.181, 0.338, 0.791, 1.254, 1, 1) (0.211, 0.372, 0.729, 1.130, 0.8, 0.8)
SC9	(0.085, 0.128, 0.252, 0.391, 1, 1) (0.094, 0.137, 0.235, 0.353, 0.8, 0.8)
SC10	(0.092, 0.142, 0.300, 0.515, 1, 1) (0.102, 0.153, 0.276, 0.452, 0.8, 0.8)
SC11	(0.041,0.060, 0.150, 0.344, 1, 1) (0.044,0.064, 0.133, 0.278, 0.8, 0.8)
with respect to E	
SC12	(0.044, 0.054,0.086, 0.116, 1, 1) (0.046, 0.056,0.081, 0.109, 0.8, 0.8)
SC13	(0.431, 0.562, 0.901, 1.146, 1, 1) (0.456, 0.591, 0.860, 1.090, 0.8, 0.8)
SC14	(0.132, 0.170, 0.283, 0.382, 1, 1) (0.139, 0.179, 0.268, 0.358, 0.8, 0.8)

Step 5: Fuzzy weights of main criteria are defuzzified. Local fuzzy weights of sub-criteria are also defuzzified using data in Table 6. Defuzzified weights are normalized and crisp weights are found as in Table 7 and Fig. 2.

Table 7. Normalized crisp weights of criteria O according to student 1

Main criteria	Student	Normalized crisp weights
O	S1	0.035
	S2	0.028
	S3	0.184
	S4	0.112
	S5	0.069

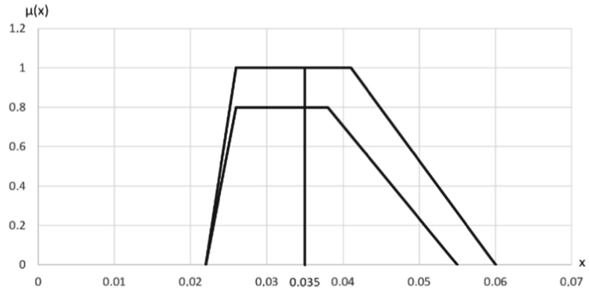

Fig. 2. Defuzzified value of O

Step 6: Using main criteria weights and sub-criteria local weights, global weights of sub-criteria are calculated. Crisp priority weights according to student 1 can be seen in Table 8. An overall result is found using the crisp weights of each criterion for each student by taking the arithmetic average of the weights shown in Table 9.

Table 8. Crisp priority weights of student 1

Main criteria	Weight	Sub-criteria		Local weight	Global weight	Global Rank
Off-Campus Opportunities	0.035	SC1	Housing	0.500	0.017	12
		SC2	Transportation	0.500	0.017	13
In-Campus Opportunities	0.103	SC3	Library	0.088	0.009	14
		SC4	Social Life	0.320	0.033	10
		SC5	Scholarship	0.593	0.061	6
Popularity	0.076	SC6	University Ranking	0.500	0.038	8
		SC7	Recommendation	0.500	0.038	9
Research	0.393	SC8	Research Area	0.508	0.200	2
		SC9	Professor Choice	0.170	0.067	5
		SC10	R&D opportunities	0.207	0.081	4
		SC11	Publication/ Conference Opportunities	0.114	0.045	7
Education	0.393	SC12	Course Contents	0.069	0.027	11
		SC13	Education Quality	0.706	0.278	1
		SC14	Professor Quality	0.224	0.088	3

Table 9. Final results and weights of criteria and sub-criteria

Criteria	Weight	Sub-criteria	Local weight	Global weight	Local rank	Global rank
Off-Campus Opportunities	0.085	Housing	0.565	0.048	1	8
		Transportation	0.435	0.037	2	12
In-Campus Opportunities	0.078	Library	0.174	0.014	3	14
		Social Life	0.257	0.020	2	13
		Scholarship	0.569	0.045	1	10
Popularity	0.125	University Ranking	0.640	0.080	1	6
		Recommendation	0.360	0.045	2	9
Research	0.357	Research Area	0.240	0.086	3	5
		Proffessor Choice	0.308	0.110	1	3
		R&D opportunities	0.259	0.092	2	4
		Publication/ Conference Opportunities	0.194	0.069	4	7
Education	0.354	Course Contents	0.109	0.039	3	11
		Education Quality	0.392	0.139	2	2
		Professor Quality	0.499	0.177	1	1

Table 10. Final weights of main criteria for each student separately

Ranking	E1	E2	E3	E4	E5
1st	Research (0.393)	Popularity (0.304)	Education (0.387)	Research (0.455)	Education (0.480)
2nd	Education (0.393)	Research (0.304)	Research (0.357)	Education (0.208)	Research (0.276)
3rd	In-Campus Opportunities (0.103)	Education (0.304)	Off-Campus Opportunities (0.184)	Popularity (0.171)	In-Campus Opportunities (0.139)
4th	Popularity (0.076)	In-Campus Opportunities (0.060)	Popularity (0.037)	Off-Campus Opportunities (0.112)	Off-Campus Opportunities (0.069)
5th	Off-Campus Opportunities (0.035)	Off-Campus Opportunities (0.028)	In-Campus Opportunities (0.035)	In-Campus Opportunities (0.054)	Popularity (0.036)

5 Conclusion

Following the Type-2 Fuzzy AHP methodology used in this study, according to a separate analysis of each student presented in Table 10, for student 1 while education and research have the highest and the same priority weights, for Student 2 popularity, research and education share the highest and the same priority. Ranking of the criteria and criteria weights vary depending on the student.

According to the overall results of the study group of five graduate-level students presented in Table 9, the criteria with the highest priority weight for graduate-level university selection are found to be professor quality, education quality, professor choice, R&D opportunities, research area, and university ranking, while other criteria have less priority. The priority ranking of the main criteria is in the order of research, education, popularity, off-campus opportunities, and on-campus opportunities.

Gathering criteria from previous studies guided the determination of criteria for graduate-level university selection in the initial process. And studies show that outcomes can be affected by many factors. Therefore, the characteristics of the sample group is also important for the study. Since this study analyzes only five graduate-level students from Istanbul, Turkey, it would not be correct to generalize the results. Future research based on graduate-level university selection criteria should focus on more students for the generalization of the problem to a degree.

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A System Proposal for Monitoring Ergonomic Risks at Workstations in a Manufacturing Company

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Abstract. In every industry, managing costs and increasing productivity and quality at the same time is one of the important goals. For this purpose, companies today pay attention to the workers' health by focusing more on ergonomic risk assessments and improvements and trying to prevent work-related musculoskeletal disorders in every part of the workplace. In most industrial workplaces, there is a shortage of resources for ergonomic improvements and a lack of attention to ergonomic issues because the production concern is at the forefront and this causes a high rate of occupational diseases. This results in less productivity and higher costs in long term. There are different examples of expert systems or software around the world established to be used for ergonomic assessments and risk monitoring, and it is critical to develop and use the most appropriate system for risk assessment and operator assignment to reach the best results in terms of productivity and minimization of occupational diseases. It also saves time compared to manual tracking and assignment processes as it is faster through software and helps prevent wastage of paper in most cases.

Keywords: Ergonomics · REBA · Expert system · Risk assessment

1 Introduction

Cost reduction in every way is one of the main issues companies face while they are trying to compete with other competitors in the industry. As inappropriate working postures cause workers to feel uncomfortable during work and various Work-Related Musculoskeletal Disorders (WMSDs) emerge depending on the body part of the exposure, providing a healthy work environment designed according to ergonomic standards is crucial along the way to reducing costs (Pulat 1997). Many different direct costs affect the overall company performance, productivity, and quality negatively which is mainly caused by absenteeism, a decrease in the number of workers, and less working time (Moradi et al. 2017). Therefore, it is very crucial to spend enough time on ergonomic issues and create a healthier work environment to lower the risks or eliminate them if it is desired to reduce the costs of the company and become more competitive.

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WMSDs are a big issue in today's industrial world as more and more people are needed in industrial work due to the growing demand for the production of different kinds of products and services. In the global aspect, it is stated that disability-adjusted life years increased between the years 1990 and 2016 by 61.6% and the percentage of WMSDs increased between 14% and 42%. As it is important to keep workers safe while continuing production and it is obvious that the incidence of WMSDs increased in the past years, ergonomic risk assessment comes up as a critical point to be considered and applied in the workplace. Many different methods focusing on different areas and risk factors are used to determine the risks which affect workers and make it possible to solve the health-related issues before they become irreversible (Hita-Gutiérrez et al. 2020).

REBA is one of those methods that is a postural analysis method examining the body parts which are the neck, trunk, legs, upper and lower arms, and wrist along with the activity, load force, and coupling factors. The method tries to determine the risk of one or more WMSDs by dividing the body into the pre-mentioned parts and examining the angles to find the scores from the tables provided. All the static, dynamic, unstable, or rapidly changing moves can be analyzed using this method as it embraces the body as a whole. Another point that makes REBA valuable for ergonomic risk assessment studies is that it also attaches importance to the type of coupling and activity, its ease of application, and the fact that it gives an output about the urgency level of action (Hignett and McAtamney 2000).

Not only the determination of risks but also recording and tracking them for the sustainability of the overall benefit of a system is vital. Many different systems, which are usually called expert systems, are currently being used for this purpose. Expert systems serve as a tool to keep information on ergonomic risks in a workplace and enable risk tracking. They can also be used to make decisions about workers according to the risk level of different jobs and the state of health of the worker. The most distinguishing feature of an expert system is its ease of use which makes it possible to use it without difficulty and make decisions for users at different levels of skill (Sak 2014). Expert systems evolved since their applications and the needs and main concerns are shaped differently according to the era. These systems firstly emerged at the beginning of the 1970s but they could not get beyond the prototype stage because of the expensiveness of meeting the hardware and software requirements. When the 1980s arrived, technology advanced, and the studies were mostly focused on the use of anthropometric data to improve the wellness of the workplace. It aimed to achieve the goal of a better work environment by getting the optimal fit between the physical properties of both the workers and the equipment (Pavlovic-Veselinovic et al. 2016).

Some systems focus on manual material handling operations and related risks such as LIFTAN. It is a system that is based on 149 rules composed of task and operator-related risks, recommendations for the redesign of jobs, and explanations related to the workers. It is directing the user to provide the information that the system needs and has an interface that enables the user to monitor the results of the analysis done (Karwowski et al. 1986). Another example of expert systems dealing with manual material handling operations was introduced in the late 1980s. It considers the characteristics of the workers such as weight, height, age, and knowledge level about the task; information about lifting tasks like the weight and size of the object, frequency, and load height; and finally, the environmental factors such as temperature and vibration. Using these inputs, the system calculates the risk level of the task and gives feedback about the maximum favorable weight that should be lifted (Genaidy et al. 1987, Kabuka et al. 1988).

In the 1990s, a variety of other expert systems were developed to determine the possibility of Cumulative Trauma Disorders (CTD). Moynihan et al. (1995) proposed one of the examples of this type of system that is called ERGONOMIST V, which was created by using fuzzy set algorithms and is concentrated on 29 risk factors for every one of CTDs. The process starts with the calculation of severity values of each CTD and then, gives the results to the user. These values are turned into numeric values by the system to sort them in descending order to bring out the output by applying an algorithm. Gilad and Karni (1999) built another system called ERGO-EX which is more extensive and can calculate the risk for a worker by examining the input data about anthropometric measures of the worker, dimensions of the layout of the worker's workplace, information about the task, and the equipment used, and environmental factors. It uses the related data with pre-defined methods and according to the results, the system makes recommendations and suggestions on how to improve the workplace design and prevent risks.

As there are many examples of expert systems focusing on manual material handling operations and CTD estimation, it is aimed to propose a system that mainly focuses on assembly operations with various repetitive tasks in this study. The fundamental inputs of the study are the skill matrix information, health restriction, training details of the workers, and the risk analysis results of the workstations that are obtained from the manufacturing company that the study was held, and the main aim is to create a system that can be used both for risk assessment and appropriate worker assignment process considering all the inputs. The research process is structured regarding this information, as can be seen in Fig. 1.

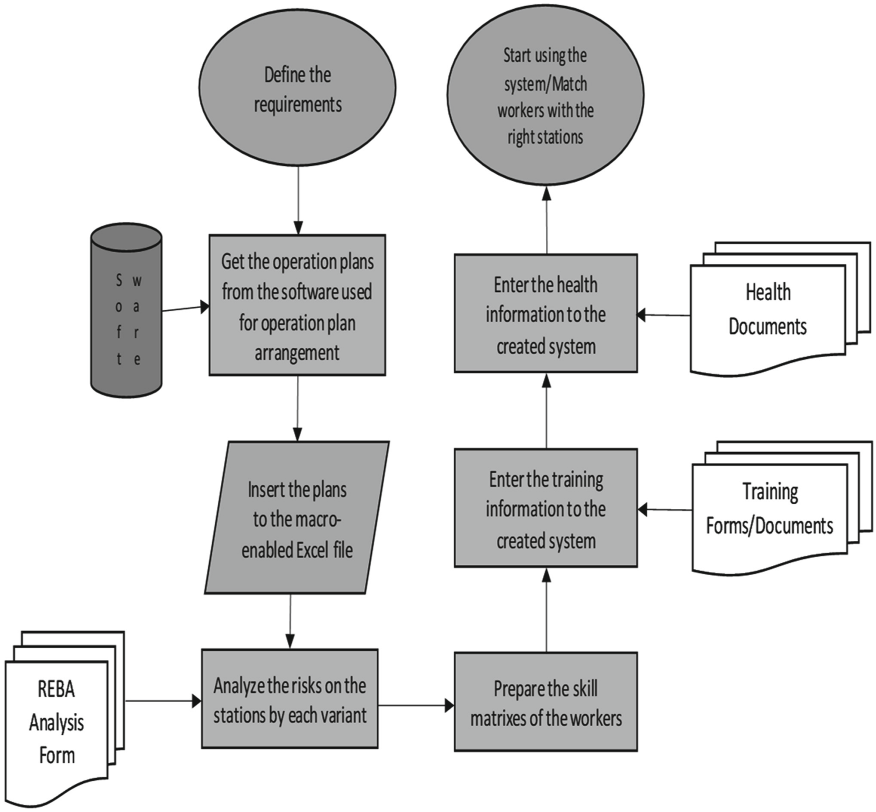


Fig. 1. Model of the study

1.1 The Characteristics of the Company

The company in which the study is held in is one of the big-scale manufacturing companies in the Turkish household appliances industry with several plants in different locations producing different products. The application for this study was held in one of the company's plants which produce clothes dryers with a wide range of personnel. Assembly lines of the plant are included in the scope of study to examine the risks and apply the proposed system. There are a total of 89 stations on the assembly lines that consist of different repetitive tasks such as grouping and screwing which cause loading on different parts of the body. As the company produces different types of dryers for different countries around the world, there are dozens of variants built by assembling hundreds of parts in various ways. As this is the case, operation steps may differ in order or application from one variant to another, and there exists a necessity to examine the risks for each separately.

2 Data and Application

2.1 REBA Analysis Form

For all stations, operation plans, seen in Fig. 2, are retrieved from the software to be used for the analysis phase. These plans have the steps to be followed on the stations, the station names and numbers, and operation codes that separate one from another. These plans in Excel format are inserted into an Excel file created using VBA codes to perform a step-by-step REBA analysis of each station.

Workstation number	Workstation	Resource	Process number	Process
U80-U80	ANAKART_1 - ECOBOX_1	Ana Kart Montajı	ana.kart.20	Ana kartı ve kablo gr. kasadan al
U80-U80	ANAKART_1 - ECOBOX_1	Ana Kart Montajı	ana.kart.30	Anakart Kablo gr. 1 nolu sokete takarak tutucu kanalından geçir
U80-U80	ANAKART_1 - ECOBOX_1	Ana Kart Montajı	ana.kart.40	Anakart 2 - 5 ve 6 nolu soketleri tak
U80-U80	ANAKART_1 - ECOBOX_1	Ana Kart Montajı	ana.kart.100	Ana kartı sağ destek braketine tak
U80-U80	ANAKART_1 - ECOBOX_1	Ana Kart Montajı	100	Butona Bas Paleti Gönder (Transfer)
U95-U95	B.BOX SOKET KAPAĞI	B.box Soket Kapağı Montajı	bb.30	Blackbox soket kapağını tak
U95-U95	B.BOX SOKET KAPAĞI	B.box Soket Kapağı Montajı	Kntrl.bb.01	B.box Soketlerin tam oturduğunu ekrandan kontrol et.
U95-U95	B.BOX SOKET KAPAĞI	B.box Soket Kapağı Montajı	bb.40	Soket Kablosu tutucusunu destek braketine tak
U95-U95	B.BOX SOKET KAPAĞI	B.box Soket Kapağı Montajı	100	Butona Bas Paleti Gönder (Transfer)
U255-U245	VİDA MONTAJI	Arka Duvar Vida Montajı	akpk.20.22	Isıtıcı Kapağını 16 ve 17 nolu konumdan sabitle
U255-U245	VİDA MONTAJI	Arka Duvar Vida Montajı	ypnl.12.07	Yan Paneli L3 konumundan sabitle
U255-U245	VİDA MONTAJI	Arka Duvar Vida Montajı	ypnl.12.06	Yan Paneli L2 konumundan sabitle
U255-U245	VİDA MONTAJI	Arka Duvar Vida Montajı	100	Butona Bas Paleti Gönder (Transfer)

Fig. 2. Operation plans

In the main section, a window opens to make the user choose an option to continue the desired operation, which can be seen in Fig. 3. The window contains six options

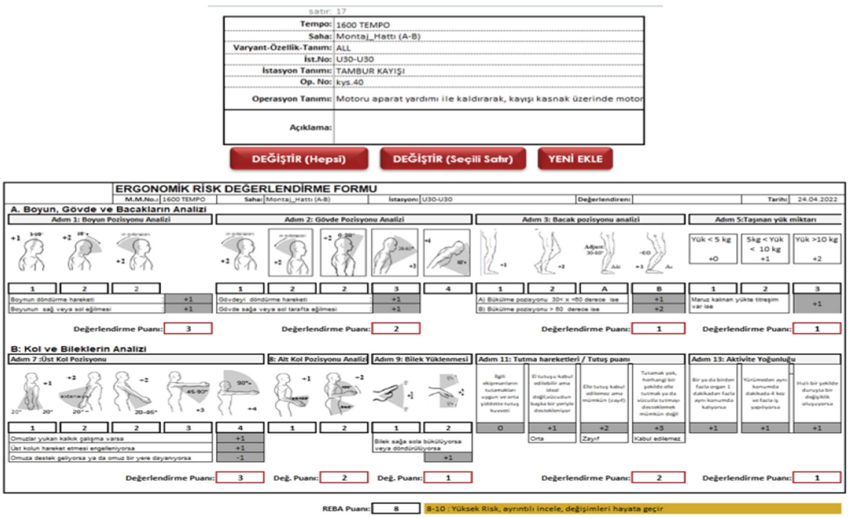


Fig. 3. REBA analysis sheet

including different analysis methods and data retrieving and storing. When one of the methods is chosen for a station to perform analysis, the code directs the user to the related form. For this study, the REBA form, shown in Fig. 4, is used.

The user should retrieve the plan details from the Excel sheet containing operation plans by clicking the button “Avix Verisi Ekle”, partaking in Fig. 4. This action gets the details of production tempo, station names and numbers, operation/process names and definitions, and material information seriatim.

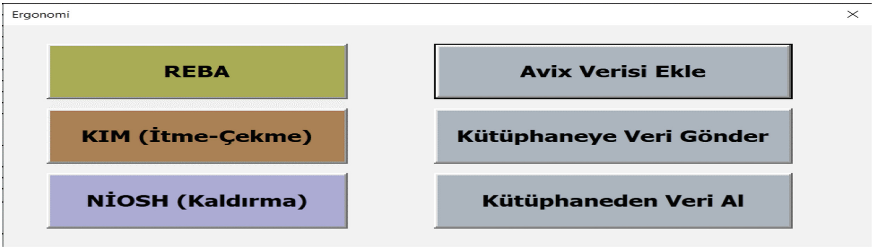


Fig. 4. Options window

After an analysis score is entered, the user can record this score to a library created to store analysis scores by an operation to reach them later when needed. To record the scores to the library, the user must click the button “Kütüphaneye Veri Gönder”. Once a score is recorded, the user can later retrieve it from the library to the main section. When the “Kütüphaneden Veri Al” button is clicked, codes enable the user to assign the same score to the operations with the same operation/process number of that related score. On the library that is demonstrated in Fig. 5, operation and material details, analysis method, overall and individual risk scores, the meaning of the scores, evaluator and his/her notes (if any), and date information is shown.

Operation					Result					REBA Scores								
Op. No	Operation Definition	Material 1	Material 2	Material 3	Analysis	Analysis Score	Score Detail	Evaluator Notes	Evaluator	Neck	Trunk	Legs	Load	Upper Arm	Lower Arm	Wrist	Coupling	Activity
100	Butona Bas Paleti Gönder (Transfer)				REBA	2	1-4 : Düşük Risk, belki değişim gerekebilir		26074126-12.04.2022	2	1	1	0	2	1	1	0	1
tmbr.50	Tambur miline 2. pul ve zeeger tak				REBA	6	5-7 : Orta Düzeyde Risk, daha fazla analiz gerekli, orta vadede değişim gerekli		26074126-12.04.2022	2	2	1	0	4	2	1	1	1
sasi.20	Su toplayıcı parçayı şasideki yerine tak	SU_TOPLAYICI			REBA	5	5-7 : Orta Düzeyde Risk, daha fazla analiz gerekli, orta vadede değişim gerekli		26074126-12.04.2022	2	2	1	0	3	1	2	1	1
mtr.3.70	Kablo Kanalını Arka duvardaki yerine tak				REBA	7	5-7 : Orta Düzeyde Risk, daha fazla analiz gerekli, orta vadede değişim gerekli		26074126-12.04.2022	2	3	2	0	3	1	2	1	1
akgr.10.53	Kelepçe fazlalığını kes				REBA	6	5-7 : Orta Düzeyde Risk, daha fazla analiz gerekli, orta vadede değişim gerekli		26074126-12.04.2022	2	2	2	0	3	1	2	1	1
kys.30	Kayışın tambur üzerinde düzeltme işlemini yap				REBA	4	1-4 : Düşük Risk, belki değişim gerekebilir		26074126-12.04.2022	1	2	1	0	3	2	1	0	1
kys.50	Tamburu çevirerek kayışı düzelt, doğru gruplandığını kontrol et				REBA	4	1-4 : Düşük Risk, belki değişim gerekebilir		26074126-12.04.2022	2	2	1	0	3	2	1	0	1
mtr.10.10	Motor ve topraklama soketini tak				REBA	4	1-4 : Düşük Risk, belki değişim gerekebilir		26074126-12.04.2022	2	2	1	0	2	1	1	1	1
kys.20	Motor gergi yayını al ve motor miline tak	KAYIS_GERGI_YAYI			REBA	4	1-4 : Düşük Risk, belki değişim gerekebilir		26074126-12.04.2022	2	2	1	0	2	1	1	1	1
ydb.40	Sağ Braketi al, gövdedeki yerine yerleştir	SAG_YAN_DES TEK_BRAKETI			REBA	3	1-4 : Düşük Risk, belki değişim gerekebilir		26074126-12.04.2022	2	1	1	0	3	1	1	1	1

Fig. 5. Analysis results library

Following these steps, all stations of assembly lines are examined, and risk scores are recorded in the library. After REBA analysis is done, results in the main section have shown that 56% of the stations are on the lower risk level. On the other hand, 6,74% of the stations have high and 2,24% of the stations have very high risks in terms of the movements occurring during repetitive tasks.

Although more than half of the stations have low risks, it is seen in Fig. 6, that there are a high number of stations that can cause intermediate and high-level loadings and related consequences. As many workers may have health issues caused by various reasons, the importance of assigning the worker to the right station increases.

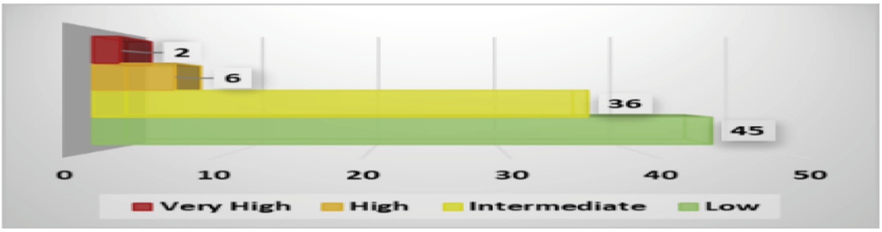


Fig. 6. Risk distribution of the stations

2.2 Skill Matrix

Preparing the skill matrixes for each worker follows the analysis and recording step in the process. A skill matrix is a structure that shows the condition of the worker based on his ability to perform the desired task on a station, as presented in Fig. 7. This matrix contains the difficulty levels of each station, and if a worker is capable of doing the work on that station, the related cell is marked to show the worker's competence. After the matrix is completed, it gives each station to be considered to make that worker work there and the total number of stations he or she can work. This structure prevents inappropriate assignment of a worker and shows the options clearly. Skill matrixes will be integrated into the system as well, to provide better matches.

Stations / OPERATOR NAME-SURNAME	Tambur Takma	Arka Duvar Takma	Isıtıcı Takma	Pano Soket Takma	Blacbox Soket Takma	Ana Kart Takma	Devirme İstasyonu	Tamir İstasyonu	Pompa Kapağı Takma	Parazit Soket Takma	Segman Takma	Yan Panel Takma İstasyonu	Tambur Kayışı ve Yay Takma	Braket Takma	Motor Takma	Tekmelik Takma	Ön Kapak Takma	Su Tankı Takma	Ana Kablo Sarma	Fonksiyon Test	Pano Gruplama Operasyonları	Tip Etiketi	Test ve Yazılım Yükleme	Ön Duvar Takma	Askıdan Alma Yan Duvar-Ön Duvar Alma	Conta Takma	Vida Montajı	Kablo Sarma	Malzeme Montajları (ön yatak ,şasi, kapı switch,pano, ısı kalkanı, kondanser, filtre, vb.	Total Number of Stations to Work
K**** Ö****																														
M***** K*****	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	29
C**** S*****	x	x							x		x	x	x	x	x	x	x	x						x	x	x	x	x	x	17
B***** A*** K****																									x	x	x	x	x	5
M*** K****															x												x		x	3
İ***** A*******			x	x	x		x	x	x		x	x			x	x	x	x	x						x	x	x	x	x	18
K**** G******												x			x	x	x	x							x	x	x	x	x	10
A** T*******																x		x	x						x	x	x	x	x	8
M**** B******															x	x			x						x	x	x	x	x	8
E*** D*****																x	x									x	x	x	x	6
G***** A****																x					x					x	x	x	x	6
S***** D****																x	x								x	x	x	x	x	7
S**** Ç*******																										x	x	x	x	4

A — Class A - High-Level Difficulty Operations

B — Class B - Intermediate-Level Difficulty Operations

C — Class C - Low-Level Difficulty Operations

M — Master Operator

Fig. 7. A skill matrix example

2.3 Main Page and Skill Matrix Part

To insert analysis results, skill matrixes, and training and health information of the operators into the system, the user should choose the action he/she deserves to perform on the main menu of the program. There are 6 options that can be selected, as can be seen in Fig. 8. Users can insert new data for different parts or change the current ones and make assignments of the operators to appropriate stations. When one of the options is chosen, the system directs the user to another page related to the desired action.

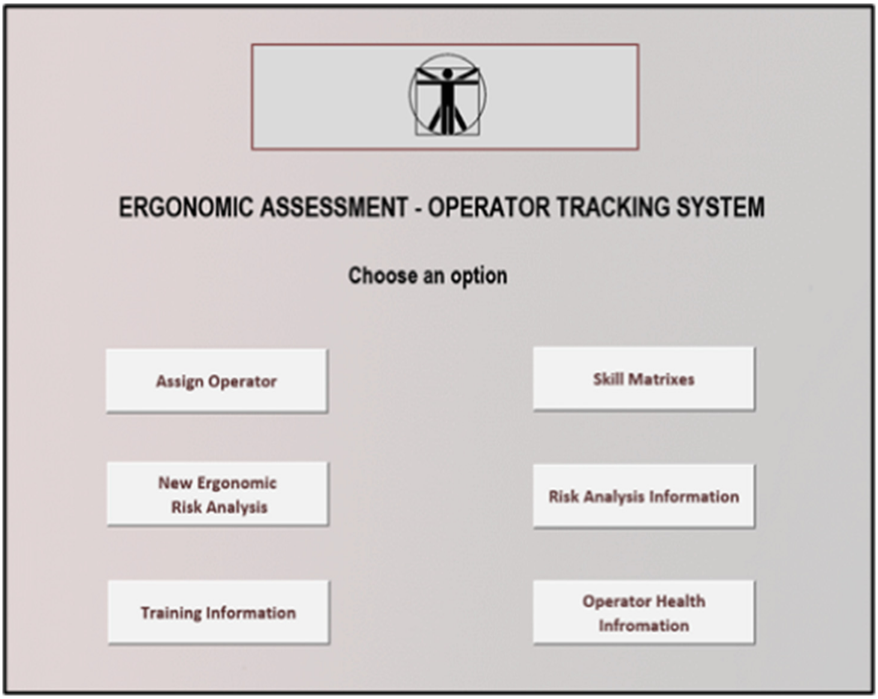


Fig. 8. Main page

In the Skill Matrixes part, two options appear in the first place and ask the user if he/she wants to view and/or change the existing skill matrix information of an operator or create a new skill matrix for a different person.

If the user selects the option "View an Existing Matrix", a new page that is seen in Fig. 9 pops up on the screen and leads the user to operator selection from a list. When the operator's name is selected, information about that operator appears on the screen which includes the operator ID, cost center, current station that he/she is working, and the total number of stations he/she is allowed to work at. Furthermore, all the operations on the assembly lines are listed below with their difficulty levels. If the operator can work on that station and perform the related task, a score of 1 is given right next to that operation and the competency level of the operator can also be entered. 1 is equal to the lowest level of competency while 4 means the competency of the operator for the related operation is at the highest level possible. It is probable to change the scores of the stations or add a new operation for the operator to indicate the appropriation of the task for the aforementioned operator.

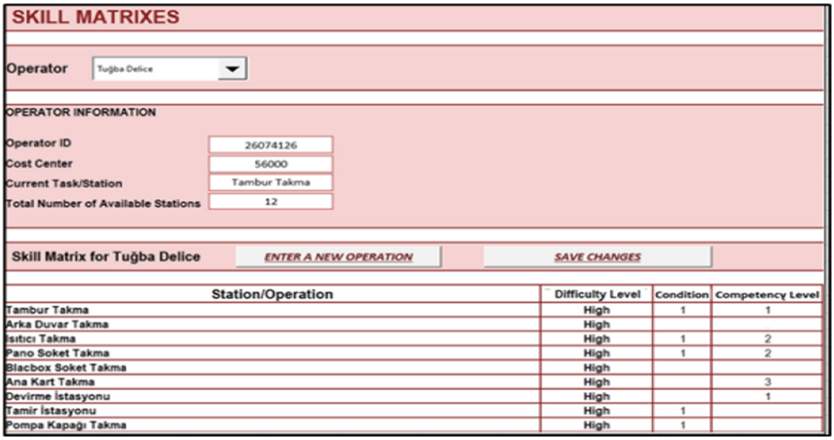


Fig. 9. Existing matrix screen

If the user decides to create a new skill matrix for an operator that is not currently on the operators' list, "Create a New Matrix" should be clicked. Once this button is clicked, a new screen opens as in the existing matrixes section. On this screen, the name and surname of the operator, his/her ID, and the cost center of the operator are entered into the related cells which are exemplified in Fig. 10. Then, the skill matrixes table is filled appropriately as in the existing matrix examples. The user can later save the operator skill matrix to the system by clicking the button "Save the Operator to the System".

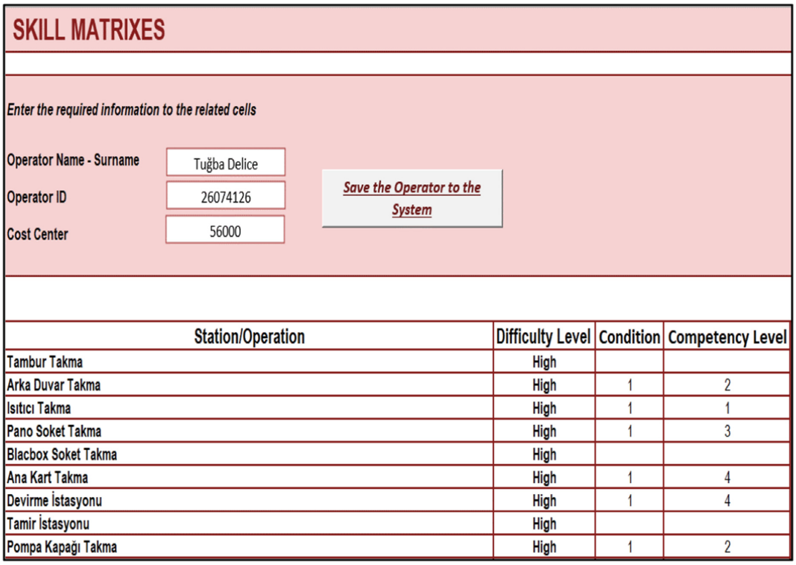
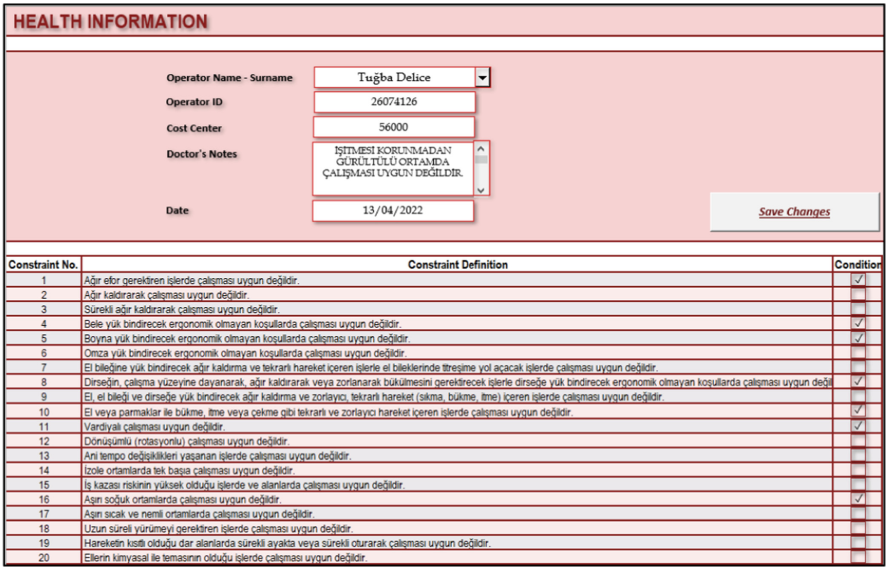


Fig. 10. New matrix screen

2.4 Health Information Part

When the "Health Information" button is clicked, a new screen meets the user. On this screen, basic operator information and the current date can be seen. All possible restrictions a worker can face such as physical, environmental, or equipment-related situations are listed in this section. An occupational health expert can select one of these restrictions if it is not appropriate for a worker to work on a station that has the work content mentioned in the constraints based on the health records of the worker. It is also allowed to enter an additional comment in the "Doctor's Notes" part. Health information can be viewed in Fig. 11.



HEALTH INFORMATION

Operator Name - Surname: Tuğba Delice

Operator ID: 26074126

Cost Center: 56000

Doctor's Notes: IŞITMESI KORUNMADAN GÜRÜLTÜLÜ ORTAMDA ÇALIŞMASI UYGUN DEĞİLDİR.

Date: 13/04/2022

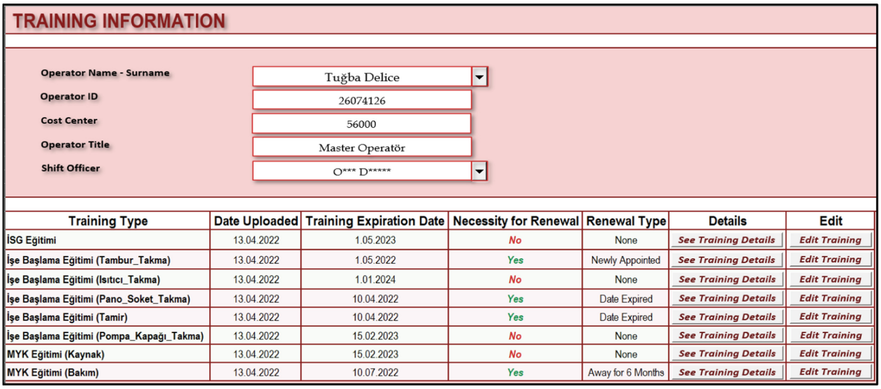
Save Changes

Constraint No.	Constraint Definition	Condition
1	Ağır efor gerektiren işlerde çalışması uygun değildir.	✓
2	Ağır kaldırarak çalışması uygun değildir.	
3	Sürekli ağır kaldırarak çalışması uygun değildir.	
4	Bele yük bindirecek ergonomik olmayan koşullarda çalışması uygun değildir.	✓
5	Boyna yük bindirecek ergonomik olmayan koşullarda çalışması uygun değildir.	✓
6	Omza yük bindirecek ergonomik olmayan koşullarda çalışması uygun değildir.	
7	El bileğine yük bindirecek ağır kaldırma ve tekrarlı hareket içeren işlerle el bileklerinde titreşime yol açacak işlerde çalışması uygun değildir.	
8	Dirseğin, çalışma yüzeyine dayanarak, ağır kaldırarak veya zorlanarak bükülmesini gerektirecek işlerle dirseğe yük bindirecek ergonomik olmayan koşullarda çalışması uygun değil	✓
9	El, el bileği ve dirseğe yük bindirecek ağır kaldırma ve zorlayıcı, tekrarlı hareket (sıkma, bükme, itme) içeren işlerde çalışması uygun değildir.	
10	El veya parmaklar ile bükme, itme veya çekme gibi tekrarlı ve zorlayıcı hareket içeren işlerde çalışması uygun değildir.	✓
11	Vardiyalı çalışması uygun değildir.	✓
12	Dönüşümlü (rotasyonlu) çalışması uygun değildir.	
13	Ani tempo değişiklikleri yaşanan işlerde çalışması uygun değildir.	
14	İzole ortamlarda tek başıa çalışması uygun değildir.	
15	İş kazası riskinin yüksek olduğu işlerde ve alanlarda çalışması uygun değildir.	
16	Aşırı soğuk ortamlarda çalışması uygun değildir.	✓
17	Aşırı sıcak ve nemli ortamlarda çalışması uygun değildir.	
18	Uzun süreli yürümeyi gerektiren işlerde çalışması uygun değildir.	
19	Hareketin kısıtlı olduğu dar alanlarda sürekli ayakta veya sürekli oturarak çalışması uygun değildir.	
20	Ellerin kimyasal ile temasının olduğu işlerde çalışması uygun değildir.	

Fig. 11. Health information section

2.5 Training Information Part

In the "Training Information" section, it is possible to monitor and edit operator training data for different tasks as observed in Fig. 12. All training received by the operator is listed, and the user can see the expiration date of the training and whether it needs to be renewed or not. Training has different necessities in terms of renewal. Training may require to be taken by the operator because the operator has been away for 6 months, had a work-related accident, he/she is newly appointed, or the training date has just expired. This information is also viewable in the section so that required cautions can be taken to keep the operator training updated. The user can go into detail about the training and can edit if it is needed.



TRAINING INFORMATION

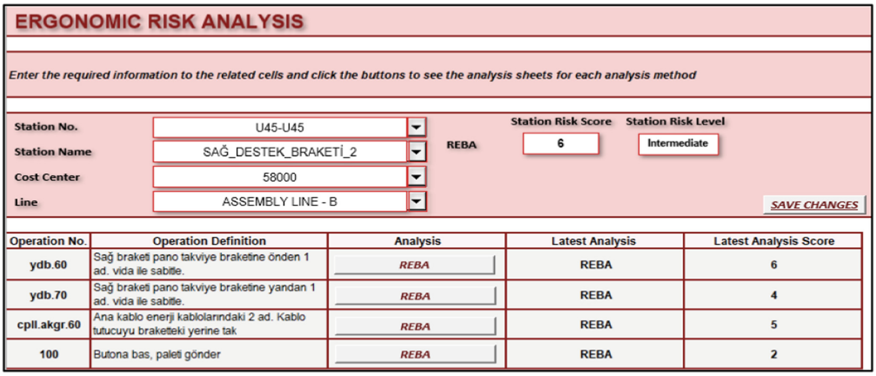
Operator Name - Surname	Tuğba Delice
Operator ID	26074126
Cost Center	56000
Operator Title	Master Operatör
Shift Officer	O*** D*****

Training Type	Date Uploaded	Training Expiration Date	Necessity for Renewal	Renewal Type	Details	Edit
İSG Eğitimi	13.04.2022	1.05.2023	No	None	See Training Details	Edit Training
İşe Başlama Eğitimi (Tambur_Takma)	13.04.2022	1.05.2022	Yes	Newly Appointed	See Training Details	Edit Training
İşe Başlama Eğitimi (Isıtıcı_Takma)	13.04.2022	1.01.2024	No	None	See Training Details	Edit Training
İşe Başlama Eğitimi (Pano_Soket_Takma)	13.04.2022	10.04.2022	Yes	Date Expired	See Training Details	Edit Training
İşe Başlama Eğitimi (Tamir)	13.04.2022	10.04.2022	Yes	Date Expired	See Training Details	Edit Training
İşe Başlama Eğitimi (Pompa_Kapağı_Takma)	13.04.2022	15.02.2023	No	None	See Training Details	Edit Training
MYK Eğitimi (Kaynak)	13.04.2022	15.02.2023	No	None	See Training Details	Edit Training
MYK Eğitimi (Bakım)	13.04.2022	10.07.2022	Yes	Away for 6 Months	See Training Details	Edit Training

Fig. 12. Training information section

2.6 The New Ergonomic Analysis Part

If a new ergonomic risk analysis for a workstation needs to be done and recorded to the system, the user can utilize the "New Ergonomic Analysis" part. The user can either choose the station name or the station number from the lists to perform ergonomic risk analysis. When one of them is chosen, the other part will be filled by the system automatically. This also applies to the cost center and the line information. Once the station information cells are filled, the operation steps are listed below that section as shown in Fig. 13. It is possible to see the operation numbers and the latest analysis done with the latest analysis score if there are any. As the user performs analysis for operations, the system automatically calculates the overall risk level by choosing the highest score among the operations.



ERGONOMIC RISK ANALYSIS

Enter the required information to the related cells and click the buttons to see the analysis sheets for each analysis method

Station No.	U45-U45
Station Name	SAĞ_DESTEK_BRAKETİ_2
Cost Center	58000
Line	ASSEMBLY LINE - B

	Station Risk Score	Station Risk Level
REBA	6	Intermediate

SAVE CHANGES

Operation No.	Operation Definition	Analysis	Latest Analysis	Latest Analysis Score
ydb.60	Sağ braketi pano takviye braketine önden 1 ad. vida ile sabitle.	REBA	REBA	6
ydb.70	Sağ braketi pano takviye braketine yandan 1 ad. vida ile sabitle.	REBA	REBA	4
cpll.akgr.60	Ana kablo enerji kablolarındaki 2 ad. Kablo tutucuyu braketteki yerine tak	REBA	REBA	5
100	Butona bas, paleti gönder	REBA	REBA	2

Fig. 13. New ergonomic analysis section

When the analysis method is clicked on the page, a new window pops up on the screen, as detailed in Fig. 14. For REBA, options for each body part are seen with related pictures to conduct the user and when all the appropriate ones are chosen, the user can save the analysis result. After the analysis result is saved, “Latest Analysis” and “Latest Analysis Score” is updated for the operation, and the risk score becomes viewable. If the analysis is done for the first time for an operation, the user must choose the “Add Record” option to save the result. It is also possible to delete an analysis result of an operation if desired.

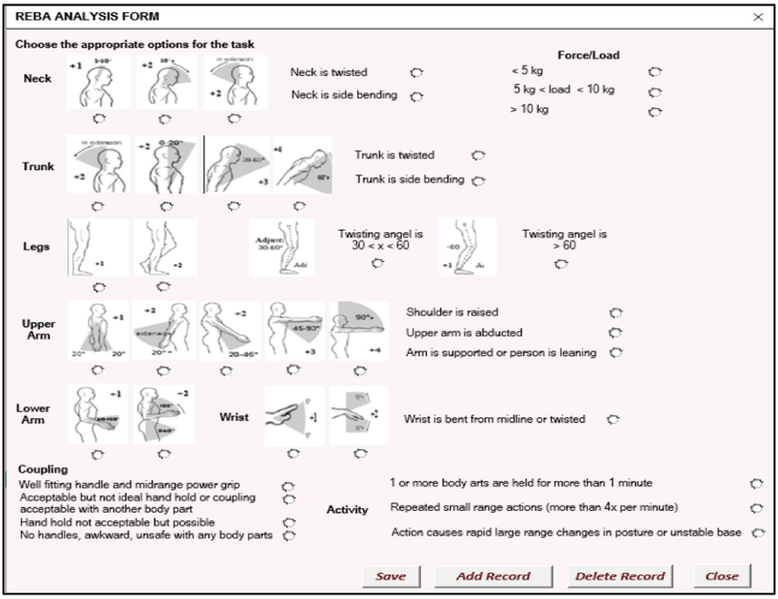


Fig. 14. REBA analysis window

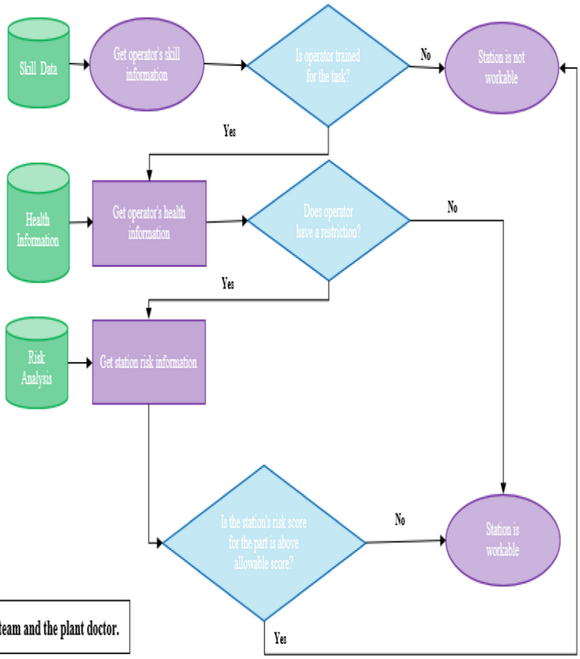
2.7 Risk Analysis Information Part

In the “Risk Analysis Information” part, total risk scores and the scores for each part can be seen for each station. These details are derived from the previously created “REBA Analysis Form”. When a new station is added to the system, it is also added to this section automatically. Once the analysis is done for the newly added station, it also is written down on the list so that the section becomes updated. The user can see the summary table which is in the same format as the detailed results table but only with the stations and the total risk scores if desired. It provides only the overall risk scores for each station unlike the table with the operation-by-operation scores and explanations.

2.8 Operator Assignment Part

While determining the workable stations, the system algorithm compares the operator skills and health restrictions to the station risk scores. In the first place, an algorithm, explained in Fig. 15, looks for the skill matrixes and sees if the operator has the necessary training for the task and then, if he/she does, the next step takes place which searches for the health restrictions of the operator. The station becomes workable automatically if the worker is skilled for the task and has no restrictions in terms of health. In case of any kind of restriction, the algorithm checks if the station is too risky or not for the operator to work. For each body part, the algorithm evaluates the health condition and risk scores differently. For example, if an operator cannot work by lifting heavy objects or in conditions where the operations put a burden on the waist, and the load is more than 5 kg which means the load score is 2 or more, that shows that the operator cannot work on that specific station. In another example, the station becomes unworkable for the operator when the aforementioned station includes tasks that force the wrist or causes vibration in the wrist which ends up with a wrist score of 2, and the operator is decided not to work on a station that might harm his/her wrist by the health officer in the "Health Information" section.

Evaluation Criteria	Allowable Risk Score Range
Neck	<2
Trunk	<3
Leg	<3
Load	<2
Upper Arm	<4
Lower Arm	<2
Wrist	<2
Coupling	<2
Activity	<2



Ranges are decided by the industrial engineers, production team and the plant doctor.

Fig. 15. Evaluation process and allowable risk range for each criterion.

When all the information is entered and then the system determines the workability of the stations for the operator according to the skills, health condition, and risk scores, the user is allowed to see two different lists on the screen. On the workable stations' list, there is a button called "Assign" for each of the stations, which can be viewed in Fig. 16, to assign the operator to a desired one if it is not already assigned to another operator before. The user can see all the assignments made from the list which is reached by clicking the button "See Assignments". For the conditions where all of the appropriate stations are assigned to different operators and the operator must be assigned to one of the stations, it is the user's initiative to assign him/her to one of the non-workable stations but when this is the case, the assignment is sent for approval to all of the people deciding to the allowable risk score ranges who are industrial engineers, production team and the plant doctor. If all agree on the assignment, then the operator can be assigned to that station although it is the last option to choose during the assignment process.

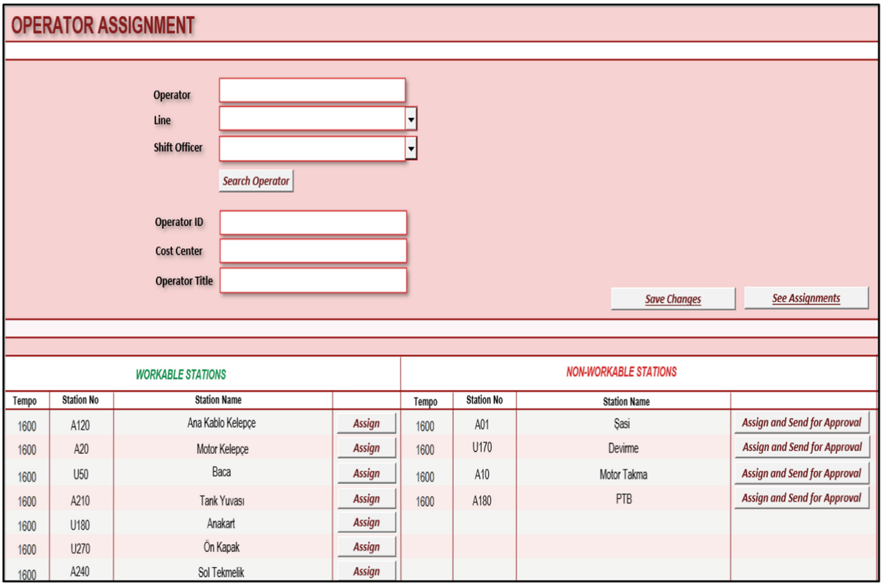


Fig. 16. Lists of workable and non-workable stations

3 Discussion and Conclusions

This study focused on building a system to use for both ergonomic risk assessment and operator assignment processes at workstations in a manufacturing environment that include many different repetitive tasks. The most significant impact of the system is that it allows users to reach all the information that is included in the operator assignment process in one place and is available to everyone in the working environment including the management team increases incentives for investments in ergonomics. This Ergonomic

Assessment – Operator Tracking System has the potential to raise awareness of the importance of ergonomic risk assessment and improvements in the company and Turkey, and be a basis for workplaces with the lowest occupational disease rates.

In the literature, there are many examples of different expert systems that focus on manual material handling operations and estimation of CTDs using different approaches and considering different aspects including anthropometric data, environmental factors, and the characteristics of the tasks. In the light of these previous studies, the needs of the proposed system and the process steps of the study were determined accurately, and it was aimed to contribute to the expert system studies, specifically for assembly tasks. All the elements that have an impact on the assignment of the operators to the appropriate workstations are defined and gathered to achieve the goal of the best results in terms of work-related diseases rate.

This study contributes to the existing literature by introducing a new system that combines ergonomic risk analysis, skills, health restrictions, and each training attributed to tasks to find the best workstation match for a worker, especially in assembly operations which consist of several repetitive movements affecting different body parts. As a manufacturing environment that includes not only assembly operations, but also manual material handling operations containing tasks such as lifting, pulling, and pushing, other risk assessment methods such as NIOSH and KIM may be added to the content of the system for further studies to create a more comprehensive risk assessment and operator assignment tool and a safer work environment for everyone who is affected. The system may also be improved by adding a feature that makes it possible to make recommendations for risky stations and workers with various health restrictions. In addition, the WMSDs rates in the company before and after the system is deployed may be compared once sufficient data is obtained for further studies.

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Inventory and Maintenance Optimization of Conditional Based Maintenance Using Fuzzy Inference System

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Abstract. Complex and multifunctional systems are used in operations in industry and service sectors and companies may have to deal with huge losses in case of breakdown and failure in them. When the system should be maintained is very important because, in the case of early maintenance, there are losses due to the replacement of the unworn machines, while in the case of late maintenance, the wear of the component affects the whole machine and the machine must be completely replaced, therefore it is important when to perform maintenance on the system. To decide when to maintain, we need to get information on the components from the system and this information can be obtained from the system about whether there is a need for maintenance with the help of sensors, but it is not economically feasible to install the sensors on each component. I propose a new policy that receives partial information from the system regarding conditional-based maintenance. I compare this policy with its subset of the classical conditional-based maintenance policy by doing numerical experimentation. I will also analyze how components with different reliability affect the system. In this study, conditional-based maintenance policies were created for maintenance work based on motor machinery driven, which was previously maintained with the Fuzzy Inference system.

Keywords: Conditional based maintenance · Fuzzy logic · Corrective maintenance · Preventive maintenance

1 Introduction

Complex and multifunctional systems are used in operations in industry and service sectors, and companies may have to deal with huge losses in case of breakdown and failure in them. Therefore, it is very important to have the right maintenance policy. Due to huge losses in case of breakdown and failure, companies must develop their maintenance policies to minimize these losses. Wind turbines and a radar system on the vessel can be shown as examples of these machines. As a result, businesses are

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turning to more complex solutions to increase system reliability, maintain safety, and decrease costs. Conditional-based maintenance (CBM) is a maintenance policy that aims to intervene in machines at the optimal time. CBM can save more than half of its maintenance expenditures (Zhang 2013). Maintaining the machines at the right time with the CBM application not only reduces the costs but also increases the life span of the systems and has features such as being environmentally friendly because it maintains the worn components in the machine without affecting other components. For all these reasons, researchers have done research on CBM policy and have tried this policy on different models to find optimal results. In most of the literature, sensors are attached to the machines. Attaching sensors to every component, not to every machine, gives us much clearer information, however, this does not seem economically feasible. For this reason, a sensor is attached to the system, and data is obtained from the system, temperature levels, vibrations, some slowdowns in the system, etc. The sensors in the system will give signals to the operators according to the deterioration level but this information is partly because we do not know the exact deterioration level of components and if we have more than one component, we do not know which component deteriorates. The operator can visit the sensors according to some rules and see how they are to deteriorate. This is getting information by cost but for most studies, getting information is not costly. Depending on the policies, there will be certain maintenance policies. According to these policies, when the component needs to be maintained within the framework of the policies, most of the literature comes from the spare parts service providers, but no study considers the situation where spare parts can be kept in the inventory, and some visits in machines. I aim to close these gaps in this literature. In this framework, besides when to maintain the machine.

2 Literature Review

There is a substantial amount of literature available on CBM. Ohnishi et al. (1986), consider a system monitored by a sensor that gives the decision-maker imperfect information about the system state in one of the first studies in the stream of single-component CBM models. The optimal inspection and replacement policy for the system, according to the authors, belongs to the modified monotonic four-region policy class. For a multi-state, Markovian deterioration system with self-announcing failures. Barata et al. (2002) performed a Monte Carlo simulation to pick an ideal maintenance strategy for lowering overall service costs. The application was also shown using a hypothetical instance involving a two-component series system. Maillart (2006) investigates the topic of scheduling perfect and imperfect observations as well as preventative maintenance operations. Amari et al. (2006) conducted investigations that Cost-Effective Condition-Based Maintenance Using Markov Decision Processes. AlDurgam and Duffuaa (2013) investigate maintenance and operation policies that increase the effectiveness of single-component systems. De Jonge et al. (2017) study how a required planning time for a single-component system that deteriorates according to a gamma process affects the cost benefits of CBM over TBM. They conclude that the preventive maintenance threshold decreases and that the cost per unit of time increase for longer required planning times. Berrade et al. (2017) consider a delay time model, where a delay time is defined as a time-lapse from the occurrence of a defect up until failure. They analyze whether it is cost-effective to postpone preventive maintenance after the detection of a defect. Chen et al. (2014) studied the topic of determining the best maintenance strategy for partially observed systems with a finite number of imperfect maintenance operations. The authors show that an optimum threshold-type maintenance policy exists. Van Oosterom et al. (2017) looked at a system with numerous spare component kinds that can't be recognized by their appearance but deteriorate according to distinct transition probability matrices. Abdul-Malak et al. (2019) expand on the model of Van Oosterom's system by eliminating some of the constraints on the system's time-to-failure distribution and considering both repair and replacement operations. Karabağ et al. (2020) for a partially visible multi-component system, looked at integrated maintenance and spare part selection. They proposed a Partially Observable Markov Decision Process (POMDP) formulation and proposed a grid-based solution approach to finding the optimal policy and conducted an extensive numerical experiment to detect how the system has been affected by the values of using optimal policy. Ingemarsdotter et al. (2021) studied challenges and solutions in condition-based maintenance implementation. They performed a multi-case study at three factories that had partially deployed CBM to achieve this goal. They looked at the three scenarios and came up with 19 difficulties and 16 solutions that covered a variety of alignment kinds. They then provided a series of 17 practice-oriented suggestions based on their findings. Furthermore, they demonstrated how some difficulties and solutions are interconnected across the various alignment types.

Lotfi A. Zadeh, a computer science professor at the University of California, Berkeley, pioneered Fuzzy Logic (1965) to address application complexities caused by non-linearities, poorly defined dynamics and lack of appropriate information, imprecision, uncertainties, and a vague description of the system. He established the concept of fuzzy sets, which he characterized as "a class of objects having a variety of membership grades.". He used some set membership concepts like union, intersection, complement, relation, and so on in the same way as they are used in set membership. After some necessary research, Fuzzy logic can apply to the inventory models. Tersine (1982) devised a four-condition inventory model: First, constant lead time and demand, next constant lead time and variable demand, constant demand and variable lead time, and finally variable demand and lead time. When both demand and lead time uncertainties exist at the same time, a probabilistic notion may be used to create a combined probability distribution for various combinations of demand level and lead time. Liao and Shyu (1991) developed the first probabilistic inventory model by using lead time as a decision variable and predefined order quantity. Yang and Pan (2004) looked at an integrated inventory model with a quality improvement investment and deterministic variable lead time. A periodic review inventory model with controllable lead time and lost-sales minimization was addressed by Ouyang et al. (2005). They demonstrated that, depending on the length of the lead time, an investment may be made to minimize it.

A system known as a fuzzy inference system (FIS) maps inputs to outputs using fuzzy set theory. Mamdani and Sugeno types of FIS are the most common and commonly used. They are made up of a defuzzification interface, a decision-making unit, a rule database, and a fuzzification interface. To evaluate the manufacturing process capability based on Cpm, Hsu and Shu (2008)presented the critical value and the fuzzy

P-value as two fuzzy inference criteria. To test its applicability, they used the suggested methodology to data on LED source luminous intensity. ANFIS is a model that Çaydaş et al. (2009) used to forecast the average surface roughness and white layer thickness (WLT) during the wire-EDM process. Fuzzy inference system (FIS) and artificial neural network (ANN) techniques are combined to create the ANFIS model, which utilizes the modeling capabilities of FIS and the learning capabilities of ANN (Senvar et al. 2016). Lo (2003) used a fuzzy inference system based on an adaptive network (ANFIS). These performance factors were examined since spindle speed, feed rate, and depth of cut are the three milling process variables that significantly affect surface roughness. During the ANFIS training phase, a comparison between the triangular and trapezoidal membership functions was done to see how well these two membership functions predicted surface roughness. When using either of the membership functions, the results indicated excellent forecasting accuracy, but when using a triangular membership function, the prediction accuracy of ANFIS went as high as 96%.

3 Model Description

3.1 Problem Definition

There is a machine with 1 critical component. This machine deteriorates over time. A sensor is attached to this machine to see certain levels of wear. The sensor provides partial information about the operation of the component to the user. This information is reflected according to 3 indicators. The first indicator is green. When we see this indicator, it can be observed that there is no problem in the system and there is no wear in the system. The second indicator is yellow. When this indicator is seen on the sensor, it means that there are partial problems in the component but the system can work and because of these problems, the problematic components do not affect the machine. After the first yellow signal is received in the system, the information about how many periods we see yellow in the system is kept. According to the policies that I mention in the next section, within some maintenance policies, decisions will be made on whether to maintain the system or not. When a red signal is received from the system, maintenance is made immediately and Corrective Maintenance Cost is paid. If a decision is made to maintain when a yellow signal is received from the system, Preventive Maintenance Cost is paid. The system allows keeping inventory in stock. Inventory policy (s, S) is inventory policy. After making a maintenance decision, if we have enough inventory, we can replace the component with the component in the inventory, but if we don't have enough inventory, then an emergency order will be ordered. Emergency order cost will be paid in addition to fixed order cost and variable order cost but inventory comes up immediately and the component can be used (Fig. 1).

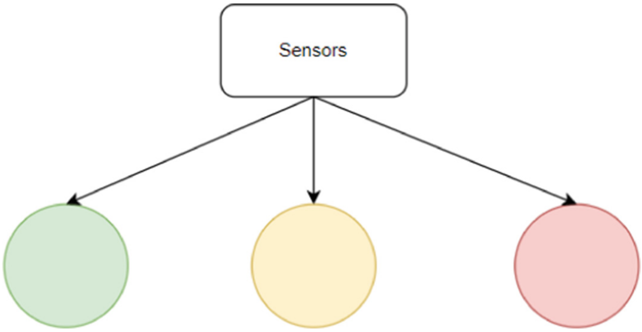


Fig. 1. Sensor representation

3.2 Assumptions

- Models are modeled as an infinite horizon.
- The component has a vibration membership function level.
- In the beginning, the vibration membership function level of the component is 0.
- Each period vibration membership function level can increase.
- Vibration membership rate will increase UNIF (0, Membership increase rate) each period.
- The vibration membership function cannot decrease without maintenance.
- Sensors are attached to each machine to get information about deterioration.
- Based on Janier and Zaharia Safari's study, if the membership function of "Acceptable" exceeds "good", there is a yellow signal in the system.
- After a certain period that seeing a yellow signal on the sensor, the machine is visited, maintained according to the policies, and information about the actual deterioration level can be obtained.
- If the highest membership function value in the system is "Very High", the sensor will show red color and the system will be intervened immediately and corrective maintenance costs will be paid and a new machine is attached to the system.
- Preventive maintenance cost is paid and the component is changed if intervention is made while the sensor is showing yellow.
- (s, S) inventory policy is followed in the system. This means if the inventory position will equal to s, the inventory is ordered up to the number of reaching the S value.
- A fixed order cost is paid for each order, and a variable order cost is paid for each component.
- Each inventory order has a fixed lead time.
- Holding cost is paid for the components in the inventory each period.
- Maintenance process times are negligible.

3.3 Notations

The notations used in the study are provided below:

Notations:

TC*:* Average Cost
MDL*:* Maximum Deterioration Level
DL*:* Deterioration Level
EOC*:* Emergency Order Cost of component
CMC*:* Corrective Maintenance Cost
PMC*:* Preventive Maintenance Cost
FOC*:* Fix Order Cost
VC: Variable Cost
IL*:* Inventory Level
IP*:* Inventory Position
LV_i*:* After how many periods we will visit when we are at deterioration level i, $i \in \{0, \ldots, MDL\}$
H*:* Holding Cost per unit per period
s*:* Re-order Point
S*:* Up-to Level
ML*:* Maintenance Level
P*:* Membership increasing rate
$\mu_A(C)$**:** Vibration membership value, C [0, 1]
VOC*:* Visiting Cost
PL*:* After how many periods we will maintain (for Changing Policy)
OP: Inventory order lead time.

3.4 Policies

Maintenance policies are policies about when to maintain a component. Generally, 2 maintenance policies are adopted. These are Changing and Visiting Policies

a) Changing Policy: In this policy, it starts counting after the sensor sees yellow for the first time. Then, after the PL period, which is the decision variable, it maintains in the system and goes to the system with the inventory it takes, changes the component, and pays the PMC and LOC. If the sensor shows red during this waiting period, the system will be intervened immediately and the CMC and LOC will be paid.

   Decision Variables: (s, S, PL)
   Objective Function: minimize (TC)

b) Visiting Policy: This policy is a bit more complicated than the other policy. After the first yellow is seen in the system, we have the information that the system is at level 1 deterioration. Whenever we have certain information, we wait until the period in the LV_i deterioration level and then visit the sensor by paying LOC to learn the exact deterioration level of the sensor. Two decisions are made during visits. The first decision is whether to intervene in the system or not, which is checked with another decision variable, ML. If the deterioration level of the system is equal to or higher than ML, the decision to maintain the system is made and the PMC is paid in addition to the LOC cost in this visit, and the second decision is not considered. If the deterioration level in the system is less than ML, LVi in the deterioration level decides to come back after a period. If the signal shows red color during these waits, immediate action can be taken and LOC and CMC are paid. If we look at the system in detail, it seems that the Changing policy is a subset of the Visiting policy. When ML is 1, the optimal results of Visiting Policy and Changing Policy are the same. The decrease in the number of ML also depends on the increase in LOC and CMC. As the CMC rises, the penalty for late intervention will increase and in optimal situations, the system will be intervened at lower deterioration levels. With the increase in LOC, the operator who wants to visit the system less will choose ML as 1 due to the high penalty which means CMC.

Decision Variables: (s, S, LV_1, …, LV_{MDL-1}, ML)
Objective Function: minimize TC.

4 Solution Methodology

Since the analytical analysis of the system is difficult, a simulation was performed. Arena Software is used for simulation. Exhaustive study or Brute-force search has been made for different experiments. Arena's OPT Quest tool was used for the exhaustive study. With Fuzzy Inference System, we can divide sensors by color. Based on Janier and Zaharia Safari's study, if the membership function of "Acceptable" exceeds "good", there is a yellow signal in the system. This can happen if the deterioration level exceeds 0.18. If the highest membership function value in the system is "Very High", the sensor will show red color and the system will be intervened immediately and corrective maintenance costs will be paid and a new machine is attached to the system.

4.1 Numerical Experiment

Numerical experiments have been done to detect the differences between the two policies. After a certain number of experiments, it was realized that the Intervene policy is a subset of the Visiting policy, a subcase where ML is one. As the VOC increases in the system, the ML gradually approaches one and the optimal of the two policies becomes equal. Table 1 shows cost calculation parameters in terms of the values that are used in the experiment and Table 2 shows the number of experiments for an emergency order and backorder cases, respectively.

Table 1. Fix parameters

Parameters	Value1	Value2	Value3
MDL	4		
EOC	650		
CMC	200	300	500
PMC	50		
FOC	150		
VC	10		
H	2		
P	0.10	0.05	
VOC	10	25	
OP	30		

Table 2. Number of experiments for both policies

No	CMC	PMC	VOC	EOC	FOC	VC	HOC	P
1	200	50	10	650	150	10	2	0.1
2	300	50	10	650	150	10	2	0.1
3	500	50	10	650	150	10	2	0.1
4	200	50	10	650	150	10	2	0.05
5	300	50	10	650	150	10	2	0.05
6	500	50	10	650	150	10	2	0.05
7	200	50	25	650	150	10	2	0.1
8	300	50	25	650	150	10	2	0.1
9	500	50	25	650	150	10	2	0.1
10	200	50	25	650	150	10	2	0.05
11	300	50	25	650	150	10	2	0.05
12	500	50	25	650	150	10	2	0.05

4.2 Output Analysis

Since we need average costs and have an infinite horizon, we need to choose the replication length correctly. While choosing the replication length, the operation in which the system will sit in the steady state for the longest time was chosen and since there are more frequent transactions as CMC increases, CMC is lower and costs per period are observed in visiting policy, it is thought that experiment number 4 will give us the most accurate replication length. Figure 2 shows the average cost per period graph obtained by assigning random but relatively low decision variables to experiment number 4. The y-axis of the graph is between 0–10 and as can be seen from the figure, there is no visible fluctuation after the 40000th period, therefore the replication length was chosen as 40000.

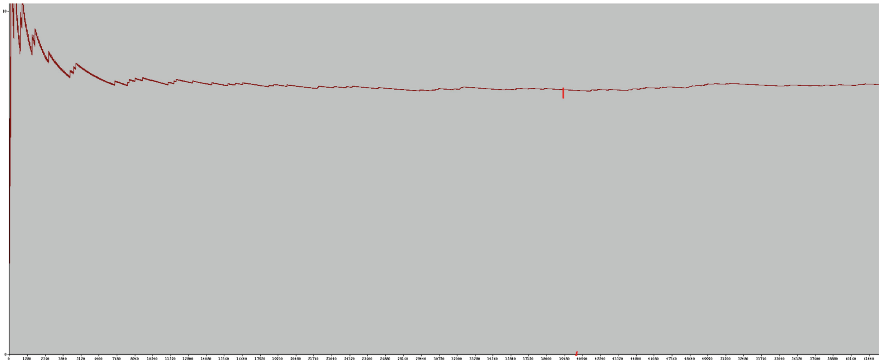


Fig. 2. Average cost per period

Tables 3 and 4 show the results of optimal values of decision variables and expected per period costs for changing and visiting policies.

Table 3. Optimal values of changing policy

No	ML	LV1	s	S	TC
1	1	9	2	6	12.98
2	1	9	2	6	13.15
3	1	9	2	6	13.50
4	1	19	1	3	8.29
5	1	19	1	3	8.35
6	1	18	2	4	8.40
7	1	9	2	6	14.20
8	1	9	2	6	14.37
9	1	9	2	6	14.72
10	1	19	1	3	8.88
11	1	19	1	3	8.93
12	1	18	1	4	9.01

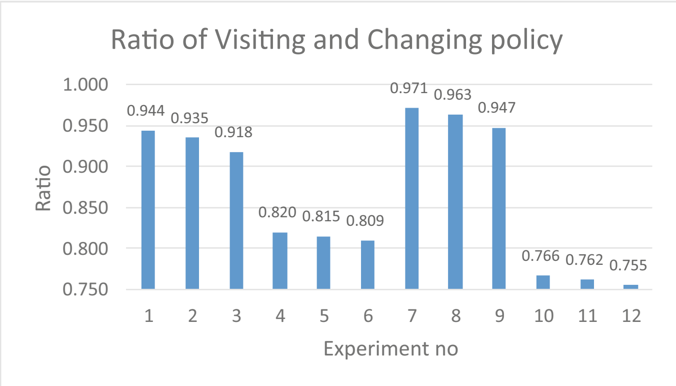
4.3 Analysis

As mentioned earlier, it was stated that the changing policy is a subset of the visiting policy. Therefore, the average cost ratios of the two cases in the same experiments were

Table 4. Optimal values of visiting policy

No	ML	LV1	LV2	s	S	TC
1	3	7	7	2	5	12.25
2	3	7	7	2	5	12.29
3	3	7	7	2	5	12.38
4	3	13	13	0	2	6.80
5	3	13	13	0	2	6.80
6	3	13	13	0	2	6.80
7	3	9	7	2	5	13.79
8	3	8	7	2	5	13.85
9	3	8	7	2	5	13.94
10	3	13	13	0	2	6.80
11	3	13	13	0	2	6.80
12	3	13	13	0	2	6.80

taken for both emergency order and backorder cases. Figure 2 shows the ratios of visiting policy to changing policy.



Considering the rates, it can be said that applying the visiting policy provides a gain of between 1 and 25%. Of course, other factors affect these percentages. One of them is CMC cost. When the CMC cost cannot intervene at the right time and we see red on the sensor, it can be called the penalty cost when we intervene. As this cost increases, the system becomes in need of more information, so the information obtained in the visiting policy allows cost reductions at higher rates. In addition to all of this, if the membership rate increasing rate is decreasing, we need to go less often, which is just another lack of information because we may have to go early and pay PMC unnecessarily.

5 Conclusion

This study is a CBM optimization study that includes inventory and maintenance optimization. While inventory policy is (s, S) inventory policy, 2 different policies have been proposed for maintenance policy. While conducting this study, it was learned that the intervention policy and the visiting policy, which is the other policy, were subsets, and it was seen that the two reached the same optimal with the increase in VSC.

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The Impacts of COVID-19 on Turkish Real Estate Industry: Perception vs. Reality

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Abstract. In the very early stages of COVID-19, a survey was conducted to find out the perception of the people living in Turkey about the effects of the pandemic on the Turkish real estate industry. 284 respondents were asked questions about their perception of how the pandemic would affect the real estate industry in terms of housing prices, mortgage interest rates, the gross sales of the shopping malls, the vacancy rates of the offices, and the occupancy rates of the hotels. This study analyzes the responses of the survey participants and compares the results with the current real estate market figures where two years left behind the declaration of the pandemic by the World Health Organization (WHO) in March 2020. According to the survey results, the participants perceived a decrease in housing prices, a decline in mortgage interest rates, and an increase in vacancy rates in offices due to COVID-19, but oppositely, the housing prices and mortgage interest rates increased and despite the remote working models, vacancy rates in the offices decreased. The decrease in gross sales in shopping malls and decline in occupancy rates in hotels during the COVID-19 period were predicted accurately by more than 70% of the respondents respectively. This research, being one of the most comprehensive studies that is covering the Turkish real estate industry during the COVID-19 period, aims to provide insight for the developers and investors while determining their future investment strategies.

Keywords: Real estate · COVID-19 · Inflation · Housing prices · Interest rates · Housing sales

1 Introduction

The global economy has been experiencing difficult times. While the new Coronavirus Disease (COVID-19) resulted in high inflation followed by recession, the ongoing war between Russia and Ukraine started in February 2022 increased the negative economic effects of the pandemic due to the rapid rise in the energy and food prices (World Bank 2022). While the world started getting recovered from the negative effects of the pandemic, the political developments added additional risks to the global economy. Under the rising inflationary environment, investors started seeking safe havens such as gold, stocks, and real estate to protect their purchasing powers and wealth. Although residential prices were negatively affected in the early stages of the pandemic, recently,

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among different hedging tools, investing in the housing industry has been more attractive due to the global increase in housing prices based on the rising inflation all around the world. On the other hand, the commercial real estate industry was negatively affected due to the remote working options and the rapidly changing behaviors of the customers from traditional shopping choices to online shopping preferences (Balemi et al. 2021). The occupancy rates of the hotels during the pandemic also decreased because people hesitated to go for vacations in crowded high-populated hotels during the COVID-19 period. In light of the changes that the COVID-19 pandemic brought to our lives and post-COVID-19 developments, this global disaster stands as an opportunity to transform the development and investment perspectives of the real estate industry. Thus, analyzing the impacts of COVID-19 on the real estate industry may give investors an important insight into the future of the industry for new and potential investment strategies and opportunities. Two years ago, in the very early stages of the pandemic, in April 2020, when the borders were closed, international transportation was stopped, the global supply chain was broken, international trade was slowed down, and when the people had to stay at home under the curfew applied, a survey was conducted to find out the perception of the people living in Turkey about the effects of the COVID-19 on the Turkish real estate industry. 284 respondents were asked questions about their perception of how the pandemic would affect the real estate industry in terms of housing prices, mortgage interest rates, the gross sales of the shopping malls, the vacancy rates of the offices, and the occupancy rates of the hotels. This study analyzes the responses of the survey participants and compares the results with the current real estate market data where two years left behind the declaration of the pandemic by the World Health Organization (WHO) in March 2020.

2 Literature Review

COVID-19 has changed our lives in many aspects. The housing choices, shopping behaviors, vacation habits, and workspace options are all changing. All these changes are somehow related directly or indirectly to the real estate industry. The effects of COVID-19 on real estate markets have been attractive for many global researchers. In the early months of the pandemic, Del Giudice et al. (2020) modeled the effects of COVID-19 on housing prices in Italy and projected a drop of 4.16% in the short run and 6.49% in the long run. The results of the study conducted by Gascon and Haas (2020) from the Federal Reserve Bank of St. Louis and by Ramani and Bloom (2021) from Stanford University Institute for Economic Policy Research (SIEPR) exhibited a more than 10% decline in housing rental prices in the US in the early stages of the pandemic. Li and Zhang (2021) analyzed the effects of the pandemic on the location selection of Americans when buying properties, and they concluded that affordable suburbs, smaller cities, and areas away from costly and high-density downtowns were preferable. They also reported a sharp increase in the housing prices later COVID-19 pandemic period in the US. Kaynak et al. (2021) studied the impact of COVID-19 on Turkish housing prices, and the results of their analysis exhibited a negative effect of the pandemic on residential prices. Allan et al. (2021) investigated the impact of the COVID-19 pandemic on the commercial property markets in the Asia–Pacific region and concluded a negative impact on market rent of approximately 15% in the first two quarters of 2020. Hoesli and Malle (2021) analyzed how the European real estate market got affected by COVID-19, and they reported that retail and hospitality properties were the two most affected assets, and these were followed by office buildings, residential and industrial sectors. Sumer and Ozorhon (2021) compared the returns of gold and the Turkish real estate investment trust (T-REIT) index including the COVID-19 period, and they concluded that T-REITs perform better than gold except for crisis periods.

3 The Housing Industry

The Turkish housing industry experienced a currency crisis and high-interest rates in the second half of 2018. The yearly mortgage interest rates increased as high as 28,95% in October 2018, and the rate of the mortgaged sales fell as low as 5,22% of the total sales in December 2018. During 2019 the industry started getting recovered, the mortgaged sales reached 39,35% in September 2019, and in the first quarter of 2020, before the pandemic was declared, the mortgage rates fell as low as 11,43% in February 2020 (The Central Bank of the Republic of Türkiye (CBRT) 2022). The pandemic negatively affected this recovery and the total monthly sales fell to 42.783 in April 2020 due to the travel restrictions and the curfew applied. In May 2020, the mortgage interest rates of public banks decreased, and that resulted in high demand for housing and a rapid increase in housing sales (Tanrivermiş 2020). Ahsan and Sadak (2021) also emphasized the government policy intervention in the COVID-19 period in determining the housing demand as the total sales numbers and the prices increased after the decrease in public banks' mortgage interest rates in May 2020.

The decrease in mortgage interest rates in May 2020 also affected housing prices. At the beginning of 2020, an average unit price of a house in Turkey was 3.000 TL and

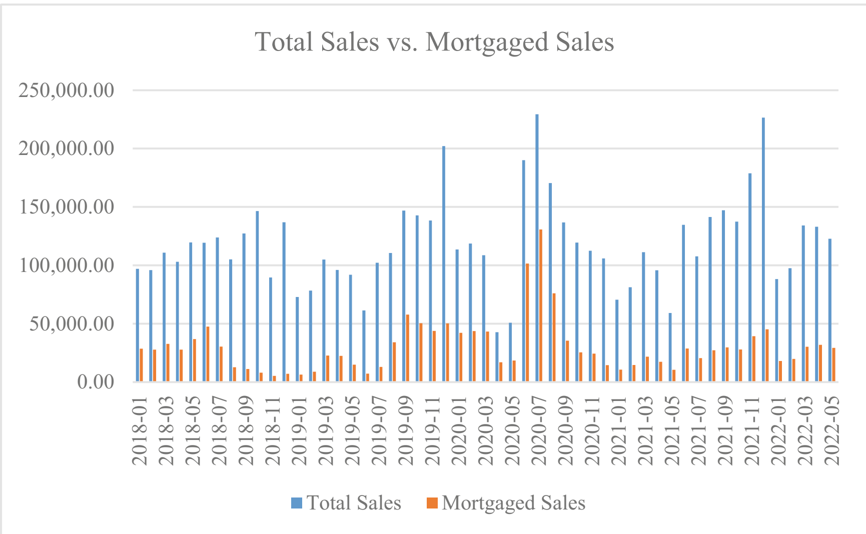

Fig. 1. Total sales vs. mortgaged sales (TUIK 2022)

at the end of 2021, the price doubled and reached 6.373. The upward trend continued in 2022 due to the high inflation and the average housing unit price hit 10.575 TL in April 2022 (CBRT 2022). Figures 1, 2, and 3 show the development of the total housing sales, mortgaged housing sales, mortgage interest rates, and average housing unit prices in Turkey including the COVID-19 period.

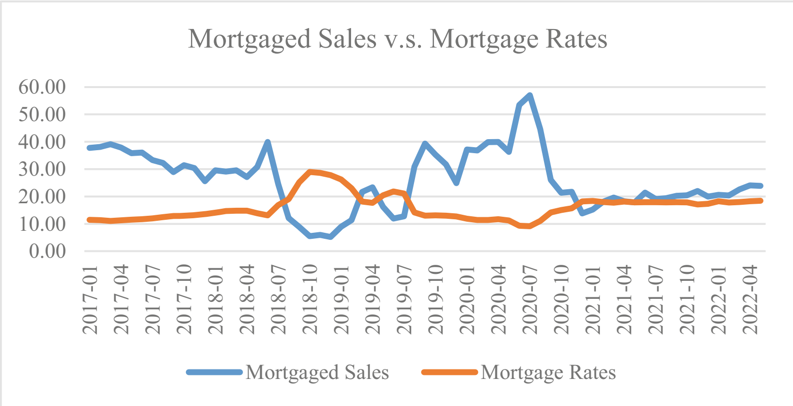

Fig. 2. Mortgaged sales vs. mortgaged ınterest rates (CBRT 2022)

Another important data about the Turkish housing industry is the total unit sales to foreigners. Since 2013, foreign citizens can purchase a house in Turkey and since then the number of units sold to foreigners is increasing. In 2020, due to the stopped travel all around the world, the number of the total housing sales made to foreigners decreased from 45.483 to 40.812, but as shown in Table 1, that figure sharply increased to 58.576 in 2021. The devaluation of the Turkish Lira (TL) against the USD Dollar in the second half of 2021 and the first half of 2022 speeded up the sales to foreigners although the unit prices per square meter increased in Turkish Lira, investing in the Turkish housing industry became more attractive to foreigners due to the attractive prices in foreign currencies.

Table 1. Total sales & sales to foreigners (TUIK 2022)

Years	Total sales	Sales to foreigners	Share (%)
2013	1.157.190	12.181	1,1
2014	1.165.381	18.959	1,6
2015	1.289.320	22.830	1,8
2016	1.341.453	18.189	1,4
2017	1.409.314	22.234	1,6

(*continued*)

Table 1. (*continued*)

Years	Total sales	Sales to foreigners	Share (%)
2018	1.375.398	39.663	2,9
2019	1.348.729	45.483	3,4
2020	1.499.316	40.812	2,7
2021	1.491.856	58.576	3,9
2022 (Jan–May)	575.889	26.753	4,6

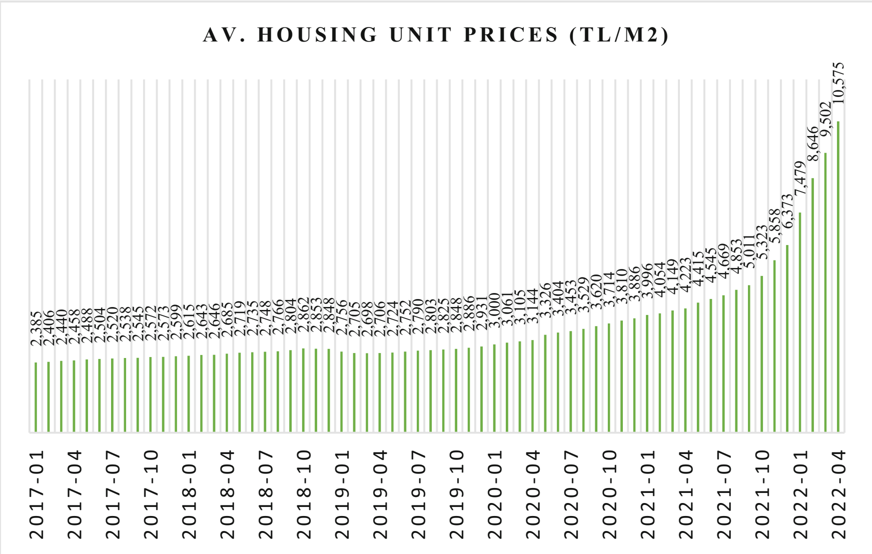

Fig. 3. Average housing unit prices (CBRT 2022)

4 Retail and Offices and Tourism

4.1 Retail

The retail industry is considered among the most negatively affected sectors by COVID-19 (Hoesli and Malle 2021). The curfew applied in many countries, and the stopped travel decreased the inbound and outbound mobility of people. In addition, keeping a distance from others, hesitating to touch products while shopping or going to a restaurant for dinner, and not leaving home if not urgently required made people use online sales channels for any type of shopping including groceries, food, clothes, etc. Thus, many retail stores in shopping malls or on the streets started shutting down due to the sharply decreased number of visitors. Figure 4 shows the initial effects of COVID-19 on the number of shopping mall visitors in Turkey. Figure 5 also shows the prolonged yearly impacts of COVID-19 on the shopping mall visitors index. As of November 2021, the number of visitors did not reach the lowest number of 2019. Another important data to follow about the impacts of COVID-19 on the retail industry is the retail turnover index shown in Fig. 6. The turning point in the retail turnover seems as October 2020, but a constant increase in turnover starts in June 2021. An increase in inflation rates may also be considered an important reason for this increase.

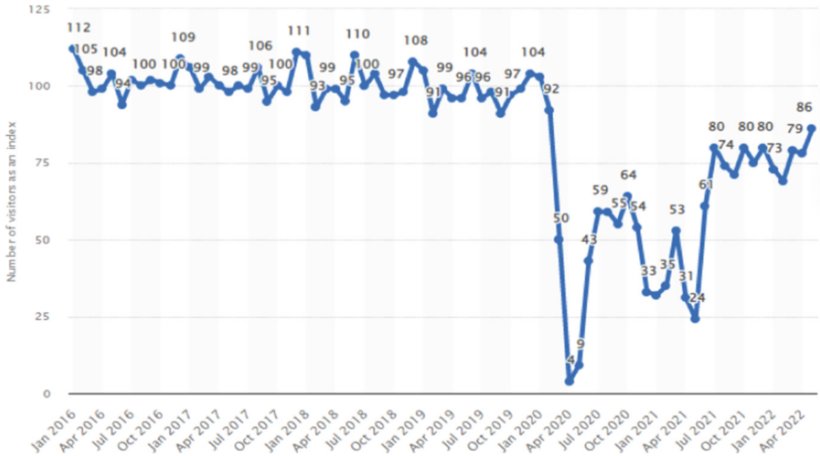

Fig. 4. Shopping malls visitors ındex (Statista 2022)

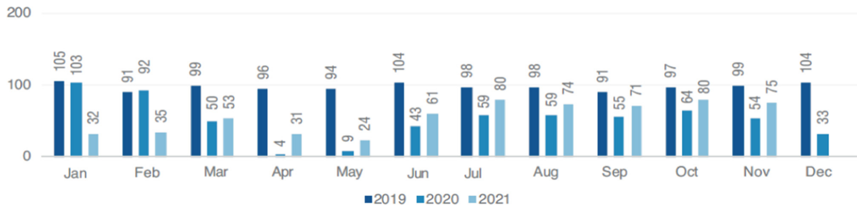

Fig. 5. Shopping mall visitors ındex (GYODER 2021)

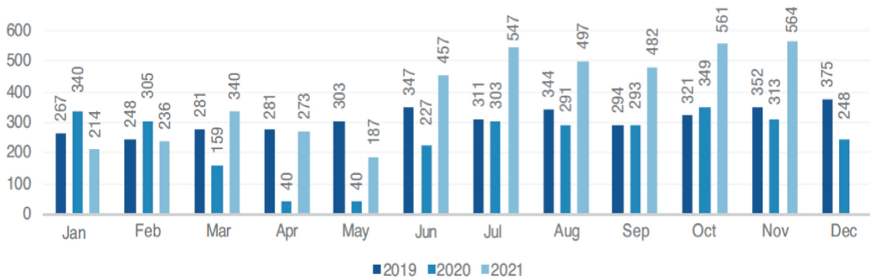

Fig. 6. Retail turnover ındex (GYODER 2021)

4.2 Offices

During COVID-19 people had to work from home due to the lockdowns, quarantines and curfews applied, and implementation of new ways of working became a must due to the pandemic (Kylili et al. 2020; Boland et al. 2020). Hybrid mode became an alternative to going to the office the whole week or completely remote working (Wang et al. 2021). It is expected that the vacancy rates of the offices to increase, but in 2020 the vacancy rates decreased from 20,5% to 17,4%, and after an increase in 2021 with an 18% vacancy rate, it started decreasing again in the first quarter of 2022. Figures 7 and 8 shows the quarterly and yearly vacancy rates of the offices in the central business district in Istanbul.

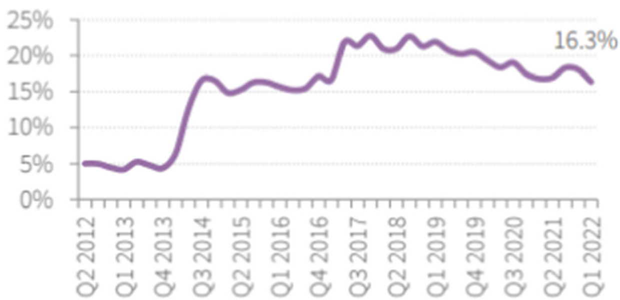

Fig. 7. Office vacancy rates - Istanbul Central Business Districts (CBD) (Jong Lang Lasalle (JLL) 2022)

4.3 Tourism

The tourism industry is considered among the most heavily affected industries in the COVID-19 period, due to the restrictions applied both to tourism companies and visitors. The decrease in mobility, and the changing habits of the customers from staying at conventional hotel tourism to preferring renting private villas or staying at home negatively affected the tourism sector. According to the report of GYODER (2022), while in 2019 45 million had visited Turkey, the number of visitors dropped to 12,7 million and 24,7 million visitors in 2020 and 2021 respectively. The occupancy rates also decreased in pandemic years. The occupancy rates in Istanbul decreased from 74% in 2019 to as low as 37,24% in 2020. After a partial recovery with 54,4% in 2021, in the first quarter of 2022, the rates increased to 65,8% which is still behind the rates in 2018. The occupancy rates in Turkey were even below the rates in Istanbul. After a sharp decrease in 2020 with 35,9% 2020, the rates in the first three months of 2022 are even behind the rates in Istanbul with 56,8%. These figures show there is still time to get recovered from the negative effects of the pandemic. Figure 9 shows the yearly hotel occupancy rates in Istanbul and Turkey.

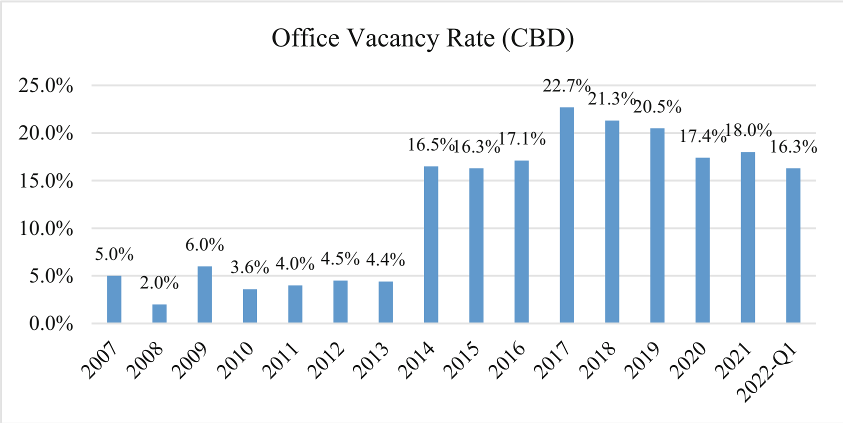

Fig. 8. Yearly office vacancy rates, CBD (JLL 2022)

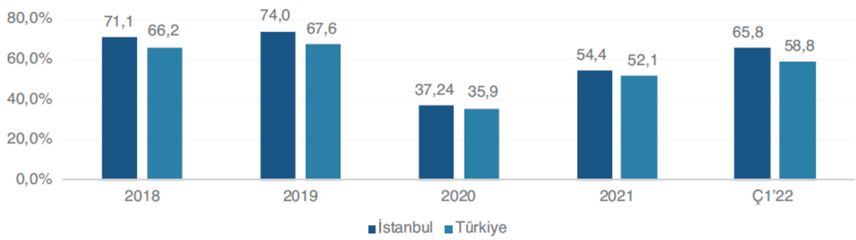

Fig. 9. Yearly hotel occupancy rates (GYODER 2022)

5 Methodology

The methodology of this study is structured on a comparison of current real estate sector data with the perception of people living in Turkey about the impact of COVID-19 on the Turkish real estate industry by surveying 284 participants 2 years ago. The participants were asked the following questions to answer whether they agree or disagree about the impact of COVID-19 on the real estate industry:

- The housing prices will increase
- The mortgage interest rates will increase
- The housing sales to foreigners will decrease
- Gross sales of shopping malls will decrease
- Vacancy rates in the offices will increase
- Occupancy rates of the hotels will decrease.

Two hundred and eighty-four (284) people who work in different industries participated in the questionnaire, and among 284 participants, the rate of the professionals who work in real estate and construction industries was 33,45%. The other respondents were from different backgrounds including finance, health, education, and tourism sectors.

Every 2 of 3 respondents were male, and 96,48% of the participants had a university or an upper degree. People with an age of 39 or younger covered 62% of the responses while 38% of them were elder than 40 years old. The categorical questions and the frequencies of the responses are shown in Table 2.

Table 2. Demographic distribution of the respondents

Sector	Frequency	Education	Frequency	Age	Frequency	Gender	Frequency
Construction	26,41%	**Ph.D**	15,49%	**15–29**	23,94%	**Male**	67,61%
Real estate	7,04%	**Graduate**	30,28%	**30–39**	38,03%	**Female**	32,39%
Finance	9,51%	**Undergraduate**	50,70%	**40+**	38,03%	**Total**	100%
Education	15,85%	**High School**	3,52%	**Total**	100%		
Health	11,62%	**Total**	100,00%				
Tourism	3,17%						
Energy	3,17%						
Food	3,17%						
Other	20,07%						
Total	100,00%						

6 Results

The responses of the participants were analyzed by using the R program. According to the survey results, the rate of the respondents who believe the housing prices will increase during the COVID-19 period was 38,03%. The participants who think the opposite was 39,03%. The respondents with no idea had a rate of 22,89%. The survey participants were also asked about the direction of the mortgage interest rates and the rate of the responses obtained were very close to each other where 31,69% of the respondents thought that the mortgage interest rates will increase. On the other hand, 35,21% of the participants disagreed with the increase in the mortgage interest rates, and 33,1% of the respondents had no idea about the direction of the mortgage rates.

Home sales to foreigners are important for the Turkish real estate industry, the number of units sold to foreigners has been increasing for the last decade. Thus, the respondents were asked about their perception of how COVID-19 would affect the number of unit sales to foreigners. More than half of the participants thought that the sales would decrease. The perception of 19,72% of the respondents was the opposite and 28,52% of the questionnaire participants had no idea about the impact of COVID-10 on home sales to foreigners.

COVID-19 also changed the work and travel behaviors of people. People started working from homes and had a vacation preference for detached villas. That is why more than 70% of the respondents thought that due to COVID-19, the vacancy rates of the offices may increase, and the occupancy rates of the hotels may decrease.

The results were also evaluated based on the age range, gender, education level, and industry backgrounds of the participants with a 5% confidence interval. The age ranges of the respondents were categorized as 15–29, 30–39, and above 40 years old. The education was categorized at undergraduate, graduate, and Ph.D. levels, and the perception of the respondents from the construction and the real estate industries were also analyzed separately. The results indicated that there is a statistically important

Table 3. The results of the Pearson's Chi-Squared Tests

The housing prices will increase	**Age**	**Gender**	**Education**	**Industry**
X-Squared	9,4739	6,6499	5,7848	1,0508
Df	4	2	4	2
P-Value	0,0529	0,03597	0,2158	0,5913
Mortgage interest rates will increase	**Age**	**Gender**	**Education**	**Industry**
X-Squared	7,2269	5,0211	6,0601	2,2809
Df	4	2	4	2
P-Value	0,1244	0,08122	0,1947	0,3197
The housing sales to foreigners will decrease	**Age**	**Gender**	**Education**	**Industry**
X-Squared	8,0861	0,9299	2,5717	7,6581
Df	4	2	4	2
P-Value	0,08847	0,6282	0,6319	0,02173
Gross sales of shopping malls will decrease	**Age**	**Gender**	**Education**	**Industry**
X-Squared	12,4410	5,1283	5,3030	0,0681
Df	4	2	4	2
P-Value	0,01436	0,07699	0,2579	0,9665
Vacancy rates in the offices will increase	**Age**	**Gender**	**Education**	**Industry**
X-Squared	8,9340	4,4577	3,6373	0,0908
Df	4	2	4	2
P-Value	0,0677	0,1076	0,4573	0,9556
Occupancy rates of the hotels will decrease	**Age**	**Gender**	**Education**	**Industry**
X-Squared	11,6910	11,1390	7,5796	4,1373
Df	4	2	4	2
P-Value	0,0198	0,0038	0,1083	0,1264

difference in the perception of the respondents regarding the impact of COVID-19 on housing prices, gross sales of shopping malls, and the occupancy rates of hotels based on different age groups. Gender was also found an important indicator of the direction of the housing prices and the occupancy rates of the hotels. While the industry background was an important indicator of the direction of the total number of sales to foreigners during the COVID-19 period, the education level had no statistically important effect on the perceptions of the respondents in any researched subject area. The results of the analysis are summarized in Table 3.

7 Discussion and Conclusion

The Turkish real estate industry has been growing for the last two decades but has also been experiencing difficult times due to the negative economic developments that started even before COVID-19. The depreciation of the Turkish Lira against many currencies, high inflation, and volatile interest rates have been affecting the real estate sector negatively. The currency crisis in 2018 had a damaging effect, and within two years before the pandemic, the sector had started getting recovered partially.

During the early stages of the pandemic when transportation stopped, international trade slowed down and a curfew was applied in many countries, the recovery in the Turkish real estate industry stopped, the home sales decreased, the vacancy rates of the offices increased, and the shopping malls were shut down and the hotels became empty. During this early period, a survey was conducted to get the perception of the people living in Turkey about the possible prolonged impact of the pandemic on housing, commercial, retail, and tourism industries. It was assumed that due to the pandemic, the demand for large and detached houses (to have additional rooms to work from home, to have windows to open to have an access to clean air, etc.) especially outside of the metropolitan areas may increase and that could increase the housing prices. Due to the continuous devaluation of the Turkish Lira, the Central Bank may increase the interest rates and that may have increased mortgage interest rates. The closed border may also affect international flights and the sales to foreigners may also be negatively affected by COVID-19. It was obvious that people would prefer online shopping to decrease their contact with others and that could decrease the gross sales in shopping malls. The restrictions applied in travel and the hesitation of people to go for vacations in crowded areas could also negatively affect the occupancy rates in hotels. The distance working may decrease the demand for offices, and the vacancy rates of the offices might increase.

During the pandemic, many central banks preferred monetary expansion, and that created a rise in inflation. Many central banks including the Federal Reserve of the US (FED) and the European Central Bank (ECB) did not increase their interest rates for a long time. The ongoing war between Russia and Ukraine also increased the speed of inflation due to the sharp rise in energy and food prices. FED started increasing the interest rates in the last few months, and the USD started gaining value against many currencies including the Turkish Lira. During the pandemic period, the Turkish government tried a different economic model where the central bank continuously decreased the interest rates and the Turkish Lira constantly kept depreciating. This policy increased inflation sharply and investing in real estate, especially in housing, become a tool to protect the purchasing power of people against the rising inflation. The construction costs kept also increasing because of the currency increase and inflation, and eventually, the housing prices increased during the pandemic period. The devaluation of TL also increased the demand for foreigners in the Turkish housing market and had an upward impact on housing prices. The housing rent prices also increased very fast. That rapid increase created a price bubble risk in the housing industry, and the prices should be followed carefully.

During COVID-19, the demand for offices decreased, but in the last few quarters, when the companies started inviting their employees to offices slightly increased the demand and the vacancy rates gradually decreased. The Pandemic also changed the purchasing habits of the customers. The rising trend in online shopping may make shopping mall investors reconsider the store mixes based on the changing demand and trends. The tourism sector also started getting recovered gradually after the government removed all the restrictions including wearing masks, using disinfection, etc.

This study compared the perception of the people about the impact of COVID-19 in the early stages of the pandemic with the real estate market data. According to the survey results, the respondents who considered the housing price increase and decrease in the pandemic period were almost the same, but the housing prices doubled in the COVID-19 period. 35% of the participants thought that the mortgage interest rates would decrease, except for the second quarter where the rates decreased for a small period by providing incentives to homebuyers, the mortgage interest rates were increased in 2020 and 2021. While more than 50% of the participants thought that the total housing sales to foreigners will decrease, these figures increased by 30% in 2021 after a 10% decline in 2020 due to travel restrictions. Despite the distance working option, the vacancy rates of the offices especially in the central business district (CBD) decreased in 2020. The decrease in gross sales in shopping malls and decrease in occupancy rates in hotels during the COVID-19 period were predicted accurately by more than 70% of the respondents respectively. This research, being one of the most comprehensive studies that is covering the Turkish real estate industry during the COVID-19 period, aims to provide insight for the developers and investors while determining future investment strategies.

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Evaluation of Understandability of the Concept of Sustainability by Companies: Automotive Sector Spare Parts Industry

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Abstract. In this study, it is aimed to show how the companies working in the spare parts industry in the automotive sector support the concept of sustainable development and to give an idea about the effect of sustainability as an added value activity that increases productivity. In the sustainability analysis of the TR62 (Adana-Mersin) region automotive spare parts sector in our country, a qualitative research method was used and certain questions were asked to the companies under the dimensions of economic, social, and environmental sustainability. The findings obtained in line with the answers received were examined in detail under the headings of sustainability. It can be qualified that the companies providing spare parts in the automotive sector have general sustainability perspectives and sensitivities about sustainability dimensions. A comprehensive analysis of sustainability in the automotive spare parts industry and the findings reveal the originality of the study by considering the contribution to the literature. With this study, spare parts companies can determine their position in terms of sustainability criteria, put the works to be implemented in the order of operations, and adapt the general sustainability framework to their company.

Keywords: Automotive industry · Spare parts sustainable development · Sustainability · TR62 region

1 Introduction

The automotive industry sector is a sector that covers a wide audience such as vehicle manufacturers, manufacturers that produce assembly and/or spare parts, maintenance and service stations, sales points, and after-sales services (Göral 2009). While all automotive parts were produced by the main automotive manufacturer until the 1960s, the automotive spare parts industry emerged with the increase in capacity and investments over time. Since the mid-1960s, Turkey has started to operate together with automotive spare parts companies with its important advantages such as quality production, product diversity, geographical location, and workforce. Today, most of these companies continue their activities under the name of SME businesses.

The automotive spare parts industry is one of the leading industrial branches of our country, where technology is developing the fastest. This sector has features that increase

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the competitiveness of the country's economy with its continuous investment, technical employment, and export activities. The Turkish automotive spare parts industry provides approximately 25 million spare parts per year to vehicles with around 5000 companies with large capacity, wide product range, and high product standards (Dinç 2017). For this reason, many automobile manufacturers have become obliged to make efforts to integrate sustainability into their business strategies and activities and to integrate sustainability practices. The automotive sector, which is among the sectors that will gain momentum in the near future in Adana, is already in a good position regionally.

The concept of sustainability; is defined as meeting the needs of today without consuming future resources, on the basis of and respecting the prudent and balanced use of the social, cultural, scientific, natural, and human resources of the society (Gladwin et al. 1995). This concept can be achieved by the limited use of natural resources, minimizing waste, and reducing the negative social and environmental impacts of supply chain practices (Darbari et al. 2015). For the continuity of sustainability; environmental protection, economic growth, and social development concepts should be managed in a balanced way. From the perspective of businesses, sustainability can be realized with a management approach where company interests do not conflict with social interests, and not only economic growth but also social and environmental issues are taken into account. In this context, sustainable development, which is seen as a long-term development model aiming at the optimum use of resources, in which sustainability criteria are taken into account, defines the needs of current generations as a system that transfers the needs of current generations to future generations without rendering natural resources non-renewable and without irreversibly destroying the environment (Freman and Soete 2003). In sustainable development, the protection of biological and physical balances can be expressed as the environmental dimension, the human-centered social dimension, and the optimal use of scarce resources can be briefly expressed as the economic dimension (Tıraş 2012).

While the automotive spare parts industry, which is an important trigger of economic development, makes significant contributions to sustainability with its wide range of employment, employee satisfaction, and opportunities offered by companies; Uncontrolled use of energy in the production process, water consumption, and harmful wastes released to the environment cause sustainability to be negatively affected.

The main purpose of this study is to analyze the sustainability practices of the manufacturers operating in the automotive spare parts industry in the TR62 (Mersin-Adana) region. The study makes a preliminary assessment of the place and importance of the sustainable approach in the automotive spare parts industry and offers suggestions for possible measures and steps to be taken.

2 Literature Review

In this section, the sustainability studies in the literature are examined on three important criteria (environment, social and economic) and the sustainability practices in the automotive sector are discussed.

An environmentally sustainable system is possible by avoiding the overexploitation of renewable resource systems and only adequately consuming non-renewable resources

(Gedik 2020). Govindan et al. (2013) examined the environmental criteria of sustainability as obtaining appropriate environmental certificates, implementing environmental protection activities, and strengthening natural resources. Jorgensen et al. (2020) considered the environmental sustainability criterion as reducing resource consumption in the land, energy, and water use. Lyytimäki (2019) drew attention to the increase in green production, products that produce recyclable waste and consume less energy in their production. Chardine-Baumann and Botta-Genoulaz (2014) included the reduction of emissions in soil, air, and water pollution as well as produced harmful substances. In order to ensure environmental sustainability, it is necessary to protect biodiversity, minimize the use of non-renewable resources, design recyclable products, and ensure that environmental sustainability plays an active role in the production of new services and products (Morelli 2011).

A socially sustainable system means equality among all members of the society in many fields such as health, education, nutrition, housing, gender and culture, the integrity of the society, and working towards common goals. Govindan et al. (2013) aimed to protect the health and safety of customers while offering products and to make improvements in product transfer to consumers, for customer values in social sustainability. Employee satisfaction and the working environment and conditions that trigger it are also important criteria of social sustainability in achieving a certain standard and quality level in the product. Considering the working environment, Amrina and Yusof (2011) included subjects such as reducing safety and health problems, preventing discrimination, and supporting employee careers in their studies.

An economically sustainable system should be able to produce goods and services on a certain basis, manage the government's external debt, and avoid sectoral imbalances that harm production (Holmberg and Sandbrook 1992). The most accepted definition of a sustainable economy is the preservation of capital and the prevention of its deterioration (Goodland 2002). The economic sustainability dimension Jha et al. (2020) considered it as a reduction in production, supply, and distribution costs. In addition to these cost reductions, Govindan et al. (2016) also included improvements in shipping time, on-time delivery rates, and product and service quality.

The biggest goal of the automotive industry within the scope of sustainability is to produce environmentally friendly, sustainable vehicles with a focus on technology. The top priority in this industry is to design vehicles that save fuel and contribute to sustainable transportation. In addition to the economic added value of the sector, it is aimed to minimize the damage to nature (Sofyalıoğlu and Kaçmaz 2020). Koplin et al. (2007) argued that the products produced in the automotive industry cause negative effects on people and nature throughout their life cycle, which is a factor that increases the pressure on this industry. This pressure on the sector also directly affects the automotive spare parts industry. It requires the main and sub-industry companies in the automotive sector to use an optimized level of sustainability performance in an integrated manner.

In the institutional sense, it has been predicted that companies are working on sustainability, but it has been the subject of curiosity the study whether SME companies are at what stage of the sustainability era.

3 Methodology

This study includes obtaining the practices of companies producing in the automotive spare parts industry on environmental, economic, and social sustainability criteria, through question-answer data collection. The study consists of a total of 35 questions, 29 of which include the sustainability criteria and 6 that show the demographic characteristics of the respondents. There are companies that contribute to the automotive spare parts industry operating in the TR62 region. Questions including sustainability factors prepared on Google forms were sent to the companies and only 14 companies responded.

This study, which deals with the manufacturing enterprises (OEM (Original Equipment Manufacturer, OES (Original Equipment Supplier), OEP (Original Equipment Part)) operating in the automotive spare parts industry, is a study in which sustainability can be evaluated. The questions used in the study were prepared by taking into account the environmental, social, and economic dimensions, which are the three main criteria of sustainability (TBL) (Table 1). Likert scale values from 1 to 5 between companies paying attention to these criteria or not ((5) definitely pay attention, (4) some attention is paid, (3) I have no idea, (2) partially not paid attention, (1) definitely not taken into account). Company representatives answered the questions by choosing the scale values suitable for them, and the findings were supported with graphics throughout the study in line with these explanations.

Table 1. Questions about sustainability

Code	Data collection questions	Sustainability dimensions
Q1	Use of ISO 9001 Quality Management System Standard in your company	ENVIRONMENT
Q2	Use of ISO-TS 16949 Automotive Quality Management System Standard in your company	
Q3	Having ISO 50001 Energy Management System certificate in your company,	
Q4	Having ISO 14001 Environmental Management System certificate in your company	
Q5	Use of water-based paint to prevent air pollution in your company	
Q6	The return levels for the products in your company	
Q7	Waste management studies in your company	
Q8	Your company has ISO 14064 Greenhouse Gases Calculation and Control Standard certificate	
Q9	To reduce water consumption in your company	
Q10	Having a Zero Waste certificate in your company	

(*continued*)

Table 1. (*continued*)

Code	Data collection questions	Sustainability dimensions
Q11	To prefer renewable energy sources in order to prevent emissions in your company	
Q12	The use of bio-based materials in vehicle parts to reduce fuel consumption and CO2 emissions	
Q13	To prepare projects to reduce the wastes generated during production in your company	
Q14	End-of-life analysis of the product in your company	
Q15	Product Life Cycle Evaluation studies in your company	
Q16	OHS standards in your company	SOCIAL
Q17	Working environment and human rights in your company	
Q18	Employee productivity and satisfaction in your company	
Q19	Women's employment and equal opportunities in your company	
Q20	Sharing your company's environmental and energy policies with employees through continuous training	
Q21	Talent management and vocational training for employees in your company	
Q22	Customer satisfaction in your company	
Q23	Education status of senior executives in your company	
Q24	R&D studies and investments in your company	ECONOMIC
Q25	Studies on lightening product/vehicle weights in your company	
Q26	Use of equivalent composite materials instead of steel and aluminum in your company	
Q27	Project studies related to increasing energy efficiency/savings in your company	
Q28	Digital factory concept applications in your company	
Q29	The level of institutionalization of your company	

According to the questions posed to the companies in line with Table 1, the factors that businesses consider most important in terms of environmental sustainability are; Using the ISO 9001 Quality Management System Standard, which produces to meet customer satisfaction, and the ISO 14001 Environmental Management System certificate, which ensures that the production process is realized by taking into account the negative effects on the environment (Table 2). These factors, respectively, provide continuous improvement in the automotive industry supply chain and assembly process, emphasizing defect prevention and reducing variation and waste, use ISO-TS 16949 Automotive Quality Management System Standard and ISO 50001 Energy, which is used to increase operational efficiency, save energy and reduce costs. Management System Certification is followed. In general, the quality certificate status of the enterprises is given in Table 2.

Table 2. Number of quality certificates of enterprises

Quality Status Certificate	Number	Percent (%)
ISO 9001	8	57,14
ISO 14001	8	57,14
ISO 9001 and ISO 14001	6	42,86
ISO-TS 16949	8	57,14
ISO 50001	3	21,43
ISO 14064	4	28,57
Zero Waste Certificate	3	21,43

The importance given to waste management studies and practices in the evaluation of environmental sustainability shows a parallel level with the sensitivity of companies in waste management towards the environment and the fact that they hold a Zero Waste Certificate. Partial attention is paid to waste management in general, and it can be stated that approximately 71% of the companies hold a Zero Waste Certificate. The use of renewable energy sources should be preferred in order to prevent emissions that occur with waste management control in the spare part production process. With the use of these resources, energy saving, environmental protection, and sustainability can be achieved in the sector. The attention levels of the enterprises that include the use of renewable

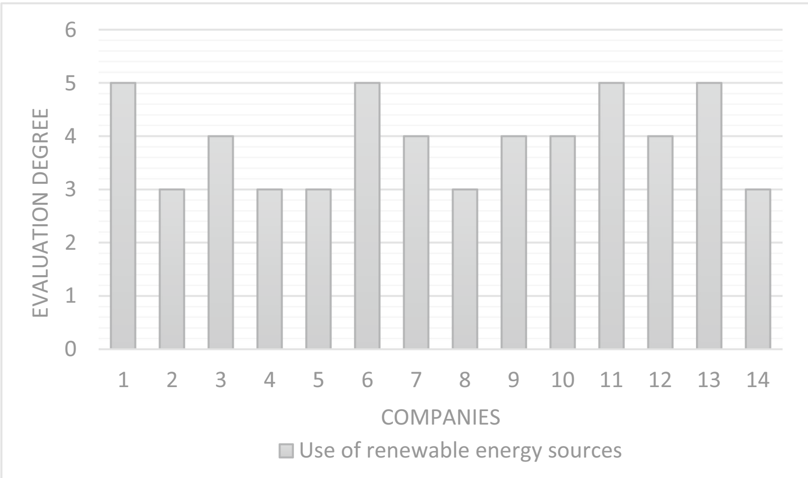

Fig. 1. Uses of renewable energy resources by companies

energy in the automotive spare parts industry sector in our country are presented in Fig. 1. Approximately 65% of the companies stated that they pay attention to using renewable energy sources. The remaining 35% should not be underestimated for energy consumption. All other employees, especially the managers of the relevant companies, should be informed about the use of renewable energy sources and their importance and should be encouraged.

Environmental protection and sensitivity should not be limited to the production process. The vehicle parts produced should be long-lasting, light, high-strength materials, but at the same time, they should be parts that provide low fuel consumption and aim to reduce CO_2 emissions. Components should be manufactured at an optimized level, taking into account their life cycle, and designed to have the highest recycling rates. End-of-life analysis should be made on the spare parts that are recycled, and the points that can be improved should be determined and evaluated. As a result of our research, life cycle evaluation and end-of-life analysis studies on spare parts produced in our country are presented in Fig. 2. Although it is observed that these studies are given partial attention on average, there are fluctuations in the graph that include the information that they are not paid attention. The importance given to the field of environmental sustainability can be increased by supporting it with R&D investments as a result of the analyzes made.

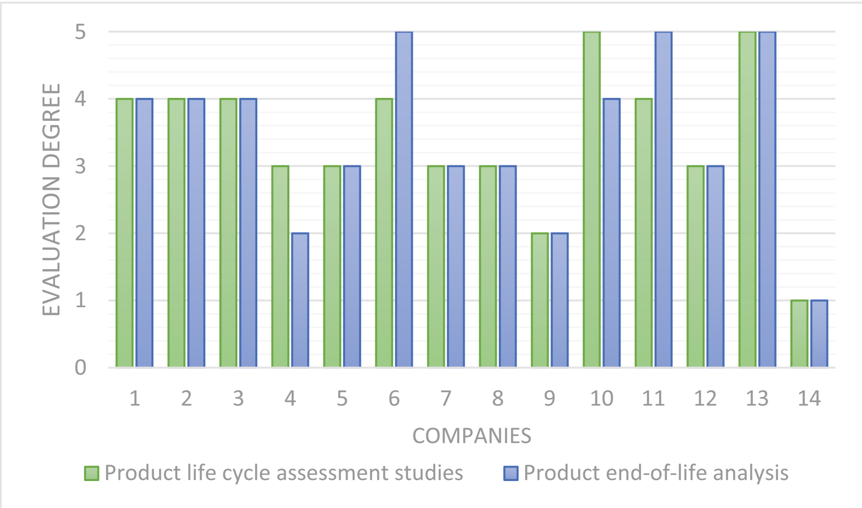

Fig. 2. Product life cycle and end-of-life evaluation studies of companies

The factor that businesses consider the most important in terms of social sustainability; is the importance given to the level of customer satisfaction. This is followed by the importance given to Occupational Health and Safety (OHS) standards and employee productivity and satisfaction, respectively. In the social sustainability criterion, all criteria other than customer relations and satisfaction are related to all personnel within the company (Table 1). The most basic of these criteria is the appropriate working environment, equal opportunities, and respect for human rights, which paves the way for employee satisfaction. The survey results on these criteria are shown in Fig. 3. All kinds of factors that will adversely affect the health and motivation of personnel should be avoided not only in the automotive industry sector but also in all other production and service sectors. The importance of the personnel for the product and the company should be brought to the agenda frequently, and the personnel should be supported with incentives and awards without discrimination.

Fig. 3. Social factors considered by firms for their personnel

About 65% of the firms indicated a certain level of importance for the factors outlined in Fig. 3, describing employee standards. Each of these factors has positive results for each other and supports each other, and can directly increase employee performance and subsequently product quality.

Digital factory concepts, which offer new opportunities by optimizing traditional ways of doing business, contribute to economic sustainability by reducing product costs. Figure 4 shows the attention levels of the companies participating in the study to digital factory concept applications. It is important in terms of all criteria of sustainability to see that approximately 79% of companies include these applications in the conditions of the Covid-19 Pandemic, which is on the world agenda today. Digitalization applications, which take place in many stages from production to consumption, should be supported and increased with relevant R&D investments.

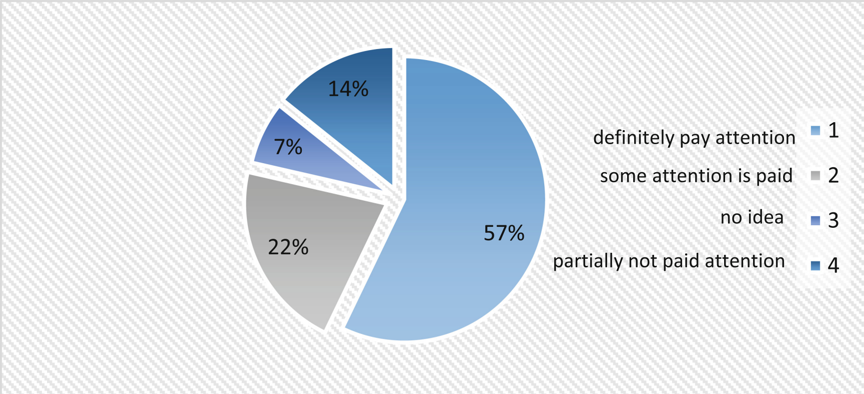

Fig. 4. Digital factory concept applications of companies

4 Conclusion

The automotive industry is in a position that should consider sustainability in the global world and plays an important role in the socio-economic development of the world. The spare parts industry is an industry branch that has a significant market share in the automotive sector and can solve serious problems in all three dimensions in terms of economic, social, and environmental aspects. Known as the "Triple Bottom Line", these three dimensions (economic, social and environmental) form the basic structure of sustainability and if desired, the main dimensions can be developed. The main purpose of this study, which takes into account sustainability in the automotive spare parts industry, is to reach the companies located in the TR62 region in Turkey, to reveal the general sustainability framework of the spare part industry as a result of the responses from them, and to contribute to improvement studies by analyzing the findings.

For this purpose, the first study was to determine the questions to be asked to the companies with the literature gains under the economic, social, and environmental dimensions.

For the sustainability criteria determined, feedback was received from 14 companies working in the spare parts industry for the Adana-Mersin region through Google forms. The findings showed that the companies working in the spare parts industry have a tendency towards sustainability.

The factors that businesses consider most important in terms of environmental sustainability; Using the ISO 9001 Quality Management System Standard, which produces to meet customer satisfaction, and the ISO 14001 Environmental Management System certificate, which ensures that the production process is realized by taking into account the negative effects on the environment. These factors, respectively, provide continuous improvement in the automotive industry supply chain and assembly process, emphasizing defect prevention and reducing variation and waste, use ISO-TS 16949 Automotive Quality Management System Standard and ISO 50001 Energy, which is used to increase operational efficiency, save energy and reduce costs. Management System Certification is followed.

The sensitivity of the companies in waste management towards the environment and the fact that they have a Zero Waste Certificate show a parallel level. Again, in the spare part production process, the use of renewable energy sources should be preferred in order to prevent emissions that occur with waste management control. With the use of these resources, energy saving, environmental protection, and sustainability can be achieved in the sector. In addition, the vehicle parts produced should be long-lasting, light, high-strength materials, as well as provide low fuel consumption and aim to reduce CO2 emissions. Components should be manufactured at an optimized level, taking into account their life cycle, and designed to have the highest recycling rates.

The factor that businesses consider the most important in terms of social sustainability; is the importance given to the level of customer satisfaction. This is followed by the importance given to Occupational Health and Safety (OHS) standards and employee productivity and satisfaction, respectively.

In the field of economic sustainability, Research and Development (R&D) studies, which express systematically carried out creative research studies and the use of knowledge to create new applications, have been the most important factor. Another factor that is considered important in economic sustainability for businesses is the level of institutionalization and digitalization practices of the company.

With the analysis of the results, the tendency toward sustainability studies in the automotive spare parts industry draws attention. It is important that sustainability-based practices are at the forefront of the efforts that companies will make to keep up with the changing world agenda.

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Usability Evaluation of Maritime Websites with Different End User Groups

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Abstract. Maritime-related websites should be properly developed to guarantee a good level of usability, especially when end users comprise a variety of people with varied wants and desires. This study's primary goal was to examine how various end users with different use purposes—including members of the working population in the maritime sector, maritime students, and seafarers' relatives—react to maritime websites in terms of usage efficiency, satisfaction, which collectively form websites' usability. The assessments were obtained through formal usability testing including think-aloud protocol during task performing and questionnaires. The results of the statistical analysis show that different groups of end users achieve different levels of efficiency in the completion of tasks. Also, it has been found that only for students there is a satisfaction difference between evaluated maritime websites. Suggestions to enhance websites' usability, particularly for inexperienced users, based on the identified weaknesses are also provided.

Keywords: Maritime · Usability evaluation · Maritime websites · Turkey

1 Introduction

A total of 5 billion people around the world use the internet today – equivalent to 63% of the world's total population. Internet users continue to grow at an annual rate of more than 4%, and current trends suggest that two-thirds of the world's population should be online by the middle of 2023 (Datareportal 2022). For millions of people, the internet and websites are vital resources for finding and retrieving information. Users of websites often obtain desired information quickly and easily (Roy et al. 2014). These behaviors are influenced not just by technical aspects of the Internet, Web, and website design, but also by users' attributes, such as demographics (gender, age range, culture, and language), educational level, experience, computer literacy, and occupation (Yoon et al. 2016). Users establish their own set of wants and expectations based on a mix of these features. As a result, requirements and expectations are more varied, as end users represent a wide group of people with various traits (Kous et al. 2020). There are studies on very different user groups such as government employees, academics, electronic sales representatives, health care workers, tourism workers, students, and service sector

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workers (Gale et al. 2021; Gopinath et al. 2016; Muhtaseb et al. 2012; Goncalves et al. 2018). For instance, there are younger web users who have grown up with information technology and anticipate high levels of functionality from websites. Senior users, on the other hand, are struggling with physical and cognitive changes as they age. They frequently need a website that is easy to use and comprehensive. A website for elderly users should also be free of distractions, have bigger fonts, and have sound signals within specific frequency ranges (Djamasbi et al. 2010; Wagner et al. 2010). All groups of web users are increasingly expecting improved website functionality, user-friendliness, and usability.

Usability is a very important factor in the evaluation of the website for the user (Djamasbi et al. 2010; Okhovati et al. 2017; Xie 2006). When end users are represented by a varied group of people, it is more difficult to ensure website usability since everyone expects the website to be developed to meet their requirements and expectations. It is vital to identify and analyze genuine end consumers to design a website that will be used by as many people as feasible (Albert and Tullis 2013; Albert et al. 2010; Battleson et al. 2001). When the existing literature is examined, it can be seen that website usability studies have been conducted on different types of websites; library, university, electronic commerce, and sales websites can be given as examples of those studies (Lin et al. 2011; Anyaoku and Akpojotor 2020; Ibrahim et al. 2020; Emre et al. 2018). However, no study has been conducted in the field of maritime that examines website usability comparatively. As in the rest of the world, digitalization and the use of websites are increasing rapidly in the maritime field. Finding the instant location of the ship, calculating the route, seeing the characteristics of the ship, and looking at the time zone of the ship's location are some of the features offered by these websites. User profiles of these websites are quite diverse in terms of the features used. Examples of users are maritime students, people working in the maritime field, people working on ships, and people with close relatives working on board. Therefore, a website's usability is highly important to appeal to a wider audience. To test usability for different groups, three different groups will be used in this study; students, seafarers' relatives, and maritime workers. Different tasks will be assigned in line to use the websites for each group, and a usability analysis will be done based on the tasks. Then, a survey will be conducted to measure the level of satisfaction. Considering the gap in the literature, this study aims to analyze the usability of two maritime websites from the perspective of three user groups.

2 Literature Review

When the existing studies are examined, it is seen that website usability analyses and studies are carried out in various areas. For example, in the study conducted on academic library websites, to assess the three dimensions of usability; effectiveness, efficiency, and learnability, eighteen measurement questions were identified. The survey assessment technique proposed herein is appropriate for analyzing academic library website usability (Lin et al. 2011). The study on the websites of university libraries in South Nigeria has evaluated websites' usefulness, efficiency, effectiveness, learnability, and accessibility. In the study, 11 university library websites in the region were examined by conducting surveys within the scope of the study (Anyaoku and Akpojotor 2020). In another study, usability research was conducted for formal and distance education students. In the study, it was determined what type of difficulties the students receiving formal and distance education face in accessing the information they need and the behavioral differences between the two groups. Different tasks and surveys were conducted for both groups. In the conclusion part of the study, the problems faced by both groups were analyzed and solution suggestions were presented (Emre et al. 2018). In another study, library website analysis was conducted in terms of different user groups such as pupils, students, working population, seniors, and researchers. This study makes two major contributions: a link between the theoretical definition and practical use of ISO 9241-11 qualities and a usability testing technique with a measurement framework that can be applied to different types of users in a given area (Kous et al. 2020). In another study, university website usability was examined. This article presents a brief overview of the many usability evaluation methodologies utilized in university websites, with a particular emphasis on Multi-Criteria Decision Making (MCDM) approaches. From 2000 to 2018, a total of 35 scholarly publications were extracted from an internet database. Usability evaluation methodologies, MCDM approaches, and automated technologies were used to categorize the reviewed material. According to the findings of the trend study, the most often utilized usability evaluation methods are automated tools, heuristic evaluation, and user testing methods (Adepoju et al. 2019). There are also studies on the usability analysis of social media sites. In one study, various social media websites were analyzed in terms of overall load time, usability, smoothness, and interactivity, perceived performance and performance measurements (Jun et al. 2021).

3 Data and Methodology

User Groups: 18 people representing different user groups were determined as potential users of the website to be examined in the study. The first user group consisted of 6 undergraduate students from the maritime field. The second group included 6 seafarer family and friends. The final group included 6 people working in various areas of the maritime sector. Each user was tested individually. The tasks of the groups differ in terms of the purposes of using the site. The purpose of using the websites for students is mostly to follow the ship they will do their internship on, to observe the ships' features they learn about in the courses, and to have a general idea about the ships they are interested in. The usage purposes for seafarers' relatives are mostly to follow the ships their relatives are working on, to calculate the time difference, to follow the weather conditions where the ship is located, and to follow the ports they go to. The purpose of use for the working population is mostly to check the information of the ships they will transport goods with, to follow the ships instantly, to follow the exact arrival time of the ship, and to control the technical characteristics of the ship.

Test Design: Marinetraffic is an open, community-based project that provides real-time information on the movements of ships and their current position in ports. Vesselfinder is a free AIS vessel tracking website. Both websites are among the most used websites in the maritime industry in terms of features such as calculating the route of the ships, displaying the instant position of the ship, displaying the information of the ship, etc.

Both websites are used by different users for different purposes in terms of the services and features they offer. 18 people participating in the study have never used these two websites before. Since each group has a different purpose for using the website, different tasks were assigned to each group and after the completion of the tasks, test subjects were asked to fill out a questionnaire. In each group, half of the subjects started the test session with one website, while the other half started with the other one. During this study, a think-aloud protocol was applied and data was obtained. The think-aloud methodology is a technique used to collect information during usability assessment in psychology, a variety of social sciences, and product design and development (Jääskeläinen 2010). Each participant expressed the problems they experienced while performing the tasks, the deficiencies they saw, and the solution suggestions by thinking aloud.

Tasks: Since the purpose of each group to use the website is different, some tasks for the groups have been determined differently. The tasks for each group are given in Table 1. The first three tasks of each group are the same, however, the 4^{th} and 5^{th} tasks are different based on the use of purpose of each group. The maximum completion time for tasks is set at 2 min. Users with a completion time exceeding 2 min will be considered unsuccessful in the missions.

Questionnaire Application: After performing the tasks on a website users filled out the WAMMI questionnaire. WAMMI questionnaire is a widely accepted tool to measure satisfaction in the usability literature (Kirakowski and Cierlik 1998; Norris et al. 2006; Steger et al. 2012; Claridge and Kirakowski 2016).

4 Results

4.1 Quantitative Results

Task Completion. In this section, the completion times of the given tasks by the groups will be examined. Users with a completion time exceeding 2 min will be considered unsuccessful in the missions. The times for all the tasks performed by each group are given in Table 2 in detail for the Marinetraffic and Vesselfinder websites. All participants completed all tasks within the predetermined 2 min limit.

Task Time. In this section, it will be shown in how many seconds the given tasks are completed by the groups. Since the first 3 tasks are the same for all groups, the total average completion time will be examined first, then the average completion time of each group will be examined separately to see the differences between the groups. In addition, the average completion times of tasks 4 and 5 will be examined. Figure 1 shows the evaluation of the first 3 tasks for all groups. To make this evaluation, first, the task completion time of the people in all groups was measured, then the average completion time was found by adding the completion time in all groups for each task and dividing it by 18, the total number of participants. For example, the completion time of task 1 for the Marinetraffic website was 8.51 s, while for the Vesselfinder website it was 9.15. On the other hand, the completion time of task 2 for the Marinetraffic website was 11.80 s,

Table 1. Tasks for each group

Groups	Tasks
Group 1: Students	1. Which ship does the IMO number 9707807 belong to? Search and find information about this ship 2. What is the estimated time of arrival of STI OSCEOLA? 3. What are the last ports of STI BOSPHORUS? 4. What is the draft of T LEYLA? 5. What is the length of the ship MT TRABZON?
Group 2: Seafarers' relatives	1. Which ship does the IMO number 9707807 belong to? Search and find information about this ship 2. What is the estimated time of arrival of STI OSCEOLA? 3. What are the last ports of STI BOSPHORUS? 4. What is the weather according to the instant position of the TRABZON ship? 5. What is the time difference between Turkey, according the current position of TRABZON?
Group 3: Working population	1. Which ship does the IMO number 9707807 belong to? Search and find information about this ship 2. What is the estimated time of arrival of STI OSCEOLA? 3. What are the last ports of STI BOSPHORUS? 4. What is the call sign of T LEYLA? 5. What is the flag and port of TRABZON?

Table 2. Demographic characteristics of groups and completion time of tasks (s).

Participants				Marinetraffic/Vesselfinder				
Gender	Age	Education	Internet usage time (daily)	Task 1	Task 2	Task 3	Task 4	Task 5
Male	22	Undergraduate	5 h	5.50/6.30	10.20/12.55	9.50/10.21	9.12/9.20	12.20/13.18
Female	22	Undergraduate	8 h	6.30/5.21	11.22/16.15	13.26/8.20	10.35/11.44	13.30/14.22
Female	21	Undergraduate	9 h	5.40/6.55	9.67/12.23	8.40/8.54	8.20/9.24	12.22/10.28
Female	21	Undergraduate	7 h	6.20/9.11	10.25/10.33	7.50/8.56	6.21/12.22	6.10/8.45
Male	22	Undergraduate	12 h	4.50/5.21	10.60/5.56	10.10/6.50	9.28/12.23	8.25/10.15
Female	21	Undergraduate	6 h	8.30/9.20	12.45/12.34	12.50/11.24	10.17/11.20	7.55/8.40
Female	45	Graduate	14 h	2.40/3.27	7.36/9.22	4.50/3.21	6.12/7.20	3.20/4.10
Male	40	Graduate	10 h	3.22/4.20	7.50/6.20	3.10/2.40	8.21/7.34	2.45/3.22
Female	29	Undergraduate	11 h	4.17/2.50	6.20/8.55	2.50/3.28	5.22/6.40	4.10/3.18
Female	28	Undergraduate	9 h	4.25/3.10	7.50/4.50	4.36/4.40	7.44/5.20	2.20/4.22
Female	30	Graduate	12 h	2.26/3.30	5.44/6.55	4.20/3.10	5.12/4.33	3.33/4.48

(*continued*)

Table 2. (*continued*)

Participants				Marinetraffic/Vesselfinder				
Gender	Age	Education	Internet usage time (daily)	Task 1	Task 2	Task 3	Task 4	Task 5
Male	26	Graduate	8 h	3.10/2.27	6.26/6.15	2.50/2.43	4.48/5.44	4.45/3.26
Male	57	Undergraduate	5 h	14.21/13.10	20.52/26.30	15.40/16.22	18.26/17.39	21.44/25.26
Female	55	Undergraduate	5 h	19.27/24.31	17.52/17.10	19.20/21.33	18.21/17.38	21.05/20.22
Male	51	Undergraduate	6 h	13.22/14.32	19.40/18.32	14.33/16.21	13.21/11.35	12.45/17.34
Female	45	Undergraduate	7 h	14.25/14.10	15.40/13.33	11.20/10.32	12.32/17.35	12.44/13.52
Female	42	Undergraduate	5 h	23.24/24.50	17.50/16.45	13.42/12.30	18.41/17.39	12.46/13.24
Male	39	Undergraduate	8 h	13.52/14.30	17.50/16.44	13.31/12.50	18.24/17.36	12.44/13.2

while it was 12.11 s for the Vesselfinder website. The average completion time for task 3 is 9.29 s for Marinetraffic and 8.94 s for Vesselfinder. For the first two tasks, Marinetraffic has lower averages.

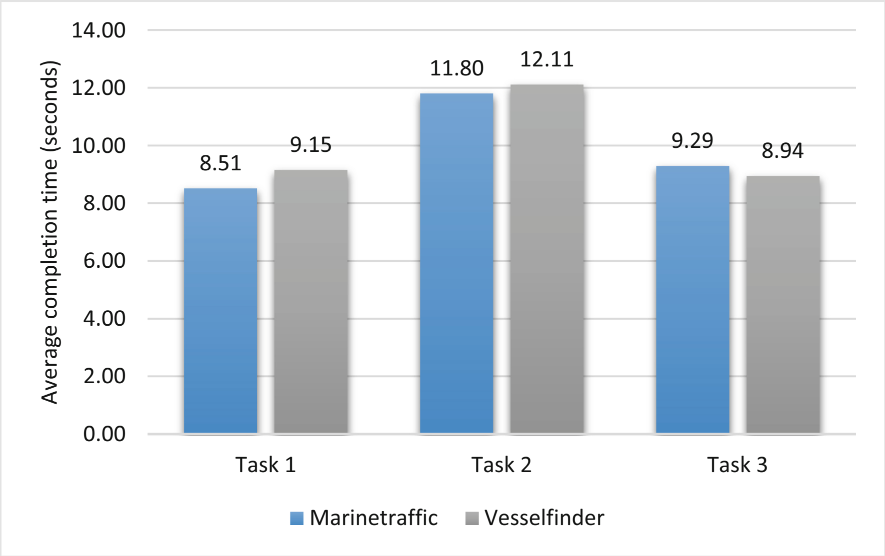

Fig. 1. Illustration of average completion time for tasks 1-2-3

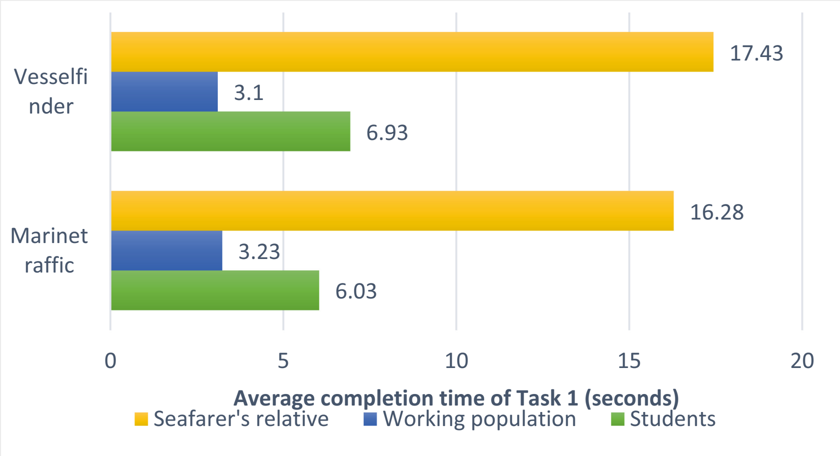

Fig. 2. Illustration of average completion time for task 1

When the completion time of task 1 is analyzed in terms of groups, the average completion time for the working population is 3.23 s for the Marinetraffic website, and 3.10 s for the Vesselfinder website as can be seen in Fig. 2. When the student group is examined, the average completion time for the Marinetraffic website is 6.03 s, while it is 6.93 s for the Vesselfinder website. The average completion time for seafarers' relatives was 16.28 s for the Marinetraffic website, while it was 17.43 s for the Vesselfinder website.

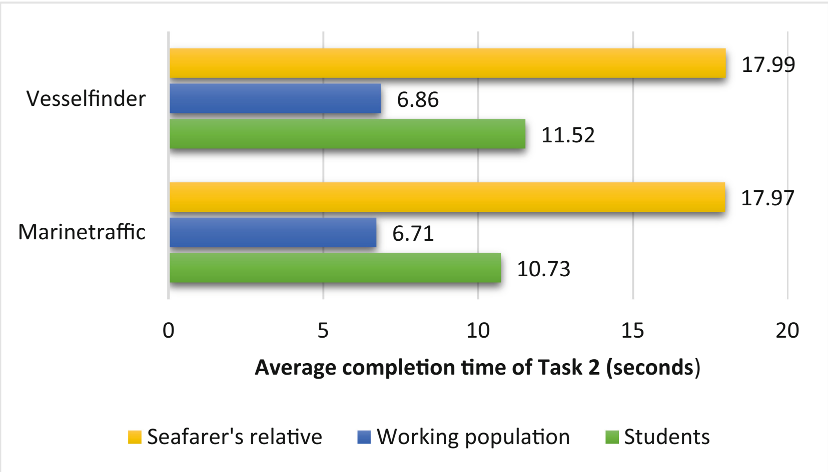

Fig. 3. Illustration of average completion time for task 2

The average completion time of each group for task 2 is given in Fig. 3. The average completion time for the working population group is 6.71 s for the Marinetraffic website, and 6.86 s for the Vesselfinder website. When the student group is examined, the average completion time for the Marinetraffic website is 10.73 s, while it is 11.52 s for the Vesselfinder website. The average completion time for seafarers' relatives was 17.97 s for the Marinetraffic website, while it was 17.99 s for the Vesselfinder website.

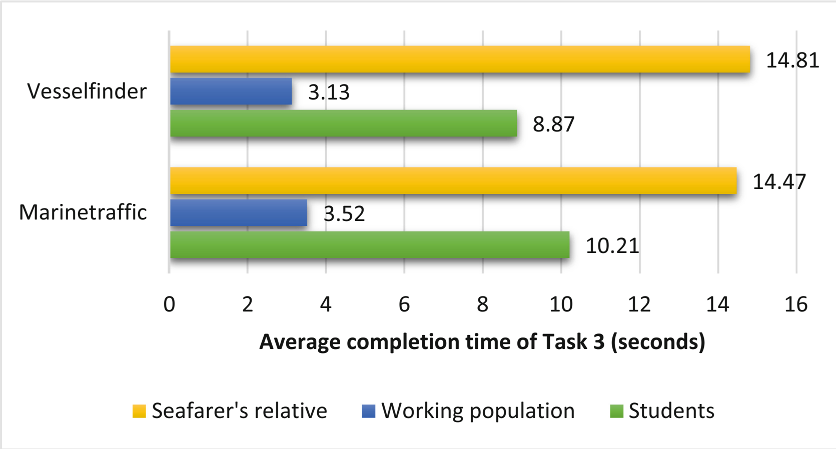

Fig. 4. Illustration of average completion time for task 3

For Task 3, the average completion time of the tests performed on the Marinetraffic and Vesselfinder websites for each group is given in Fig. 4. The average completion time for the working population group is 3.52 s for the Marinetraffic website, and 3.13 s for the Vesselfinder website. When the student group is examined, the average completion time for the Marinetraffic website is 10.21 s, while it is 8.87 s for the Vesselfinder website. The average completion time for seafarers' relatives was 14.47 s for the Marinetraffic website, while it was 14.81 s for the Vesselfinder website. Across all 3 tasks which were shared by all user groups, the average task completion times for the working population on both websites are the shortest.

Since the fourth task is different for each group, it has been analyzed separately and shown in Fig. 5. Accordingly, while the average time of the relatives of seafarers for the fourth task on the Marinetraffic website was 16.44, the average time was 16.37 s with the Vesselfinder website. At the same time, the average completion time for students on the Marinetraffic website was 8.88, while it was 10.92 s for the Vesselfinder website. The working population average completion time is 6.09 s for Marinetraffic versus 5.98 s for Vesselfinder.

The average completion time for the fifth task is given in Fig. 6. When using the Marinetraffic website, it took 3.28 s on average for the working population users to complete the task, compared to 3.69 s on Vesselfinder. For the students' group, on the Marinetraffic website, the task was completed in 9.93 s on average, however, with the Vesselfinder website, the average time was 10.78 s. Finally, when the seafarers' relatives performed the task on the Marinetraffic website, they completed the task in 15.38 s on average, while on the Vesselfinder website task completion took 17.14 s.

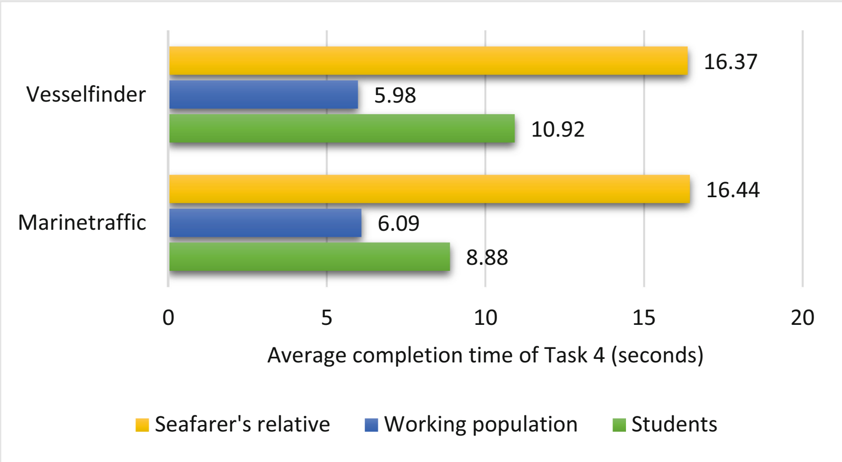

Fig. 5. Average completion time of task 4 for each group

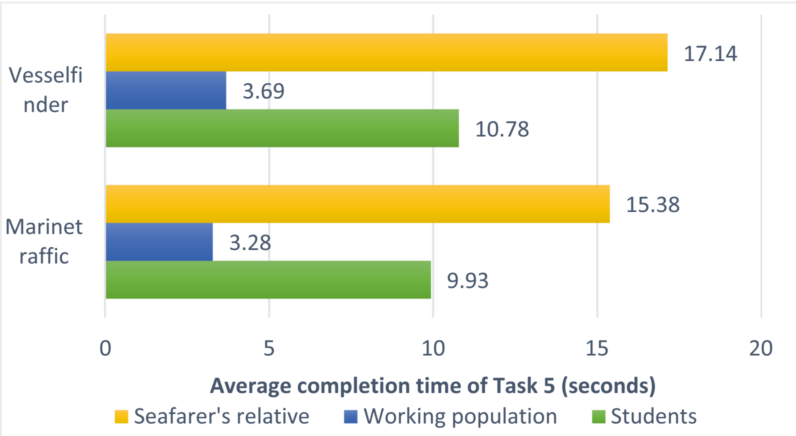

Fig. 6. Average completion time of task 5 for each group

Due to small sample sizes, non-parametric tests have been adopted to examine the differences statistically between groups and between websites. A Kruskal-Wallis H test showed that there was a statistically significant difference in completion times for task 1-2-3 between different groups on both websites. When Task 1 is examined statistically significant differences between groups on both websites have been observed (with $\chi 2(2) = 15.158$ $p = 0.001$ on Marinetraffic and with $\chi 2(2) = 15.174$ $p = 0.001$ on Vesselfinder), with a mean rank task completion of 9.50 for students, 3.50 for the working population, 15.50 for seafarer's relatives on Marinetraffic, while mean rank task completion time of 9.50 for students, 3.50 for the working population and 15.50 for seafarer's relatives on Vesselfinder. The pairwise comparison revealed a significant difference between the working population and seafarer's relatives' performance on both websites

($p = 0.000457$ for Marinetraffic, $p = 0.000466$ for Vesselfinder). Another Kruskal-Wallis H Test run for Task 2 has also shown that there are statistically significant differences in task completion times between groups on both websites, with $\chi 2(2) = 15.189$ $p = 0.001$ on Marinetraffic and with $\chi 2(2) = 12.877$ $p = 0.002$ on Vesselfinder, with a mean rank task completion of 9.50 for students, 3.50 for the working population, 15.50 for seafarer's relatives on Marinetraffic, while mean rank task completion time of 8.83 for students, 4.33 for the working population and 15.33 for seafarer's relatives on Vesselfinder. The pairwise comparison revealed a significant difference between the working population and seafarer's relatives' performance on both websites ($p = 0.000352$ for Marinetraffic, $p = 0.000446$ for Vesselfinder). Also, the Kruskal Wallis H test run for Task 3 showed that there were significant differences in task completion time between the groups on both websites, with $\chi 2(2) = 14.377$ $p = 0.001$ on Marinetraffic and with $\chi 2(2) = 14.749$ $p = 0.002$ on Vesselfinder, with a mean rank task completion of 9.83 for students, 3.50 for the working population, 15.17 for seafarer's relatives on Marinetraffic, while mean rank task completion time of 9.67 for students, 3.50 for the working population and 15.33 for seafarer's relatives on Vesselfinder. The pairwise comparison revealed a significant difference between the working population and seafarer's relatives' performance on both websites ($p = 0.000402$ for Marinetraffic, $p = 0.000378$ for Vesselfinder).

When it is examined whether there is a difference between the websites for each group on a task basis, the Wilcoxon Signed-Ranks Test indicated that only the performance of the students for the fourth task was different between the Marinetraffic and Vesselfinder websites ($Z = -2.201$, $p < .028$), showing they performed significantly faster on Marinetraffic.

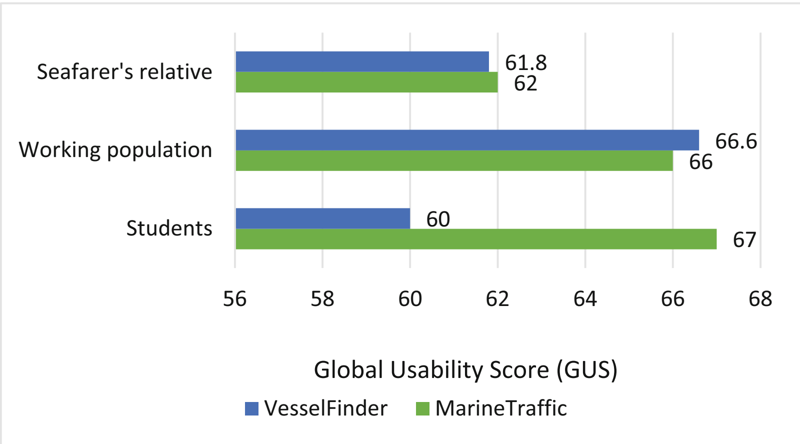

Fig. 7. Average satisfaction levels for each group on both websites

The satisfaction scores of the groups are given in Fig. 7. After calculating the individual score of each participant, the average scores of the groups were found. According to the WAMMI survey, the average score is 50, while the best score is 100 (WAMMI 2020). Based on the scores given in Fig. 7, it can be said that, for all groups, the satisfaction levels for both websites are above average. There were no differences between groups in terms of satisfaction both for Marinetraffic ($\chi 2(2) = 2.565$ $p = 0.277$), and Vesselfinder ($\chi 2(2) = 0.840$ $p = 0.657$).

When the satisfaction levels towards each website were examined on a group basis, it has been found that only for students there is a satisfaction difference between Marinetraffic and Vesselfinder websites. Wilcoxon Signed-Ranks Test indicated that students were significantly more satisfied with the Marinetraffic website ($Z = -2.032$, $p < 0.042$).

4.2 Qualitative Results

In this section, the most common two problem groups encountered on both websites and the comments of the users will be examined. The comments made by the participants as part of the think-aloud protocol while performing the tasks are shown in Table 3. Nielsen's 10 usability heuristics were used to group the problems faced by users and the comments they made (Nielsen 2005).

Table 3. Comment numbers

Heuristics related to comments	Students	Working population	Seafarer's relative	Total	%
Aesthetic and minimalist design	5	4	5	14	77
Help and documentation	6	5	6	17	94

Participants performed the think-aloud protocol while performing the tasks. In this way, the difficulties encountered and the shortcomings of the websites were noted. While performing the tasks, the seafarers' relatives and students had difficulties in detecting ship details, finding the length of the ship, routing, locating port information, and finding other information. In addition, seafarers' relatives had some difficulties interpreting the meaning of some maritime terminology words such as ETA (Estimated Time Arrival), ETD (Estimated Time Departure). Their meanings are not provided on the websites, so the task execution took longer. In addition, it has been reported that it was not very clear where to access the related information while performing tasks. The participants sought help and guidance as they were using the website for the first time. A total of 13 participants, six participants from students, five participants from the working population, and six from relatives of seafarers, faced this problem. These issues have been associated with Nielsen's help and documentation heuristic. As a solution to this problem, explanation information should be included on both websites. To understand various maritime terminology words when using the website for the first time, and to understand the features of the website, tooltips, directions, and various guides should be added to the website (Khajouei et al. 2018).

In addition to that, when accessing both websites, satellite positions of the ships and various other features are displayed directly on the home page. This has distracted participants who are visiting the websites for the first time while performing tasks, making the interface look very busy and complex. This also negatively affects the aesthetics of both websites. In addition, both websites have too many tools in the left and top navigation menus. This also increased the time taken by the participants to perform the tasks while they were working on both websites and made it difficult for them to access correct information. Five participants from students, four participants from the working population, and five participants from seafarers' relatives reported this problem. This problem has been associated with Nielsen's aesthetic and minimalist design heuristic, as it violates aesthetics and poses a problem for a more minimal design. As a solution, the elements that spoil the aesthetics, create noisiness and complexity, and adversely affect the design can be incorporated into a more minimalist design, which can make the design better (Baharuddin et al. 2013).

5 Limitations and Future Work

Some limitations need to be addressed in this research. Firstly, the number of participants used in the study can be considered as low. It was stated that a test with 5 people would be sufficient while performing a usability analysis, but this number could be increased in line with the availability of the research resources (Norman 2013). There were 18 participants in the study, 6 for each group. Group diversity and characteristics can be increased by increasing the number of participants for further studies to be carried out. Secondly, the number of tasks was kept low. This does not make it possible to analyze all functions of both websites. In further studies, by increasing the number and variety of given tasks, more functions of websites can be investigated and a more detailed study can be made.

6 Conclusion

In this study, different groups were included to analyze the usability of two websites used in the maritime field. Students, relatives of seafarers, and the working population are groups tested. Websites were analyzed qualitatively and quantitatively. In the qualitative results section, the verbal comments of the users while performing the tasks are discussed. Some of these are related to the intricate design of the website. In the quantitative results section, the completion times of the five tasks assigned to the groups were examined. The first 3 tasks given to each group were the same. Results indicated that for all three tasks, seafarers' relatives needed significantly more time compared to the working population. This may be due to their higher age and not being familiar with maritime terminology. When each task duration was analyzed on a group basis to see whether there is a difference between websites, it has been found that all groups performed similarly on both websites for all tasks, except task four done by the student group. For task four, students performed better on Marinetraffic. At the same time, questionnaires were filled out by the groups after the completion of the tasks to find out their satisfaction levels of the groups. Similar to the performance results on both websites, there were no significant satisfaction differences between websites for the seafarers' relatives group and the working population group. However, results indicated that the students are more satisfied with the Marinetraffic website. These results indicate that based on two usability dimensions, efficiency, and satisfaction, defined by ISO9241-11, Marinetraffic and Vesselfinder operate on similar usability levels for the majority of user groups (ISO/IEC 1998).

According to the comments made by the users during testing sessions, the adoption of a more minimal design, especially on the homepage, and providing a higher level of help and guidance were suggested for both websites to improve their usability.

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A Stochastic Multi-objective Model for Sustainable Soybean Supply Chain Network Configuration

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Abstract. Over the years, economic, environmental, and social challenges in the food sector have led researchers to focus on research on incorporating sustainability concepts into the design of food supply chains. This paper presents a new multi-objective model, using stochastic mixed-integer linear programming to design a sustainable agri-food supply chain network under an uncertain environment. Moreover, the presented model is applied to a Canadian soybean company. Total profit, total job opportunities, and CO_2 emissions are three objective functions in this model. Furthermore, to facilitate the decision-making process for decision-makers, the multi-objective model is solved using the augmented ε-constraint method. The results show that the model can perform well in an uncertain environment. Finally, the obtained results indicate the model's significance in incorporating all three sustainability dimensions for studying food supply chains.

Keywords: Sustainability · Soybean · Food supply chain configuration · Multi-objective programming

1 Introduction

As companies and decision-makers become more aware of the impact of sustainable development on the agri-food sector's economic, environmental, and social well-being, sustainable measures are becoming a part of their supply chain design (Yadav et al. 2022). Moreover, the pressure of governments' regulations and environmental advocacy groups makes it essential to move toward a sustainable food supply chain. However, designing an efficient food supply chain is a complex task since many variables (e.g., flows of products, opening or closing of different facilities) need to be considered (Abdali et al. 2021). Furthermore, due to their impacts on the environment, production and transportation directly correlate with sustainability performance (Adams et al. 2021). Moreover, these factors affect tactical and strategic decisions related to supply chains, such as supplier selection, location of facilities, the quantity of production, and transportation networks (Salehi et al. 2022). Therefore, a sustainable supply chain design requires a simultaneous examination of a company's tactical and strategic decisions.

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Several factors make soybeans a valuable resource, such as their land utilization efficiency, protein content, and calories (Thoenes 2004). The Canadian soybean industry has been on the rise in recent years. Canadian soybeans contribute 0.3% to the country's Gross Domestic Product (GDP). Additionally, it provided more than 54,000 jobs to Canadian workers across the country in 2014 (Soycanada 2021). Sustainable considerations in the design of soybean supply chains are critical to the survival of the soybean industry in Canada in this highly competitive market. In addition to CO_2 emissions and food insecurity for the local population, exporting soybean products long distances to meet the global demand has resulted in environmental and social problems (He et al. 2019). Additionally, when international entities are involved in the supply chain, global economic factors such as exchange rates and customs duties play a key role (Amin and Zhang 2013). The cultivation of soybeans poses many environmental challenges, such as soil erosion, negative impacts on biodiversity, and many others. As a means of addressing these issues, researchers have focused on different ecological aspects of soybeans over the years, including water and land use (e.g., Taherzadeh and Caro 2019), deforestation (e.g., Cohn and O'Rourke 2011), and greenhouse gas emissions (e.g., Newton et al. 2013).

It is, therefore, necessary to design a sustainable Supply Chain (SC) for soybean products. However, the research conducted by Jia et al. (2020) suggests that the studies investigating the food supply chain network configuration by considering all sustainability pillars and global factors are somewhat limited. The limitations of such networks result from the complex interactions and structures of the entities involved and the inherent uncertainties in designing such networks. Moreover, the literature shows a dearth of research on the social aspects of sustainability in soybean supply chains and explorations outside of tropical regions like Brazil and Argentina.

This paper is based on a stochastic optimization model for a soybean company in Canada that makes use of the Multi-objective Mixed-Integer Linear Programming (MoMILP) optimization model. In this model, economic, environmental, and social factors are considered. To find the Pareto solutions, the augmented ε-constraint method is also used. This study presents what, to our knowledge, is the first to consider "global economic factors", "CO_2 emissions", and "created jobs" as the objective functions under uncertainty in the context of a food supply chain (e.g., soybean supply chain). Finally, a Canadian soybean company is used as a case study to demonstrate the model's efficiency.

2 Mathematical Model

In this section, a multi-objective MILP model is developed to design a sustainable soybean supply chain under uncertainty. The model presented in this study seeks to establish several strategic and tactical choices to attain sustainability goals. It consists of the locations of entities, the amounts of on-hand inventory of suppliers, processing plants, and distributors, and the flow of raw materials and final products throughout the network of the food supply chain. Moreover, certain assumptions and characteristics are considered in this paper. In the first assumption, the demand, sales, and purchase prices are stochastic. This study employs a two-stage stochastic programming approach. In addition, it is assumed that there are different modes of transportation in the mentioned supply chain.

In the context of this study, three transportation modes of rail, road, and sea are considered. In addition, the capacity of each entity involved in the soybean supply chain is known.

The candidate locations of different entities are assumed to be known in advance. In addition, the model does consider global factors, including exchange rates and customs duties since there are both domestic and international customers in this case. This model is expressed by the following notations:

Sets

S	Set of suppliers, $s = \{1, 2, \ldots, S\}$
P	Set of products, $p = \{1, 2, \ldots, P\}$
G	Set of processing plants, $g = \{1, 2, \ldots, G\}$
D	Set of distributors, $d = \{1, 2, \ldots, D\}$
M	Set of transportation modes, $m = \{1, 2, \ldots, M\}$
T	Set of time periods (4-month), $t = \{1, 2, \ldots, T\}$
I	Set of scenarios, $i = \{1, 2, \ldots, I\}$
N	Set of countries, $n = \{1, 2, \ldots, N\}$
J	Set of customers, $j = \{1, 2, \ldots, J\}$

Parameters

C_p	Raw materials rate of conversion to product p
$Sca_{s,t}$	Supplier s production capacity in time period t
$Wca_{g,t}$	Processing plant g warehouse capacity in time period t
FC_s	Fixed cost of utilizing supplier s
HC''_d	Variable cost for handling one ton of product for distributor d
FC'_g	Fixed cost of opening processing plant g
υ_g	CO_2 emission Metric Tons (MT) of opening processing plant g
η_s	CO_2 emission (MT) of selecting supplier s
ρ_d	CO_2 emission (MT) of selecting distributor d
FC''_d	Fixed cost of opening distributor d
H_g	Holding cost per unit in processing plant g
I_d	Holding cost per unit in in distributor d
$PC_{g,p}$	Product p processing cost in processing plant g
EX_n	Country n currency exchange rate to Canadian dollars
$\varphi_{p,j,n}$	Product p customs fee for customer j located in country n
$TPC_{s,m}$	Transportation cost per km per unit for supplier s using transportation mode m
$TPC_{g,m}$	Transportation cost per km for processing plant g via transportation mode m
$TPC_{d,n,m}$	Unit transportation cost per km per unit for distributor d using transportation mode m based on country n rates
HC_s	Variable cost for handling one ton of product for supplier s
HC'_g	Variable cost for handling one ton of product for processing plant g
$Dis_{s,g}$	Supplier s distance to processing plant g
$Dis'_{g,d}$	Processing plant g distance to distributor d
$Dis''_{d,j,n}$	Distributor d distance to customer j located in country n

θ_g — CO_2 emission (MT) of storing each ton of product in processing plant g
ϕ_d — CO_2 emission (MT) of storing each ton of product in distributor d
λ_s — CO_2 emission (MT) processing each ton of products for supplier s
σ_g — CO_2 emission (MT) processing each ton of products for processing plant g
γ_d — CO_2 emission (MT) processing each ton of products for distributor d
$\pi_{s,g,m,t}$ — CO_2 emission (MT) of shipping each unit of products from supplier s to processing plant g using transportation mode m in time period t
$\pi'_{g,d,m,t}$ — CO_2 emission (MT) of shipping each unit of products from processing plant g to distributor d using transportation mode m in time period t
$\pi''_{d,j,m,t}$ — CO_2 emission (MT) of shipping each unit of products from distributor d to customer j using transportation mode m in time period t
JC_s — New job opportunities as a result of utilizing supplier s
JC'_g — New job opportunities as a result of opening processing plant g
JC''_d — New job opportunities as a result of utilizing distributor d
$Dca_{d,t}$ — Distributor d warehouse capacity in time period t
$Pca_{g,t}$ — Processing plant g production capacity in time period t
$Net_{s,g,m}$ — 1 if shipping using mode m is feasible between supplier s and processing plant g, else 0
$Net'_{g,d,m}$ — 1 if shipping using mode m is feasible between processing plant g and distributor d, else 0
$Net''_{d,j,m}$ — 1 if shipping using mode m is feasible between distributor d and customer j else 0

Scenario-Based Parameters

Pr_i — Scenario i occurrence probability
$SP_{p,j,n,i}$ — Product p selling price to customer j located in country n in scenario i
$TD_{j,p,t,i}$ — Costumer j demand for product p at time period t in scenario i
$B_{s,p,i}$ — Product p buying price from supplier s in scenario i

First Stage Decision Variables

X_g — 1 if a processing plant is opened in location g otherwise 0
Z_s — 1 if supplier s is utilized, otherwise 0
Y_d — 1 if a distribution center is utilized in location d, otherwise 0

Second Stage Decision Variables

$Inv_{g,p,t,i}$ — Stock level of product p stored in processing plant g warehouse in time period t in scenario i
$Inv'_{p,d,t,i}$ — Stock level of product p stored in distributor d warehouse in time period t in scenario i
$N_{g,d,p,m,t,i}$ — Amount of product p transferred from processing plant g to distributor d by transportation mode m in period t for scenario i
$Pro_{g,p,t,i}$ — Number of products p produced in processing plant g in time period t in scenario i

$O_{d,j,p,m,t,i}$ Amount of product p distributed from distributor d to customer j by transportation mode m in time period t in scenario i

$M_{s,g,p,m,t,i}$ Number of raw materials sold to processing plant g for product p by transportation mode m in time period t from supplier s in scenario i

$$\begin{aligned} Max f_1 = & \sum\nolimits_i Pr_i \Big[\sum\nolimits_d \sum\nolimits_j \sum\nolimits_p \sum\nolimits_n \sum\nolimits_m \sum\nolimits_t \big(EX_n (1 - \varphi_{p,j,n}) SP_{p,j,n,i} \\ & - TPC^d_{n,m} Dis''_{d,j,n} \big) O_{d,j,p,m,t,i} - \Big[\sum\nolimits_s \sum\nolimits_g \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t \left(TPC^s_m Dis_{s,g} + B_{s,p,i} \right) M_{s,g,p,m,t,i} \\ & + \sum\nolimits_g \sum\nolimits_d \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t TPC^g_m Dis'_{g,d} N_{g,d,p,m,t,i} + \sum\nolimits_g \sum\nolimits_p \sum\nolimits_t PC_{g,p} Pro_{g,p,t,i} \\ & + \sum\nolimits_p \sum\nolimits_g \sum\nolimits_t Inv_{g,p,t,i} H_g + \sum\nolimits_p \sum\nolimits_d \sum\nolimits_t Inv'_{d,p,t,i} I_d + \sum\nolimits_s \sum\nolimits_g \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t M_{s,g,p,m,t,i} HC_s \\ & + \sum\nolimits_g \sum\nolimits_d \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t N_{g,d,p,m,t,i} HC'_g + \sum\nolimits_d \sum\nolimits_j \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t O_{d,j,p,m,t,i} HC''_d \Big] \Big] \\ & - \sum\nolimits_s FC_s Z_s - \sum\nolimits_g FC'_g X_g - \sum\nolimits_d FC''_d Y_d \end{aligned} \tag{1}$$

$$\begin{aligned} Min f_2 = & \sum\nolimits_s \eta_s Z_s + \sum\nolimits_g v_g X_g + \sum\nolimits_d \rho_d Y_d + \sum\nolimits_s \sum\nolimits_g \sum\nolimits_m \sum\nolimits_t \pi_{s,g,m,t} Dis_{s,g} \\ & + \sum\nolimits_g \sum\nolimits_d \sum\nolimits_m \sum\nolimits_t \pi'_{g,d,m,t} Dis'_{g,d} + \sum\nolimits_d \sum\nolimits_j \sum\nolimits_m \sum\nolimits_t \sum\nolimits_n \pi''_{d,j,mt} Dis''_{d,j,n} \\ & + \sum\nolimits_i Pr_i \Big[\sum\nolimits_p \sum\nolimits_g \sum\nolimits_t \theta_g Invv_{g,p,t,i} + \sum\nolimits_p \sum\nolimits_d \sum\nolimits_t \phi_d Invv'_{d,p,t,i} \\ & + \sum\nolimits_s \sum\nolimits_g \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t M_{s,g,p,m,t,i} \lambda_s + \sum\nolimits_g \sum\nolimits_d \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t N_{g,d,p,m,t,i} \sigma_g \\ & + \sum\nolimits_d \sum\nolimits_j \sum\nolimits_p \sum\nolimits_m \sum\nolimits_t o_{d,j,p,m,t,i} \gamma_d \Big] \end{aligned} \tag{2}$$

$$Max\, f_3 = \sum\nolimits_s JC_s Z_s + \sum\nolimits_g JC'_g X_g + \sum\nolimits_d JC''_d Y_d \tag{3}$$

s.t.

$$\sum\nolimits_s \sum\nolimits_m M_{s,g,p,m,t,i} \geq \sum\nolimits_d \sum\nolimits_m N_{g,d,p,m,t,i} \qquad \forall g, p, t, i \text{ if } Net_{s,g,m} = 1 \tag{4}$$

$$\sum\nolimits_g \sum\nolimits_m N_{g,d,p,m,t,i} \geq \sum\nolimits_j \sum\nolimits_m O_{d,j,p,m,t,i} \qquad \forall d, p, t, i \text{ if } Net_{s,g,m} = 1 \tag{5}$$

$$\sum\nolimits_s \sum\nolimits_m M_{s,g,p,m,t,i} \leq Z_s Sca_{s,t} \qquad \forall g, p, t, i \text{ if } Net_{s,g,m} = 1 \tag{6}$$

$$\sum\nolimits_d \sum\nolimits_m N_{g,d,p,m,t,i} \leq X_g Pca_{g,t} \qquad \forall p, g, t, i \tag{7}$$

$$\sum\nolimits_j \sum\nolimits_m O_{d,j,p,m,t,i} \leq Y_d Dca_{d,t} \qquad \forall p, d, t, i \tag{8}$$

$$\sum\nolimits_d \sum\nolimits_m O_{d,j,p,m,t,i} \geq TD_{j,p,t,i} \qquad \forall j, p, t, i \text{ if } Net''_{d,j,m} = 1 \tag{9}$$

$$\sum\nolimits_s \sum\nolimits_m M_{s,g,p,m,t,i} = C_p Pro_{g,p,t,i} \qquad \forall p, g, t, i \tag{10}$$

$$\sum_p Pro_{g,p,t,i} \leq Pca_{g,t} \qquad \forall g, t, i \tag{11}$$

$$\sum_p Inv_{g,p,t,i} \leq Wca_{g,t} \qquad \forall g, t, i \tag{12}$$

$$\sum_p Inv'_{d,p,t,i} \leq Dca_{d,t} \qquad \forall d, t, i \tag{13}$$

$$Inv_{g,p,t-1,i} + Pro_{g,p,t,i} - \sum_d \sum_m N_{g,d,p,m,t,i} = Inv_{g,p,t,i} \qquad \forall p, g, t, i \text{ if } t > 1 \tag{14}$$

$$Inv'_{d,p,t-1,i} + \sum_g \sum_m N_{g,d,p,m,t,i} - \sum_j \sum_m O_{d,j,p,m,t,i} = Inv'_{d,p,t,i} \qquad \forall p, d, t, i \text{ if } t > 1 \tag{15}$$

$$Z_s, X_q, Y_d \in \{0, 1\} \qquad \forall s, g, d \tag{16}$$

$$M_{s,g,p,m,t,i}, N_{g,d,p,m,t,i}, O_{d,j,p,m,t,i}, Invv_{g,p,t,i}, Inv'_{d,p,t,i}, Pro_{g,p,t,i} \geq 0 \qquad \forall s, g, d, m, t, p, j, i \tag{17}$$

The first objective function of the presented model is f_1 and it represents the total profit. It includes the exchange rates, customs fees, transportation costs between each entity, and processing costs. Also, fixed costs of opening or selecting different entities are included in f_1 expression. Moreover, the first objective function considers inventory holding costs and handling costs for processing plants and distributors. The second objective function is represented by f_2 and it is related to the minimization of total CO_2 emissions of the supply chain. It includes the emissions resulting from selecting or opening each site, transportation, inventory holding and inventory handling for different entities involved in the supply chain. Finally, the third objective function f_3 represents the total number of jobs created due to utilizing each facility.

Constraint (4) links the raw materials transported from the suppliers to the processing plants and the transported products from the processing plants to the distributors. Constraint (5) indicates that the number of products produced in the processing plants should be equal to or greater than the products sold by the distributors in the markets. In accordance with Constraint (6), raw materials should be transported from suppliers to the processing plants in an amount less than or equal to their production capacity. According to Constraint (7), a similar limit applies to processing plant. Constraint (8) states that the total volume of soybeans transported from the distributors to the customers should not exceed the capacity of their warehouses. Additionally, Constraint (9) indicates that the total demand of the customers should be met. Constraint (10) represents the balance between the raw materials received from suppliers and the processed products produced by the processing companies. According to Constraint (11), the production volume in the processing plants should be less than or equal to the related production capacity. Constraint (12) guarantees that the amount of inventory available in the processing plants is at least equal to or less than the maximum warehouse capacity. Constraint (13) indicates that distributors are under similar restrictions. The material balance for processing plants is shown in Constraint (14). Constraint (15) stated that the sum of incoming products from suppliers plus previous period inventories minus outgoing products should equal to the available stock. Constraint (16) relates to binary variables. In addition, Constraint (17) relates to non-negative variables.

3 Model Application and Results

This section investigates the supply chain of a Canadian soybean company using the presented method in this study. This company owns a processing plant in Windsor, which is adequate to satisfy the existing domestic demand. This company's market includes seven main groups spread throughout the Canadian provinces of Ontario, Quebec, Saskatchewan, and Manitoba. It should be noted that all the suppliers for this company are operating in Ontario. Increasing demand and sustainability concerns and proposed incentives by the Government of Canada (Agriculture and Agri-Food Canada 2019) led this company to consider expanding its operations and customer market. Europe, USA, and China are selected as the new international markets, and eight different groups are in these locations. The sale percentage of these new markets is 50–70% of the total sales. This company cannot meet this new demand due to its limited production capacity. Hence, the policymakers and stakeholders seek to design a new supply chain for their operations that can satisfy new demands while complying with the sustainability requirements according to Canada's Sustainable Development Goals (SDGs).

Hamilton, Ontario, and Becancour, Quebec, are potential processing sites, as they are located close to the USA border and coastal shipping ports, respectively. Raw materials are delivered to the processing facilities by five suppliers. Ontario (Toronto, Mississauga, and Windsor), Manitoba (Winnipeg), and Quebec (Montreal) are the locations of these suppliers. In addition, ten distributors operate in Ontario, Manitoba, Quebec, and Saskatchewan. A company's supply chain design is heavily influenced by international demands from the perspective of transportation, exchange rate, and customs duties. Multimodal transportation, including road, rail, and sea, is essential to the company's effort to reduce costs. The company must receive raw materials and deliver finished products to distributors and customers via multiple channels. Table 1 includes some of the data collected about the soybean company.

Table 1. Summary of obtained data for the soybean company

$\theta_g = 0.2$	$\gamma_d = 0.3$	$J = 15$
$\phi_d = 0.2$	$C_p = 0.7$	$T = 3$
$\lambda_s = 0.3$	$I_d = 0.7$	$I = 18$
$\sigma_g = 0.3$	$HC_s = 0.02$	$n = 4$
$D = 10$	$HC'_g = 0.02$	$PC_{g,p} = 0.2$
$\upsilon_g = 3,000,000$	$HC''_d = 0.02$	$H_g = 0.5$
$\eta_s = 1,000,000$	$M = 3$	$P = 3$
$\rho_d = 400,000$	$S = 5$	$G = 3$

3.1 Multi-objective Model Results

This subsection presents the efficient solutions for the presented model using IBM LOG CPLEX 20.1.0. To solve the multi-objective problem, the augmented ε-constraint method is used (for more details, see Mavortas (2009)). In this method, the total profit is considered the most critical objective function due to the existing competitive environment in the food industry. Hence the rest of the objective functions are transferred to the constraints.

The results of deterministic and stochastic models are calculated for ten different values of ε_2 and ε_3 which are the right-hand side values of the second and third objective functions, transferred to constraints. The values of objective functions are presented in Tables 2 and 3. Moreover, the data on selected (opened) processing plants, suppliers and distributors are shown in Table 3. Based on the values shown in Tables 2 and 3, the first and second objective functions values of the stochastic model are deteriorated compared to the deterministic model, indicating the effect of uncertain parameters on the model. In addition, Table 4 demonstrates the differences in the supply chain structure for both models. For example, in Iteration 7, more processing plants are opened in the stochastic model compared to the deterministic model to satisfy the uncertain demand.

Table 2. The augmented ε-constraint method results in the deterministic model

I#	ε_2	ε_3	f_1	f_2	f_3
1	2.00E+07	5.87E+03	3.33E+07	1.93E+07	5.88E+03
2	2.00E+07	5.00E+03	4.53E+07	1.75E+07	5.04E+03
3	1.70E+07	4.00E+03	4.28E+07	1.67E+07	4.27E+03
4	1.60E+07	3.00E+03	4.94E+07	1.57E+07	3.93E+03
5	1.50E+07	3.00E+03	3.19E+06	1.32E+07	3.63E+03
6	1.40E+07	2.50E+03	1.11E+07	1.22E+07	3.29E+03
7	1.40E+07	4.00E+03	1.02E+07	1.26E+07	3.57E+03
8	1.30E+07	3.50E+03	4.03E+06	1.26E+07	3.51E+03
9	1.30E+07	3.50E+03	1.02E+07	1.26E+07	3.57E+03
10	1.20E+07	2.00E+03	1.02E+07	1.18E+07	2.98E+03

Table 3. The augmented ε-constraint method results in the stochastic model

I#	ε_2	ε_3	f_1	f_2	f_3
1	2.00E+07	5.88E+03	3.59E+07	1.93E+07	5.88E+03
2	2.00E+07	5.00E+03	4.39E+07	1.75E+07	5.04E+03
3	1.70E+07	4.00E+03	4.53E+07	1.67E+07	4.27E+03
4	1.65E+08	5.00E+02	4.79E+07	1.57E+07	3.93E+03
5	1.60E+07	3.00E+03	4.79E+07	1.57E+07	3.93E+03
6	1.57E+07	2.50E+03	4.14E+07	1.57E+07	3.93E+03
7	1.56E+07	3.00E+03	3.40E+07	1.53E+07	3.69E+03
8	1.53E+07	3.00E+03	3.36E+07	1.53E+07	3.69E+03
9	1.52E+07	1.00E+03	1.58E+07	1.52E+07	3.66E+03
10	1.52E+07	1.50E+03	1.41E+06	1.52E+07	3.70E+03

Table 4. Selected and opened facilities for the stochastic and deterministic model

I#	Stochastic model			Deterministic model		
	S	*G*	*D*	*S*	*G*	*D*
1	1, 2, 3, 4, 5	1, 2, 3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	1, 2, 3, 4, 5	1, 2, 3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
2	1, 3, 4, 5	1, 2, 3	1, 2, 4, 5, 7, 8, 9, 10	1, 3, 4, 5	1, 2, 3	1, 2, 4, 5, 7, 8, 9, 10
3	1, 2, 4, 5	1, 2, 3	1, 3, 4, 5, 7, 8, 10	1, 2, 3, 4	1, 2, 3	1, 3, 4, 7, 8, 10
4	1, 3, 4	1, 2, 3	1, 3, 4, 7, 8, 10	1, 3, 4	1, 2, 3	1, 3, 4, 5, 7, 8, 10
5	1, 3, 4	1, 2, 3	1, 3, 4, 7, 8, 10	1, 2, 3, 5	1, 3	2, 4, 7, 8, 10
6	1, 3, 4	1, 2, 3	1, 3, 5, 7, 8, 10	1, 3, 5	1, 3	2, 5, 7, 8, 10
7	1, 3, 4	1, 2, 3	1, 3, 4, 6, 10	1, 3, 5	1, 3	2, 4, 7, 8, 9, 10
8	1, 3, 4	1, 2, 3	1, 3, 4, 6, 10	1, 2, 3	1, 3	1, 2, 6, 7, 9, 10
9	1, 3, 5	1, 2, 3	3, 4, 7, 8, 10	1, 3, 5	1, 3	2, 4, 7, 8, 9, 10
10	1, 3, 5	1, 2, 3	3, 4, 7, 9, 10	1, 3, 5	1, 3	3, 4, 6, 10

The supply chain configuration for Iteration 8 is illustrated in Fig. 1 for the stochastic model.

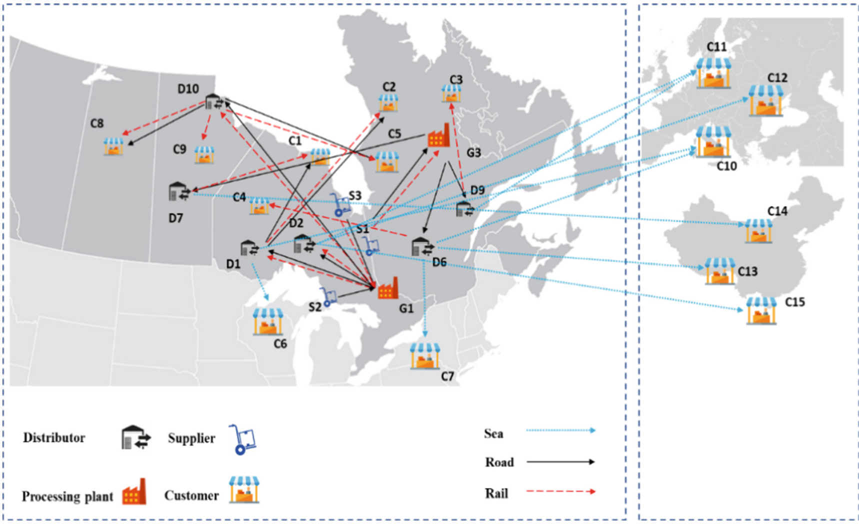

Fig. 1. The soybean supply chain configuration for the stochastic model (Iteration 8)

The Pareto front graph is a helpful tool for decision-makers to compare different scenarios and to select the best solutions based on their preferences. Figure 2 illustrates the Pareto frontier for total profit and total CO_2 emission for both deterministic and stochastic models.

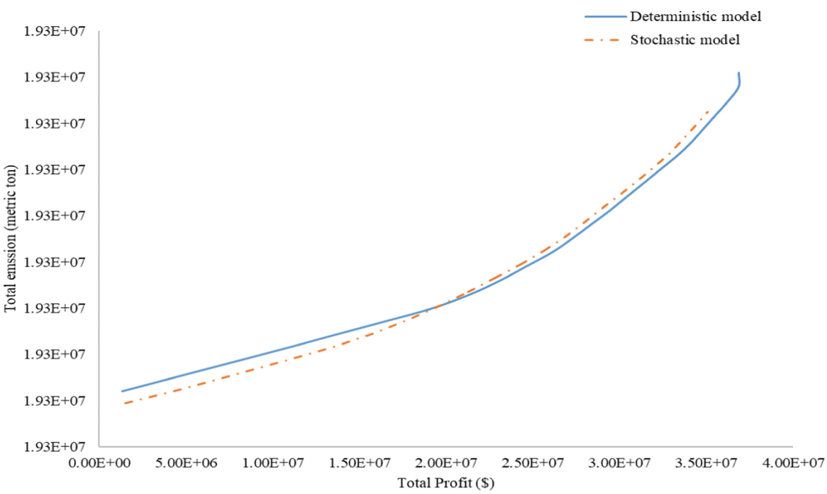

Fig. 2. The obtained Pareto front for total profit vs total CO_2 emission values

The performance of the supply chain regarding uncertainty under different scenarios is studied using the scenario-based analysis for the presented model. To achieve that, buying price, selling price and demand parameters are identified as the sources of uncertainty. The results showed that the presented model could perform well under uncertain conditions.

4 Conclusions

Integration of the sustainability concept into supply chain design has been the focus of many researchers in recent years. However, there are limited studies on supply chain network configuration where all three pillars of sustainability are considered due to their complex nature. This study has presented a stochastic multi-objective model to configure a sustainable agri-food supply chain under uncertain conditions. Moreover, a case of a soybean company in Canada is selected to show the application of the presented model. The proposed model in this study consists of three objective functions to cover sustainability's economic, environmental, and social aspects. In this study, the augmented ε-constraint method is applied to solve the multi-objective model, which led to the Pareto optimal solutions. The obtained results indicate that focusing on one of the objective functions significantly deteriorates other objective function values. Also, the presented model is tested under uncertain conditions using two-stage stochastic programming to be more efficient for real-world applications. Finally, based on the obtained results, the proposed model can be a helpful decision support tool for stakeholders and policymakers involved in the food supply chain to achieve their companies' sustainability goals.

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A Novel Arc-Routing Optimization Model for Residential Waste Collection Problem with Time Windows, Vehicle-Arc Compatibility, and Fullness Information

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Abstract. Waste collection is an important public health service provided by municipalities using public funds. Service must be provided within specific periods considering waste generation and the fullness of bins to be collected, otherwise uncollected waste can become hazardous to public health and the environment. Based on these concerns and owing to the complex nature of this problem, the decision to efficiently collect waste is an important and improvable study area. Recent years have witnessed several developments in the use of sensors for waste containers, enabling collection information regarding their current fullness. Consequently, implementing this information can enable the management of resources efficiently and effectively. We propose an extended novel arc-routing-based mathematical model for the residential waste collection problem by considering a heterogeneous vehicle fleet, fullness information of the bins, vehicle-arc compatibility, driving limits, and lunch-rest breaks planning in the Waste Collection Vehicle Routing Problem with time windows. The objective here is to minimize the total collection cost consisting of total traveling cost, as well as the expected penalty cost due to overfilling of the uncollected bins, utilizing information regarding current fullness via sensors. The proposed model is tested using IBM OPL CPLEX and analysis of results from test cases is provided.

Keywords: Waste collection · Mathematical programming · Arc routing · Time windows · Fullness data · Vehicle-arc compatibility

1 Introduction

The amount of waste generated over the last couple of decades has been increasing faster than the population and this fact has led waste management to become a major problem for modern societies. (Han and Ponce-Cueto 2015) Waste collection is defined, as the collection and transportation of waste from collection points to the disposal facilities. It is a critical issue in both waste management and reverse logistics. Waste collection is a public health service that must be performed at a minimum cost using public funds. Therefore, decision-making regarding the efficient collection of waste is an important and improvable study area. In the Waste Collection Vehicle Routing Problem (WCVRP),

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specialized collection vehicles collect waste from the collection points (containers and bins) and transport them to disposal facilities or mid-collection centers. Due to the nature of the problem, it is considered a form of reverse logistics problem. Researchers so far have been mostly focusing on shortening the routing distance, locating collection bins and disposal containers, and minimizing the number of vehicles used. The complexity of the problem increases as practical realistic constraints are considered. These practical and realistic constraints include the filling speed of containers, time windows for collection, requirements like lunch-rest breaks, driving limits, etc., which as a whole can make the problem significantly complex. Three main types of WCVRPs are considered in the literature: commercial, industrial (roll-on-roll-off), and residential (Golden 2002). This categorization is made according to the type of waste collected. The primary focus of this paper is residential waste collection.

1.1 Residential Waste Collection

The residential waste collection involves servicing private houses and collecting household wastes. (Kim et al. 2006) Vehicles along the streets collect waste from garbage bins. The exact location of each bin may not be required since the collection is performed along the streets. Certain factors such as weather conditions, geography, topography, and the cost of the service may affect the frequency of collection. In literature, residential waste collection is usually considered and solved as an Arc (or edge) Routing Problem (ARP) where the objective is to distribute or collect commodities along the arcs of a road network. Still, Node Routing Problem (NRP) approach is widely used.

The proposed model in this paper enables a smarter routing for waste collection that takes into account all relevant practical constraints. The problem is modeled as an Arc Routing Problem (ARP).

The rest of this study is structured as follows. The analysis of the existing related literature is presented in the Literature Review section. The problem description is provided in the Problem Definition section. In the Solution Approach section, the proposed solution method is presented. The proposed model's verification and computational results are also presented in this section. Finally, the last section summarizes the findings and gives plans and directions for further research.

2 Literature Review

Waste collection is a public service that must be provided by using public funds, it is necessary to minimize operational costs in lack of any revenue. Among the studies that exist, many propose mathematical models and approximate algorithms as solutions to some part or version of the problem. Waste collection operations are primarily related to Capacitated Vehicle Routing Problem. Since CVRP in its more generic form is proven to be NP-hard, optimization models may be insufficient for solving practically large instances. At this point, heuristics are needed for obtaining feasible solutions. Metaheuristics such as GA, tabu search, and local search algorithms are believed to be the most promising methods. We present a summary of the most relevant research for the problem in Table 1, which is helpful also in pointing out the research gap and contribution of this study.

The amount of waste is highly variable and factors such as the number of residents sharing the bin and time of the year affect the accumulation (Nuortio et al. 2004). Therefore, information on fill is important since this uncertainty may lead to inefficient collection and hence the use of resources. In addition to forecasting methods, stochastic models and simulation models utilizing real-time information is an option. Another option to utilize generated waste is the fuzzy approach. Within this context, Aliahmadi et al. (2021) propose a novel bi-objective math model and a genetic algorithm for multi-depot waste collection problems with time windows and a heterogenous fleet.

Waste bins can be now equipped with online sensors. With the use of these "smart" bins, it is possible to know how full each container is (Karthik et al. 2021). This data can be used for planning collection activities more intelligently. The only study that so far found in the literature that uses this kind of information is by Faccio et al. (2011) Their study estimates bins which are/will be full enough to be collected and route the trucks accordingly with a homogeneous fleet, without using sensor information in decision making directly.

Satyamanikanta and Narayanan (2017) focus on the advantages of using RFID in waste collection collaborating with the Internet of Things (IoT) technology compared to conventional methods. But they do not propose a solution method integrated with the RFID system for routing decisions. Ramos et al. (2018) present the Smart Waste Collection problem with the use of sensor technology. The study presents a model with no time windows to estimate the amount of waste at each bin and the fill rates.

Our study introduces a novel arc-routing-based optimization model for residential waste collection. To the best of our knowledge, this study is the first in integrating sensor information in routing decisions. We incorporate the "probability of being full before the next day's collection" obtained from the sensors into the proposed model, as well as an expected penalty cost associated with this probability. Consequently, this enables more intelligent routing decisions. Our model also includes vehicle-arc compatibility (some streets cannot be entered by certain vehicles due to their sizes), time windows, a heterogeneous vehicle fleet, and break planning for employees.

3 Problem Definition

We look at the problem of collecting residential waste from bins located along streets or street sections. Depending on location (residential, commercial), there are area-specific time windows associated with certain arcs. Some are tight and cover only a few hours (Golden 2002). For instance, on streets excessively used by pedestrians, or in residential, school, commercial, downtown, and historic areas, the collection is allowed only during certain times. A heterogeneous vehicle fleet consisting of three distinct types of trucks (rear loader trucks, maxi dumper trucks, and mini dumper trucks) with different capacities is assumed to be available for collection. This is because it is not possible to serve every arc with every type of vehicle. For example, narrow streets in city centers cannot be entered by rear loader trucks due to their size. The geography and topology of the city can limit accessibility as well. For example, some streets can only be entered

Table 1. Summary table of literature analysis (2002–2021).

Authors	Year	Problem	Solution Methods	Objective	Vehicle Fleet	Time Win.	Sensor Info.
Golden, B.	2002	VRP Applications	-	Review of VRP applications	-	-	-
Nuortio et al.	2006	WCVRP	Conceptual model & heuristic approach	Min. total distance, time, or cost	-	-	-
Kim et al.	2006	WCVRPTW	Heuristic approach	Min. total distance	Homogenous.	*	-
Kallenhauge, B.	2008	VRPTW	-	Review of formulations & algorithms	-	*	-
Benjamin, A.M & Beasley, J.E.	2010	WCVRPTW	Heuristic approach	Min. total distance	Homogen.	*	-
Faccio et al.	2011	WCVRP	Multi. objective routing model & Framework, heuristic model	Min. num. of vehicles, time & dist.	Homogen.	*	*
Buhrkal et al.	2012	WCVRPTW	MIP & Heuristic models	Min. total travel cost	Homogen.	*	-
Das, S., & Bhattacharyya, B. K.	2015	WCVRP	Heuristic approach	Min. collection cost	-	-	-
Han, H., & Ponce-Cueto, E.	2015	WCVRP	-	Literature review	-	-	-
Satyamanikanta, S. D., & Narayanan, M.	2017	Smart Garbage Monitoring systems	-	Review of using RFID sensors in waste collection	-	-	*
Ramos et al.	2018	Smart WCVRP	Math. & Heuristic models	Max. waste collected Min. dist.	Homogenous.	-	*
Aliahmadi, Barzinpour & Pishvaee	2021	MDWCVRPTW	Math. & Heuristic models	Min. Total cost & Time	Heterogenous.	*	-

by mini dumper trucks and traversed downhill (like hills in Istanbul or Izmir in Turkey). Therefore, there also exists vehicle-arc compatibility. Each arc has a service time associated with vehicles. Vehicle-arc compatibility is ensured by service time, providing impossibly large service times to incompatible arcs for vehicles. It is assumed that all arcs are connected. Vehicles depart from a depot, collect waste, visit the disposal site and unload. In the final step, because every vehicle returns to the depot, the disposal site to depot distance is omitted. There is a daily driving time limit for the drivers (vehicles) for safety. All drivers (vehicles) must take one lunch break and at most one rest break during the collection. Breaks use time but have no additional cost.

Some waste bins can be now equipped with sensor technology. To the best of the authors' knowledge, this development had not been utilized fully yet in waste collection. We envision current fullness via sensor and long-term collected data can be used to calculate a "probability of being full before the next day's collection. This probability along with a penalty of a full bin not being collected can be used to decide whether to collect specific bins every day. The objective is to minimize the total collection cost consisting of total traveling cost and expected penalty cost due to overfilling.

4 Solution Approach

We propose a novel mixed integer linear programming model to solve this problem. We assume arcs where bins are, the amount of waste on arcs, service times, vehicle fleet, and capacities are given. We utilize fullness information via sensors as explained in the problem definition.

4.1 Mathematical Model

Parameters and variables necessary for modeling are presented in Table 2 below.

Table 2. Indices, sets, parameters, and decision variables for the model

Indices	
i, j	Arc indices
l	Vehicle index
Sets and parameters	
A	Set of arcs representing the streets where A = Ad ∪ Af ∪ As
Ad	Set of the arc where the depot is located Ad = {0}
Af	Set of the arc where the disposal site is located Af = {1}
As	Set of arcs representing trash bins are located As = {2,…, m}
V	The set of vehicles is defined as V = Vrlt ∪ Vmax ∪ Vmin
Vrlt	Set of rear loader trucks Vrlt = {1,…, v1}

(*continued*)

Table 2. (*continued*)

Indices	
Vmax	Set of maxi dumper trucks Vmax = {v1 + 1,…, v1 + v2}
Vmin	Set of mini dumper trucks Vmin = { v1 + v2 + 1,…, v1 + v2 + v3}
tij	The time associated with traveling between arcs i and j i, j ∈ A
cij	Cost of traveling between arcs i and j, i, j ∈ A
sil	Service time matrix which represents the time required for servicing arc i ∈ A by vehicle l ∈ V
[ai, bi]	The pre-determined time window for collection, i ∈ A
qi	The expected amount of waste collected from arc i where i ∈ A
Cl	Vehicle capacity l ∈ V
[au, bu]	Earliest and latest starting times for lunch break
su	Lunch break duration
sr	Rest break duration
g	Driving time limit
pi	Prob. of bin located on arc i ∈ As being full before next day's collection
penaltyi	Penalty cost associated with the bin located on an arc i ∈ As being full before the next day's collection
Decision variables	
xijl	{1, if vehicle l ∈ V visits arc j ∈ A immediately after visiting arc i ∈ A today, 0, otherwise}
yijl	{1, if a lunch break occurs between visiting arcs i, j ∈ As by vehicle l ∈ V today, 0, otherwise}
zijl	{1, if a rest break is taken between visiting arcs i, j ∈ As by vehicle l ∈ V today, 0, otherwise}
dil	The accumulated amount of collected waste at arc i ∈ A for l ∈ V
wil	Service start time at arc i ∈ A for l ∈ V
hil	The accumulated driving duration at arc i for a vehicle i ∈ A for l ∈ V
rl	The ratio of the driving done between two arcs when vehicle l ∈ V takes a break

The model finds a set of routes for vehicles to collect waste from compatible arcs, visiting them at most once, within the time window while minimizing the total traveling and expected penalty costs due to overfilling of the uncollected bins.

The

$$minimize \sum_{i\in A}\sum_{j\in A}\sum_{l\in V} c_{ij}x_{ijl} + \sum_{j\in A^s}(1 - \sum_{i\in A\backslash A^f, i\neq j}\sum_{l\in V} x_{ijl})p_j penalty_j \quad (1)$$

Subject to:

$$\sum_{j \in A^s} x_{0jl} = 1 \qquad \forall l \in V \tag{2}$$

$$\sum_{i \in A^s} x_{i1l} = 1 \qquad \forall l \in V \tag{3}$$

$$\sum_{i \in A \setminus A^f, i \neq j} \sum_{l \in V} x_{ijl} \leq 1 \qquad \forall j \in A \tag{4}$$

$$x_{iil} = 0 \qquad \forall l \in V \tag{5}$$

$$\sum_{j \in A} x_{1jl} = 0 \qquad \forall l \in V \tag{6}$$

$$\sum_{i \in A} x_{i0l} = 0 \qquad \forall l \in V \tag{7}$$

$$\sum_{i \in A, i \neq j} x_{ijl} - \sum_{h \in A, h \neq j} x_{jhl} = 0 \qquad \forall j \in A^s, l \in V \tag{8}$$

$$\sum_{i \in A^s} \sum_{i \in A^s} y_{ijl} = 1 \qquad \forall l \in V \tag{9}$$

$$\sum_{i \in A^s} \sum_{j \in A^s} z_{ijl} \leq 1 \qquad \forall l \in V \tag{10}$$

$$y_{ijl} + z_{ijl} \leq x_{ijl} \qquad \forall i, j \in A^s, l \in V \tag{11}$$

$$a_i \leq w_{il} \leq b_i \qquad \forall i \in A, l \in V \tag{12}$$

$$w_{il} + s_{il} + t_{ij} + y_{ijl} s^u + z_{ijl} s^r \leq w_{jl} + \left(1 - x_{ijl}\right) M \qquad \forall i, j \in A, l \in V \tag{13}$$

$$a^u + s^u + t_{ij}(1 - r_l) \leq w_{jl} + \left(1 - y_{ijl}\right) M \qquad \forall i, j \in A, l \in V \tag{14}$$

$$w_{jl} + s_{jl} + t_{ji} r_l \leq b^u + \left(1 - y_{jil}\right) M \qquad \forall i, j \in A, l \in V \tag{15}$$

$$h_{il} + t_{ij} \leq h_{jl} + \left(1 - x_{ijl} + z_{ijl}\right) M \qquad \forall i, j \in A, l \in V \tag{16}$$

$$h_{il} + t_{ij} r_l + t_{ij}(1 - r_l) \leq h_{jl} + \left(1 - z_{ijl}\right) M \qquad \forall i, j \in A, l \in V \tag{17}$$

$$h_{il} + t_{ij} r_l \leq g + \left(1 - z_{ijl}\right) M \qquad \forall i, j \in A, l \in V \tag{18}$$

$$h_{il} \leq g \qquad \forall i \in A, l \in V \tag{19}$$

$$d_{0l} = 0 \qquad \forall l \in V \tag{20}$$

$$d_{il} + q_i \leq d_{jl} + \left(1 - x_{ijl}\right)M \qquad \forall i \in A \backslash A^f, j \in A, l \in V \tag{21}$$

$$d_{il} \leq C_l \qquad \forall i \in A, l \in V \tag{22}$$

$$d_{il} \geq 0 \qquad \forall i \in A, l \in V \tag{23}$$

$$0 \leq r_l \leq 1 \qquad \forall l \in V \tag{24}$$

$$0 \leq p_i \leq 1 \qquad \forall i \in A^s \tag{25}$$

$$penalty_i \geq 0 \qquad \forall i \in A^s \tag{26}$$

$$x_{ijl} \in \{0, 1\} \qquad \forall i, j \in A, l \in V \tag{27}$$

$$y_{ijl} \in \{0, 1\} \qquad \forall i, j \in A^s, l \in V \tag{28}$$

$$z_{ijl} \in \{0, 1\} \qquad \forall i, j \in A^s, l \in V \tag{29}$$

The objective function (1) minimizes the total traveling cost and expected cost of full bins under the following constraints. Constraints (2) and (3) ensure that each vehicle must leave the depot and return to the disposal facility. Constraint (4) makes sure that each arc is at most serviced once. Constraints (5), (6) and (7) are elimination constraints. It is ensured by constraint (8) that inflow and outflow must be equal for every arc except the depot. Constraint (9) ensures that each vehicle takes exactly one lunch break during collection. Constraint (10) explains that each vehicle takes at most one rest break during collection. Constraint (11) ensures that a break can only occur if arc j is visited immediately after i and ensures that vehicles must take at least one break on the same arc. (12) states the time window. (13) states the calculation of the service start time with the consideration of breaks. Constraints (14) and (15) are adapted from Buhrkal et al. (2020) and ensure that the lunch break takes place within a specific time window. Driving time is provided by (16). In case of a rest break the driving, duration is provided and limited by constraints (17) and (18). Constraint (19) limits the accumulated driving time with a driving time limit. In constraint (20) it is explained that the vehicles must be empty at the start. The collected waste is accumulated for all arcs except the disposal sites with constraint (21). Constraint (22) limits the accumulated demand with vehicle capacities. Constraints (23)–(29) explain the domain of the parameters and the decision variables.

4.2 Sample Implementation

In this section, we present the implementation of the model for validation and verification purposes. Test problem consists of a single depot, single facility and 18 streets (arcs) to be served. A total of six vehicles, two of each type (capacities 50, 30, and 20 units) are used for the collection. Traveling and penalty costs, traveling and service times (in minutes), waste amount to be collected and time windows are generated randomly (The detailed data is available from the authors upon request). Lunch and rest break durations are set as 45 and 15 min respectively and driving time is limited to 300 min. The solution is presented in Table 3.

Table 3. Solution representation of small test problem

Vehicle	Route	Cost	Lunch break
1	0-6-10-7-1	$10.99 + 6.42 + 5.5 + 5.17 = 28{,}08$	6–10
2	0-9-18-1	$8.89 + 5.77 + 7.96 = 22{,}62$	9–18
3	0-13-14-2-1	$6.86 + 6.3 + 5.16 + 7.01 = 25{,}33$	13–14
4	0-11-12-1	$7.28 + 6.22 + 8.39 = 21{,}89$	11–12
5	0-8-17-1	$5.73 + 6.69 + 10.58 = 23{,}00$	8–17
6	0-4-16-1	$5.86 + 7.02 + 7.55 = 20{,}43$	4–16

Solution time is 1:04:28 min. The total cost is found as 145,803. 4,453 of the total cost is expected penalty from fullness es explained above due to the decision of not visiting four arcs. As a result, the successful solution to this test problem and the result verifies and validates our model.

5 Conclusion

We study the problem of collecting residential waste. We propose a novel mathematical programming model formulated as an Arc Routing Problem. The proposed model's contributions are the consideration of the heterogeneous vehicle fleet; vehicle-arc compatibility; inclusion and planning of lunch breaks, rest breaks, and max allowable driving time, and utilization of sensor technology. Bins' probability of being full before the next day's collection and a penalty cost associated are inserted into the optimization model. The main objective is to minimize the total collection cost (total traveling cost and expected penalty) using current fullness information from sensors.

In the future study, we plan to collaborate with Izmir Municipality to obtain real-life data and implement the proposed solution with real data and distances. Based on performance, heuristic models will be considered. Additionally, the model is planned to be extended by including a multi-period planning horizon.

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Demand Forecasting Using Machine Learning and Deep Learning Approaches in the Retail Industry: A Comparative Study

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Abstract. Demand forecasting is one of the crucial issues in the retail industry in terms of minimizing costs, setting correct inventory levels, optimal use of inventory space, and reducing the out-of-stock problem. Predicting future demand accurately is a challenging task for retailers and wholesalers because of sudden changes in demand levels, lack of historical data, new trends, and seasonal demand spikes. This paper presents a comparative analysis of Machine Learning (ML) and Deep Learning (DL) techniques (i.e., Random Forest, Gradient Boosting Regression, and Long Short-Term Memory) to forecast the product demand, using large amounts of time series historical data. The forecasting models' performance and accuracy are evaluated by comparing Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE). The results indicate that Random Forest is more efficient and more promising than the other considered techniques in this study due to its prediction accuracy.

Keywords: Demand forecasting · Time series · Machine learning · Deep learning

1 Introduction

A time series forecasting technique predicts the future pattern at a particular point in time by exploring the trends of past observations (Weigend 2018). A time series can be defined as a continuous sequence of random variables observed repeatedly over regular time intervals (Box et al. 2015). While the most common time series frequency is yearly, monthly, weekly, daily, and hourly, other intervals such as biennial or decennial are sometimes used. In the retail industry, demand forecasting uses historical data and insights to estimate and predict what amount of a particular product or service customers will wish to buy over a specific period. As the market grows, accurate prediction of demand is a critical process as demand fluctuations occur often based on different bias factors (Hofmann and Rutschmann 2018).

Machine learning techniques enable software applications to explore large batches of data and identify patterns that predict future trends in current data (Murphy 2012). Previous studies suggest that ML demand forecasting could improve the performance

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in many supply chains (Carbonneau et al. 2007; Feizabadi 2022). A novel forecasting method, combining Long Short-Term Memory (LSTM) and Random Forest (RF) was proposed in multi-channel retail by Punia et al. (2020), and the experimental result showed that the proposed proposition was statistically significantly better. Tsoumakas (2018) focused on the advantages of ML techniques for short-term forecasting in the food industry, such as in supermarkets, grocery stores, restaurants, bakeries, and confectioneries. Villegas et al. (2018) proposed a novel framework for demand forecasting, using the SVM method. A survey was conducted by Amirkolaii et al. (2017) to select the best-performing forecasting methods in service and non-service supply chains, using supply chain data from the aircraft spare parts industry.

The overall structure of this study is presented in Fig. 1.

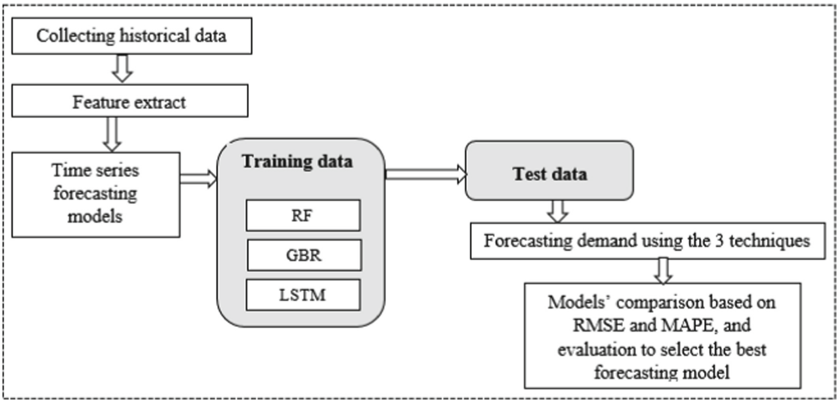

Fig. 1. Model of this study.

2 Data and Methodology

In this study, the dataset used is related to a large e-commerce store's daily time series data, where the sales-related observations from January 1, 2013, to December 31, 2017, are available for model training. Related data from January 1 to March 31, 2018, are also available for testing. The dataset provides the daily sales history for 50 different items sold at 10 different stores. As this study focuses on three specific products of a store, three different time series are obtained where each consisting of 1,826-time steps. These are univariate time series forecasting, where one field 'time' is considered to forecast another field 'demand'. The datasets have daily granularity and no missing value to treat. Figure 2 presents the time series of each product for 5 years. In the data, some patterns are apparent as the year starts with low demand and it always goes up in the middle of the year, and it goes down at the end of each year. The time series of sales for Product 1 in the store is depicted in Fig. 3.

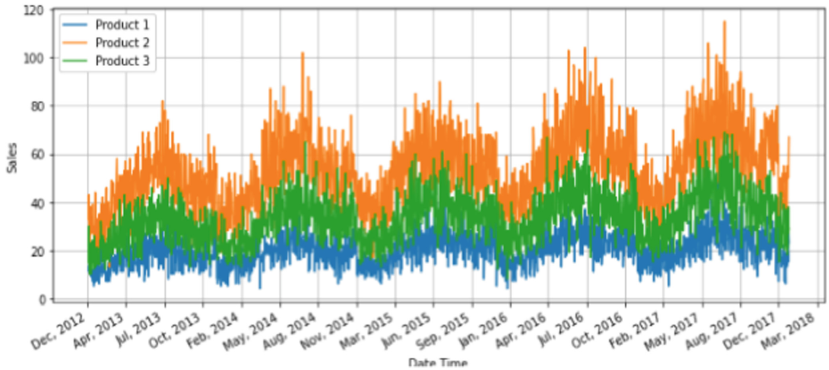

Fig. 2. Time series of sales for the selected three products.

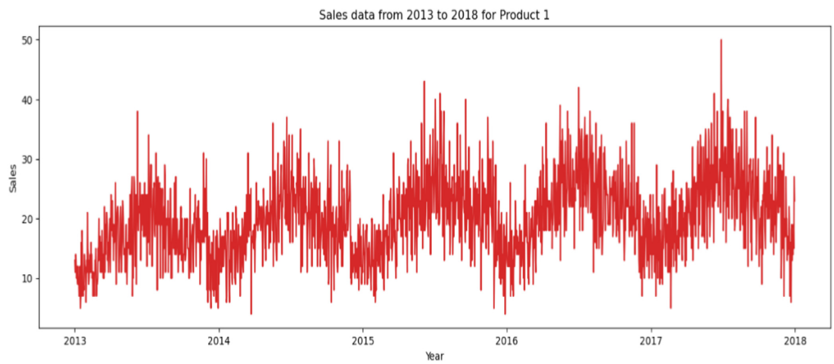

Fig. 3. Time series of sales for Product 1.

In this study, two ML techniques, Random Forest (RF) and Gradient Boosting Regression (GBR), and a DL technique (i.e., LSTM) are explored for forecasting. These techniques are adopted, as they are the most widely used ML and DL techniques that have been applied successfully for prediction (e.g., Goehry et al. 2021; Husna et al. 2021; Islam and Amin 2020; Punia et al. 2020; Vairagade et al. 2019; Wu et al. 2020). These models are also successful at capturing the underlying nonlinearity in the dataset.

The ensemble technique RF is the bagging method introduced by Breiman (2001). The bagging method is also known as the bootstrap aggregation method (Breiman 1996). RF constructs several independent and not correlated Classification And Regression Tree (CART) instances, instead of a single tree. This approach trains several trees in parallel and uses the bagging method to aggregate the results for the final prediction. More details of the RF algorithm can be found in Biau and Scornet (2016). GBR which is a boosting ensemble method was proposed by Friedman (2001). It generates multiple decision trees sequentially, combined with the earlier model to learn from the previous mistake to minimize the overall prediction error. In this approach, strong model learnability is achieved by combining the results of each step (Friedman 2001). LSTM model is a special form of Recurrent Neural Network (RNN) model, used on a large variety of problems with outstanding performance. It was first proposed by Hochreiter and Schmidhuber (1997).

3 Results and Discussion

In this study, the demands for 3 products are predicted for 2 years in the future using RF, GBR, and LSTM. These models have been developed using the Anaconda Python software. To optimize the model's performance, several hyperparameter tuning (optimization) factors have been implemented. For example, to improve the RF model's performance, the number of trees and the number of features are considered. The demand is forecasted for one day at a time, and the process continues.

A wide variety of model performance measure metrics were discussed by Hyndman and Koehler (2006). Among all, Root Mean Squared Error (RMSE) and Mean Absolute Percentage Error (MAPE) are utilized in this study to evaluate and compare the forecasting models' performances. These metrics are chosen because RMSE and MAPE are the most commonly used metrics in many research studies that have been conducted over the past 25 years. The comparison of RF, GBR, and LSTM models based on average RMSE and MAPE is shown in Table 1.

Table 1. The average performance evaluation and comparison of the ML and DL models.

Performance criteria	ML and DL forecasting models		
	RF	GBR	LSTM
RMSE	9.74	11.95	12.40
MAPE	16.51	21.46	21.79

The lower value of RMSE and MAPE means that the model's performance is better. Based on the results, the RF model outperforms GBR and LSTM models, achieving the lowest RMSE (i.e., 9.74), and the lowest MAPE (i.e., 16.51). Table 2 presents the future 2 years forecasted values, generated by RF, GBR, and LSTM models.

Table 2. The future 2 years forecasted values.

Period	Product 1			Product 2			Product 3		
	RF	GBR	LSTM	RF	GBR	LSTM	RF	GBR	LSTM
Quarter 1 Jan. -18	1,282	1,275	1,753	3,448	3,351	4,944	2,169	2,141	2,892
Quarter 2 Apr. -18	1,948	1,845	2,001	5,298	5,106	5,008	3,313	3,180	3,482
Quarter 3 July. -18	2,028	1,930	2,304	5,389	5,294	5,123	3,366	3,272	3,516
Quarter 4 Oct. -18	1,574	1,564	2,252	4,326	4,237	5,128	2,619	2,468	4,118
Quarter 1 Jan. -19	1,194	1,121	2,248	3,287	3,082	4,995	2,032	1,930	3,329
Quarter 2 Apr. -19	1,783	1,640	2,306	4,865	4,463	5,085	3,040	2,803	3,226
Quarter 3 July. -19	1,866	1,729	2,038	4,986	4,650	5,162	3,144	2,949	3,507
Quarter 4 Oct. -19	1,496	1,425	1,776	4,021	3,770	5,048	2,480	2,480	3,086

4 Conclusions

In the retail sector, accurate product demand forecasting is one of the major aspects of running an efficient business. In this work, three ML and DL techniques, including RF, GBR, and LSTM have been applied to forecast the three different products' demands quarterly for the next two years, using large data, which could further help the retailers and manufacturers. The study findings noted that Machine Learning assemble method, especially the RF model's performance is more promising than the other algorithms, such as GBR and LSTM for forecasting this dataset. Considering various comprehensive ML and DL forecasting methods in the retail industry can lead to new research opportunities. Additionally, forecasting other relevant factors, such as purchasing costs can be considered for future research.

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Demand Forecasting of Spare-Parts Using the Data Mining Techniques

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Abstract. Nowadays, many businesses use traditional inventory management techniques. Proper inventory management techniques save businesses from additional costs. Make traditional and experience-based forecasting is not enough to manage inventory. Collecting, storing, and interpreting data is vital for the future of businesses. Vehicle maintenance is necessary for safe, comfortable, and accessible public transportation services. The quality of the vehicles is crucial for the satisfaction of passengers. Spare parts that are out of stock cause delays in the maintenance of the vehicles and the inability to provide service. On the other hand, spare parts purchased more than needed cause increasing holding costs and unnecessary expenses. The increase in spare part prices after the pandemic affects public transportation negatively, especially in our country. That is why demand forecasting is much more important today. The majority of public transport vehicles are buses. Filters are one of the most common spare parts affecting the operation of the buses among the spare parts. There are so many filter types in the business where the study was conducted. The aim of the study is to minimize the loss with the proposed inventory management practices and to ensure that the maintenance of the buses is done at the right time. In the study, the needs of filters were calculated using "Linear Regression", "Support Vector Regression", "Neural Network" and "Random Forest". The accuracy of the techniques used was proven by using real data.

Keywords: Data mining · Inventory management · Public transportation · Spare parts · Forecasting

1 Introduction

The increase in spare part prices after the pandemic affects public transportation negatively, especially in our country. Proper inventory management techniques save businesses from additional costs. Nowadays, many businesses use traditional inventory management techniques. Making traditional and experience-based forecasting is not enough to manage inventory. Collecting, storing, and interpreting data is vital for the future of businesses. All organizations big or small have the bulk of data that needs to be stored

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or retrieved systematically to form information. Vehicle maintenance is necessary for safe, comfortable, and accessible public transportation services. On the other hand, this situation reduces the quality of public transportation and also puts public transportation companies in a difficult situation. Notably, the cost of spare parts, number of stocks, and lifespan of maintenance parts or items have been proven to be factors that influence maintenance performance. The quality of the vehicles is crucial for the satisfaction of passengers. Spare parts that are out of stock cause delays in the maintenance of the vehicles and the inability to provide service. On the other hand, spare parts purchased more than needed cause increasing holding costs and unnecessary expenses. Consumable spare parts play an important role during regular and periodic maintenance activities depending upon equipment criticality. Many firms store thousands of spare parts in inventory which shares the major percentage of inventory cost. Effective demand management and inventory control for spare parts collectively referred to as spare parts management, play a central role in this by taking measures to achieve target service levels while minimizing the incurred costs. Having high levels of inventory adds to expenses and increases overhead costs, hence, inventory levels and stock-outs are critical metrics for the development of a proactive inventory management policy in any organization. The majority of public transport vehicles are buses. Filters are one of the most common spare parts affecting the operation of the buses among the spare parts. There are so many different bus and filter types in the business where the study was conducted. The need for spare parts differs according to filter types and where these filters are used. The study aims to minimize the loss with the proposed inventory management practices and to ensure that the maintenance of the buses is done at the right time. In the case study, the need of filters was calculated using data mining techniques. The accuracy of the techniques used was proven by using real data. This study was carried out using Weka machine learning software. The company provides transportation services with 340 lines and nearly 1800 buses for passengers in every day. More than 20 different types of buses.

2 Literature Review

Demand forecasting is the key factor in successful businesses. Proper forecasts minimize the error between actual and estimated values. If the error is minimized, then planning is more accurate. Moreover, business uses their sources (labor, time, budget, etc.) efficiently whether it is a manufacturing or service business. In some cases, it can be both. In this review, the aim is to analyze past works related to demand forecasting especially spare-parts forecasting using data mining techniques. There are many techniques used for forecasting in literature. This review is divided into two parts to analyze the literature. The first part of the review focuses on spare parts forecasting in different areas. The second part focuses on various demand forecasting. (i.e., Labour Market, Human Talent) Data mining has been widely used for spare-parts forecasting in various fields, such as automotive, military, and shipping. Moreover, there are related works spare parts forecasting based on the reliability and dependency of parts. In the automotive sector, Stefanovic (2015), use a data mining Clustering Algorithm to group together stores into clusters and this allows predictive algorithms such as Decision Trees and Neural Networks to use the results of the clustering process to improve out-of-stock automotive spare parts forecasting quality. Another study is applied by Bala (2010) for forecasting the demand for one item in an automobile servicing station in the eastern part of India. The proposed framework for the study is developed by combining with time-series forecasting method ARIMA with the Decision Tree data mining technique. In the military sector, the usage of data mining techniques to forecast spare parts is quite popular, especially in Korea. Choi and Suh (2020) applied Random Forest, Support Vector Regression, Linear Regression, and Neural Network to military aircraft spare parts data. At the end of the study, they agreed to the Random Forest technique is more suitable for data than other techniques. Another study was conducted by Pawar and Tiple (2019) to forecasting Anti-Aircraft missile spare parts. They used Support Vector Machine, Random Forest, Logistic Regression, Decision Tree, Neural Network, and XGBoost. Boukhtouta and Jentsch (2018) applied the Support Vector Machine (SVM) approach for forecasting the demand for Canadian Armed Forces (CAF) spare parts to reduce inventory costs and increase system operational availability. In the shipping industry, Anglou et al. (2021) proposed a methodological approach and a decision support tool using the clustering approach, Random Forest, due to its ability to avoid overfitting, Generalized Linear Model (GLM), due to its simplicity and ability to handle error distributions and Principal Component Regression (PCR), due to its ability to be applied when the number of variables is high. The other studies related to spare-parts forecasting are Moharana and Sarmah (2016) based on Association Rule Mining methodologies by using item-item relationship or dependency and Kontrec and Panic (2017) applied Rayleigh's or Weibull's methods depending on data availability to spare parts forecasting based on reliability.

Data Mining techniques are not just used for spare-part predictions. Kaya and Turkyilmaz (2018) applied Artificial Neural Networks, Support Vector Regression, and Decision Tree Techniques to simulate intermittent demand data. Parikh (2003) proposes two data mining models, the Pure Classification model and the Hybrid Clustering Classification model. Pure Classification model uses the k-Nearest Neighbour Classification technique, and Hybrid Clustering Classification first uses k-Mean Mode Clustering to define clusters and then k-Nearest Neighbour classification to find k most similar objects to demand forecasting and product allocation on the store, product, and shopper's data sets. Also, Ibrahim and Nihad (2021) used Linear Regression and Support Vector Machine to be forecasting gold prices, and Baraka and Abuzir (2019) used Artificial Neural Networks for performance prediction of the movements price stock. Kaliyaperumal et al. (2010) predicted closing stock price changes by using Typical Price (TP), Bollinger Bands, Relative Strength Index (RSI), CMI, and Moving Average (MA). In addition, Alsultanny (2013) applied Naïve Bayes Classifiers, Decision Trees, and Decision Rules techniques to predict labor market needs, Xydas (2013) used Decision Table, Decision Trees, ANN, and SVM to electric vehicle load forecasting, Napagoda (2013) applied

Gaussian Process, Multilayer Perceptron, Linear Regression, and SMO Regression to web site visit forecasting via Weka Software and as a final, Jantan et al. (2010) applied Decision tree, Fuzzy Logic and Rough Set Theory to personnel selection, Association rule mining to training, Fuzzy Data Mining and Fuzzy Artificial Neural Network and Decision Tree to employee development and performance evaluation. Generally, the accuracy of data mining techniques is evaluated based on Mean Squared Error (MSE), Mean Absolute Error (MAE), Rooted Mean Squared Error (RMSE), Relative Mean Squared Error (RMSE), and Relative Absolute Error (RAE). Ulutagay et al. (2015) used fuzzy clustering algorithms for bearing fault diagnosis.

3 Methodology

This research adopts a case study approach. This study was developed using Weka machine learning software. First, previous research was analyzed to determine the machine learning methods to be used in this study. It was decided to use "Linear Regression", "Support Vector Regression", "Neural Network" and "Random Forest" machine learning techniques which are the most common methods based on the previous research. However, redundant data was removed before applying the methods in the data preprocessing phase of the study. In order to obtain correct information from the data, the J48 algorithm was applied to the data and divided into four classes. Errors were calculated after applying machine learning methods to the data. Finally, the most suitable machine learning methods were selected for the groups, the annual estimation of the filters was made, and the study was completed (Fig. 1).

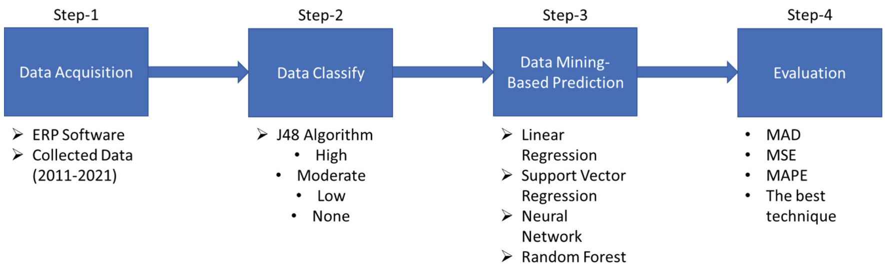

Fig. 1. The case study framework

3.1 Data

(See Figs. 2 and 3).

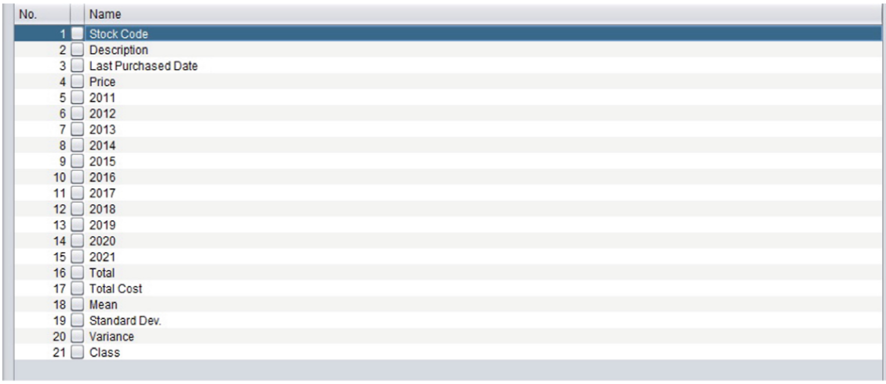

Fig. 2. Classify data

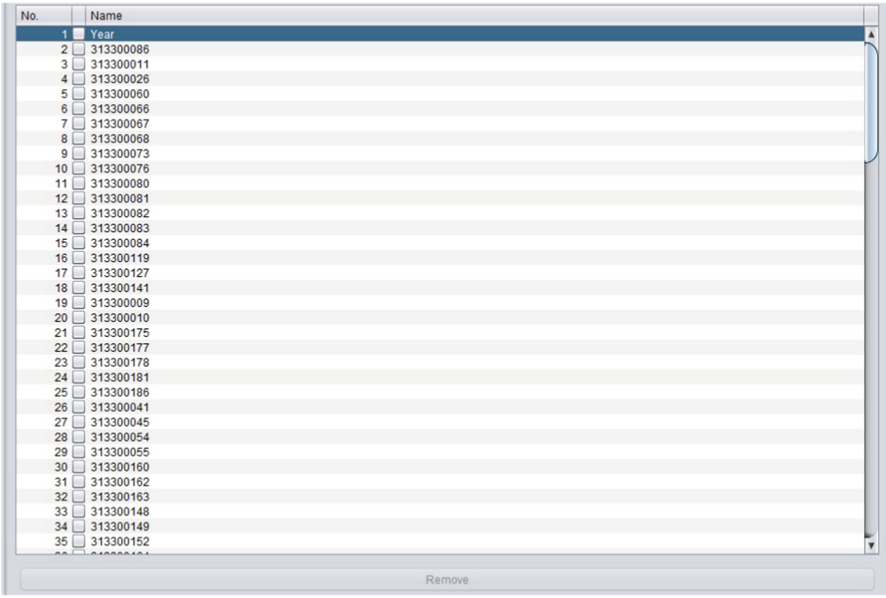

Fig. 3. Forecasting data

4 Application

There are 143 different filter types in the stored data. Unprocessed data includes stock code, description, bus type, engine type, 10-year entry, and exit values, total values, suppliers, the department used, personnel info, last purchase date, brand and model information, and location information. At this phase, all attributes except stock codes, years, and quantities have been removed and the data has been cleared since they do not contribute anything while forecasting the annual demand. However, while classifying the data according to their characteristics, total output, price information, 10-year average consumption, standard deviation, and variance values were used. In this respect, the study used two different data separately for demand forecasting and classification.

The main reason for dividing the data is to split the data into classes using the attributes of the data to find the most appropriate forecasting method within each defined class. When a different type of material is added to the stock, accurate demand forecasting and evaluation can be made after determining which class this material belongs to by using the method that gives the best classification ratio.

4.1 J48 Algorithm

The J48 algorithm was applied to the data and divided into four classes. These classes are "High", "Moderate", "Low" and "None". The "High" class is the one with the highest need and cost. It is more difficult to predict than others and has a direct impact on the company's annual planning. The "Moderate" class is less important than the "High" class, but it's still hard to predict. The "Low" class is a class created by newly collected data and the frequency of need for filters in this class is low. The "None" class consists of classes that have no data. As a result, annual estimates of filters in "High" and "Moderate" Classes were made according to these classes (Table 1).

Table 1. The output of J48 algorithm

Summary		Confusion Matrix							
Correctly Classified Instances	138	**96,5035%**	a	b	c	d		<-- classified as	
Kappa statistic	0,9478		36	1	0	0	|	a = High	
Mean absolute error	0,0175		2	32	1	0	|	b = Moderate	
Root mean square error	0,1322		0	1	63	0	|	c = Low	
Relative absolute error	5,193%		0	0	0	7	|	d = None	
Root relative squared error	32,2699%								
Total Number of Instances	143								
Detailed Accuracy By Class									
	TP Rate	**FP Rate**	**Precision**	**Recall**	**F-Measure**	**MCC**	**ROC Area**	**PRC Area**	**Class**
	0,973	0,019	0,947	0,973	0,960	0,946	0,977	0,929	**High**
	0,914	0,019	0,941	0,914	0,928	0,905	0,948	0,881	**Moderate**
	0,984	0,013	0,984	0,984	0,984	0,972	0,986	0,976	**Low**
	1,000	0,000	1,000	1,000	1,000	1,000	1,000	1,000	**None**
Weighted Avg.	0,965	0,015	0,965	0,965	0,965	0,95	0,975	0,942	

4.2 Knowledge Flow

The second part of the application is using the Knowledge Flow. Knowledge Flow is a tool that allows using all the features of the Weka from a single screen (Tables 2, 3, 4 and 5).

Table 2. K-nearest neighbors classifier. KNN = 2

Summary		Confusion Matrix							
Correctly Classified Instances	102	**71,3287%**	a	b	c	d		<-- classified as	
Kappa statİstic	0,5819		33	4	0	0	|	a = High	
Mean absolute error	0,159		5	24	6	0	|	b = Moderate	
Root mean square error	0,333		3	20	41	0	|	c = Low	
Relative absolute error	47,2156%		0	0	3	4	|	d = None	
Root relative squared error	81,2681%								
Total Number of Instances	143								
Detailed Accuracy By Class									
	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0,892	0,075	0,805	0,892	0,846	0,791	0,937	0,856	High
	0,686	0,222	0,500	0,686	0,578	0,422	0,741	0,431	Moderate
	0,641	0,114	0,820	0,641	0,719	0,549	0,817	0,734	Low
	0,571	0,000	1,000	0,571	0,727	0,748	0,808	0,675	None
Weighted Avg,	0,713	0,125	0,747	0,713	0,718	0,59	0,829	0,688	

Table 3. K-nearest neighbors classifier. KNN = 3

Summary		Confusion Matrix							
Correctly Classified Instances	106	**74,1259%**	a	b	c	d		<-- classified as	
Kappa statİstic	0,6141		32	5	0	0	|	a = High	
Mean absolute error	0,1607		3	20	12	0	|	b = Moderate	
Root mean square error	0,3129		2	12	49	1	|	c = Low	
Relative absolute error	47,7430%		0	0	2	5	|	d = None	
Root relative squared error	76,3691%								
Total Number of Instances	143								
Detailed Accuracy By Class									
	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0,865	0,047	0,865	0,865	0,865	0,818	0,944	0,901	High
	0,571	0,157	0,541	0,571	0,556	0,406	0,762	0,513	Moderate
	0,766	0,177	0,778	0,766	0,772	0,589	0,854	0,753	Low
	0,714	0,007	0,833	0,714	0,769	0,761	0,808	0,676	None
Weighted Avg.	0,741	0,130	0,745	0,741	0,743	0,612	0,853	0,729	

Table 4. K-nearest neighbors classifier. KNN = 4

Summary		Confusion Matrix							
Correctly Classified Instances	107	**74,8252%**	a	b	c	d		<-- classified as	
Kappa statİstic	0,624		31	5	1	0	|	a = High	
Mean absolute error	0,1625		3	22	12	0	|	b = Moderate	
Root mean square error	0,3048		1	13	49	1	|	c = Low	
Relative absolute error	48,2664%		0	0	2	5	|	d = None	
Root relative squared error	74,3906%								
Total Number of Instances	143								
Detailed Accuracy By Class									
	TP Rate	FP Rate	Precision	Recall	F-Measure	MCC	ROC Area	PRC Area	Class
	0,838	0,019	0,939	0,838	0,886	0,851	0,950	0,919	High
	0,629	0,167	0,550	0,629	0,587	0,442	0,781	0,542	Moderate
	0,766	0,190	0,766	0,766	0,766	0,576	0,866	0,794	Low
	0,714	0,007	0,833	0,714	0,714	0,761	0,898	0,674	None
Weighted Avg,	0,748	0,131	0,761	0,748	0,748	0,623	0,868	0,759	

Table 5. K* (K Star) classifier

Summary			Confusion Matrix						
Correctly Classified Instances	124	**74,8252%**	a	b	c	d		<-- classified as	
Kappa statİstic	0,8011		29	8	1	0	|	a = High	
Mean absolute error	0,1203		1	29	5	0	|	b = Moderate	
Root mean square error	0,2968		2	1	60	1	|	c = Low	
Relative absolute error	35,7279%		0	0	1	6	|	d = None	
Root relative squared error	72,4250%								
Total Number of Instances	143								
Detailed Accuracy By Class									
	TP Rate	**FP Rate**	**Precision**	**Recall**	**F-Measure**	**MCC**	**ROC Area**	**PRC Area**	**Class**
	0,784	0,028	0,906	0,784	0,841	0,794	0,973	0,883	**High**
	0,829	0,083	0,763	0,829	0,795	0,725	0,867	0,659	**Moderate**
	0,938	0,076	0,909	0,938	0,923	0,859	0,962	0,935	**Low**
	0,857	0,007	0,857	0,857	0,857	0,850	0,973	0,868	**None**
Weighted Avg,	0,867	0,062	0,87	0,867	0,867	0,809	0,942	0,851	

According to Cleary and Trigg (1995), K* is an instance-based learner which uses such a measure, and results are presented which compare favorably with several machine learning algorithms. Amongst other things, it provides a consistent approach to the handling of symbolic attributes, real-valued attributes, and missing values (Table 6).

Table 6. Locally weighted learning

Summary			Confusion Matrix						
Correctly Classified Instances	119	**74,8252%**	a	b	c	d		<-- classified as	
Kappa statİstic	0,7422		21	16	0	0	|	a = High	
Mean absolute error	0,1552		0	34	1	0	|	b = Moderate	
Root mean square error	0,2768		2	1	64	0	|	c = Low	
Relative absolute error	46,0905%		0	0	7	0	|	d = None	
Root relative squared error	67,5503%								
Total Number of Instances	143								
Detailed Accuracy By Class									
	TP Rate	**FP Rate**	**Precision**	**Recall**	**F-Measure**	**MCC**	**ROC Area**	**PRC Area**	**Class**
	0,568	0,000	1,000	0,568	0,724	0,702	0,968	0,929	**High**
	0,971	0,148	0,680	0,971	0,800	0,742	0,749	0,857	**Moderate**
	1,000	0,101	0,889	1,000	0,941	0,894	0,956	0,932	**Low**
	0,000	0,000	?	0,000	?	?	0,814	0,131	**None**
Weighted Avg,	0,832	0,082	?	0,832	?	?	0,950	0,873	

Like Weka explorer, the J48 Classify algorithm is the best suitable method for the Filter data set with %96.5.“Linear Regression”, “Support Vector Regression”, “Neural Network” and “Random Forest” were applied to the filter data in “High”, “Moderate” and “Low” classes using via Weka Machine Learning Software. Errors were calculated using the forecast values obtained and the actual data of the estimated year. Since the data of the “Low” class is insufficient, no error calculation has been made.

5 Conclusion

The case study uses machine learning approach and focuses on the forecast of spare parts public transportation company. The application is dynamic, all methods can change each spare part for every update of the data. The framework selects the most appropriate method based on errors that happened in past predictions which is the framework has an error-minimizing orientation. The method cannot handle sudden changes in data because of the structure itself. The method cannot work properly when data is missing or wrong which means data collection and storage are a must for the proposed framework. Based on the MAD and MSE results, the best machine learning algorithm for Class "High" was "Support Vector Regression" and "Random Forest" for Class "Moderate". In addition, based on the MAPE results, the best machine learning algorithm for the "High" class was "Neural Network" and "Support Vector Regression" for the "Moderate" class (Tables 7 and 8).

Table 7. Results for "high" class

Class: High			
Total Error			
LR	SVR	NN	RF
4605.1573	3706.5359	4320.9901	4859.9551
Total Squared Error			
LR	SVR	NN	RF
1171794.31	619013.439	1052403.06	1566736.244
Total Absolute Percent Error			
LR	SVR	NN	RF
33943.7519	50513.6596	29882.8835	36023.19087
Error Table			
	MAD	**MSE**	**MAPE**
LR	124.463711	31670.1164	917.3987007
SVR	100.176646	16730.0929	1365.234044
NN	116.783516	28443.3259	807.6454991
RF	131.350138	42344.2228	973.5997534

Table 8. Results for "moderate" class

Class: Moderate			
Total Error			
LR	SVR	NN	RF
1313.5978	2743.1121	1520.7531	876.3116
Total Squared Error			
LR	SVR	NN	RF
97001.9059	1677641.962	253994.9346	40330.19027
Total Absolute Percent Error			
LR	SVR	NN	RF
4360.531534	3765.275356	5005.945833	35638.9147
Error Table			
	MAD	**MSE**	**MAPE**
LR	38.63522941	2852.997232	128.2509275
SVR	80.67976765	49342.41066	110.7433928
NN	44.72803235	7470.439252	147.233701
RF	25.77387059	1186.182067	1048.203374

Various machine learning approaches and algorithms can add to the proposed framework. Aim to develop a machine learning-based approach combined with a traditional method that outperforms the current technique that is used by the company, at the same time evaluating the influence of different modeling approaches in terms of forecast accuracy. The proposed framework can be applied to various work areas. The previous method was based on just personal experience however the framework is based on scientific approaches and algorithms, and we can see some big improvements between actual and forecast.

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Evaluating the Quality of Water & Performance of WTPs in Iraq Using RII & TOPSIS Methods

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Abstract. The quality of drinking water is always considered the highest significant field for researchers worldwide as it has a direct impact on the population's lives. In Fallujah city - Iraq, this research was conducted to evaluate the water quality & the overall performance of three water treatment plants WTPs. A survey was designed with a specific question related to the Water Quality (WQ) generally and the WQ Parameters (WQPs) particularly to identify the significance or the impact of the number of fourteen parameters that have a direct impact on the quality of drinking water. The survey was carried out with 32 experts working in the same field. The assessment of the WQPs in the survey was conducted based on the Likert scale of 1–7. The RII calculation was implemented on the primary weights to extract the more reliable weights required for the TOPSIS method. Then, the TOPSIS was executed using Octave software where three variables were identified and created which represent the decision matrix taken from the WQ testing results of these WTPs, the final weights generated using RII values, and the beneficial & non-beneficial values that were identified using the water quality parameters scale prepared for this research. The results of the TOPSIS method reveal that the final ranking over the six months showed that WTP-2 got the highest ranking for January and February 2021, while for March, April, May, and June WTP-3 got the highest ranking than WTP-1 & WTP-2.

Keywords: WTPs · Water quality · RII · TOPSIS method · Octave · Fallujah city

1 Introduction

Since fewer than 1% of the world's water is drinkable, drinking water is the most crucial natural resource. The development of the public's health and well-being depends critically on a steady supply of potable drinking water (Omar and Aziz 2020). The most prevalent substance in the world is known to be water, however not all locations have access to drinking water. The fact that the major civilizations of antiquity were built alongside or adjacent to water sources shows how important water is.

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To attain a water quality that satisfies certain objectives or requirements established by the end-user or a community through its regulatory authorities, water must be processed. The history of empirical and scientific advancements challenges faced, and successes in the creation of water treatment facilities are extensive. A water treatment plant (WTP) is necessary to provide residents with clean, and safe water. In order to properly treat raw water, it is necessary to assess the performance of the WTPs. To provide fresh drinkable water, the majority of modern drinking water treatment plants (WTPs) employ traditional treatment techniques such as coagulation-flocculation, sedimentation, sand filtration, and disinfection. An intake, raw water, treatment, and transmission analysis were once employed to determine the water system's quality. Every treatment plant must take into account the various units depending on the quality of the raw water for appropriate treatment. It should be operated and maintained properly moving forward.

The methods of evaluating a WTP's performance involve determining its operational efficiencies based on some pre-established performance indicators, such as the extent to which pollutants like turbidity, color, suspended impurities, etc. are removed. Water treatment and purification are regarded to be major challenges, especially in developing nations where they are necessary to protect public health and the environment by eradicating bacteria and illnesses that are spread by contaminated water (Issa 2017). The non-optimized use of chemicals, the operation of unit processes, and energy consumption are the most frequent issues seen nowadays in drinking WTPs. Despite this, the standard method for evaluating WTP efficiency nearly always relies only on the treated water's compliance with the water quality regulations prior to being distributed to the customer, (Hassan and Mahmood 2018). Although the requirements for drinking water have become stricter throughout time, the method of purification has not changed. Through the decades, the water treatment plants' units were built with the drinking water standards in mind at the time of construction.

There has been a dramatic rise in population in Fallujah. There is now an urgent need to apply monitoring and evaluation methodologies to ensure that the output of WTPs are in the same range as the Iraqi water quality standards and assess the overall performance of these WTPs and come up with recommendations that make it easy for the decision maker to put larger focus in which plant needs to be rehabilitated and monitored. Fallujah City receives drinking water from three primary water treatment facilities and a number of water treatment stations. There is a definite need for research to concentrate on describing a performance evaluation system for WTPs because of certain ongoing issues in the operation and maintenance of these WTPs.

This study focuses on detecting these issues by assessing each plant's efficiency for several characteristics through the analysis of output samples' results to determine how well these WTPs are actually performing. This research will conduct to evaluate the water quality & the performance of three WTPs. A survey will design with a specific question related to the water quality generally and the WQPs particularly to identify the significance or the impact of the number of fourteen parameters that have a direct impact on the quality of drinking water. The survey was carried out with 32 experts working in the same field. The assessment of the WQPs in the survey was conducted based on the Likert scale of 1–7 (Çetintav et.al. 2016a, b). The RII calculation will implement on the primary weights to extract the weights that are required for the TOPSIS method to extract the final scoring in order to rank the three WTPs.

1.1 The Case of Study

Fallujah is an Iraqi city on the Euphrates River's left bank, 60 km west of Baghdad. The Euphrates River, which serves as a vital supply of fresh water for a population of nearly 530,000 people by 2019 (Huda et al. 2018), forms Fallujah's western border (Fig. 1). The people have access to piped water sourced by Euphrates River after purification process in the WTPs. For a long time, the residents complained of the contamination of the supplied water (Ali et al. 2019). The city center's treated water is supplied by three major water stations and more than five sub-stations. The Old project (WTP-1), Al-Azrakiyah\The New project (WTP-2), and Al-Resalah project (WTP-3) are the primary stations. Al-Cement, Al-Tahade, New Shuhada, and The Old Shuhada, Al-Askary can be classified as substations. Many of both classified WTPs installed along the riverbank had been damaged due to military operations between 2014 and 2016. Many of the city's community members are claiming that the water quality and availability in the city and its adjacent areas are both low. Since it is untreated well, the people used to have small-sized water station filters at home for drinking purposes; and add to this, the mineral water also became major safe water for 64% of the city residents (Huda 2018).

Therefore, it is necessary to investigate the water quality and assess the performance of the water treatment plants (WTPs) to determine the challenges and address them by the right actions to provide high-quality drinking water. This will enable the water quality decision makers, project managers, and other stakeholders to identify the risk factors associated with the variation between the ranking results of this study and the water quality standards.

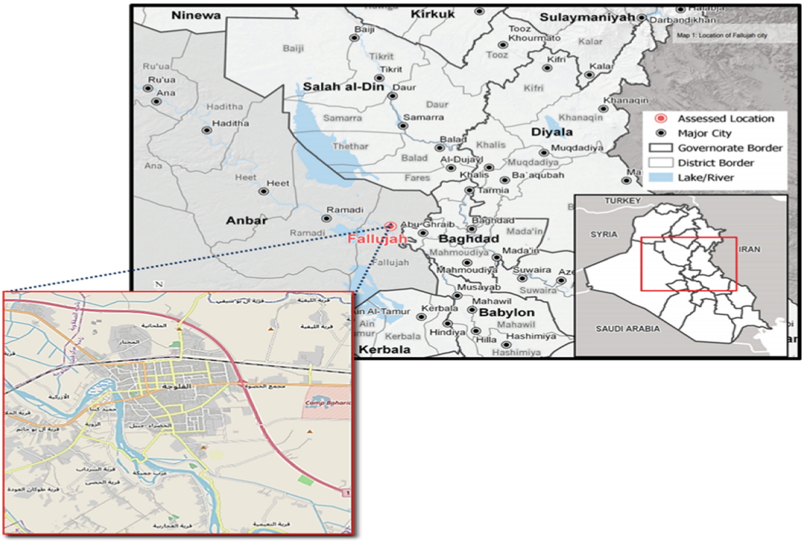


Fig. 1. The study area

2 Data and Methodology

In this part, the three major Water Treatment Plants (WTPs) would be explained. These WTPs called The Old Fallujah's (WTP-1), Fallujah New project or Al-Azrakiyah project (WTP-2), and Al-Resalah project (WTP-3). These three WTPs responsible of delivering clean water to around 60% of Fallujah's population. By 2016, following the liberation of the towns of Anbar province from the hands of the terrorist group ISIS. It was difficult to gain an accurate picture of the sector's influence from war is problematic owing to the inability to access key cities due to the high hazards of the relics of war. However, the limited evidence gathered by the UN and other international organizations such as UNICEF, International Organization for Migration (IOM), and the Danish Refugee Council (DRC), indicates that the war has exacerbated water and sanitation problems in liberated governorates such as Anbar province which were controlled by the terrorist organization during 2014–2017. The outcomes of these evaluations suggested that most of these WTPs and pumping stations were damaged, and bombs have caused severe disruptions in power and water distribution networks in cities.

2.1 Fallujah's Old Project (WTP-1)

This WTP is located at the bank of the Euphrates River, on the border of the city's only surface water source. This project produces treated water for up to 30% of Fallujah. It provides clean water to the city and some nearby villages, supplying around 1500 m^3/h to a population of between 100,000 and 150,000. As shown in Fig. 2.

Fig. 2. WTP-1 located at the Riverbank about 111 m

The raw water is provided from the same intake of the WTP-2 because of poor water management and the impact of climate change, the river's flow is very irregular, with high flows in December and April and low flows in the remaining months. Table 1 below includes the major specifications of this WTP.

Table 1. Specification of the WTP-1

Project's name	The Fallujah's old DWTP		
Location	33°21′16.7″N 43°45′33.7″E	West of Fallujah city 2.5 km of the city center	
Construction date	2005	Last rehabilitation date	2018
Designed capacity	1500 m^3\h		
Staff no.	12	Project's engineers	1

2.2 Fallujah's New Project\Al-Azrakiyah Plant (WTP-2)

The Azrakiyah WTP is located 207 m from the Euphrates the only surface water source of the city as shown in Fig. 3 below. This DWTP produces treated water for up to 60% of Fallujah. It provides clean water to the city, supplying around 2500 m^3/h to the center of the city with a population between 250,000 and 350,000. As shown in Fig. 3.

Fig. 3. Showing the WTP-2 location for the river and its intake

Intake it is 4 m deep in the Euphrates River and 217 m from the intake to the WTP. There is no control system near the intake to measure river water extraction. The river water is then pumped up to the 3 rapid mixture basins. Rapid mixing basins are the first step in treating river water. In addition, there are no blenders in these basins, and the water plant process blending is sluggish at this station. The water from the intake is sent to a rapid mixture, then to sedimentation basins to remove sands and dams. On the way to the consumers, it passes through sand filters and is cleaned by high-pressure air. Table 2 below shows the specifications and details of this WTP.

Table 2. Specification of the WTP-2

Project's name	The Fallujah's old DWTP		
Location	33°21′13.8″N 43°44′43.0″E	Fallujah's Northwestern5.3 km of city center 5.3 km of city center	
Construction date	2005	Last rehabilitation date	2018
Designed capacity	1500 m^3\h		
Staff No.	18	Project's engineers	2

2.3 Al-Resalah Project (WTP-3)

The third WTP selected for our case study was the Al-Resala project. It's installed at the riverbank 17 m from the Euphrates as shown in Fig. 4. This WTP produces treated water for up to 10–15% of the Fallujah population. It provides clean water to the old city center market in the city, supplying around 800 m^3/h to a population of between 25,000 and 35,000. As shown in Fig. 4 (Table 3).

Fig. 4. Location of the WTP-3

Table 3. Specification of the WTP-3

Project's name	The Fallujah's old DWTP		
Location	33.34509689743496, 43.762322345109745	Western Fallujah's city 2 km of city center	
Construction date	2005	Last rehabilitation date	2017
Designed capacity	800 m^3\h		
Staff no.	10	Project's engineers	1

3 Survey Report

After selecting the three WTP's, in this section, a survey would be carried out to gather sampled data from different specialists related to the same field of study. The survey was collected from 32 experts. These surveys include several WQPs and each one would be evaluated based on seven factors. These factors were: (extremely important, very important, somewhat important, neither important, not unimportant, somewhat unimportant, not very important, and not at all important).

Table 4. The transformation of factor scale and the related values (likert scale)

Factor scale	Factor value
Extremely important	7
Very important	6
Somewhat important	5
Neither important nor unimportant	4
Somewhat unimportant	3
Not very important	2
Not at all important	1

Additionally, another related to the quality of water for drinking and satisfaction with the quality of water provided by the three studied WTP's. These surveyed responses were collected in Excel to be furthered handle for the next steps as shown in Fig. 5.

	R	T	V	X	Z
1	Turbidity	Temperature	EC	pH	Alkalinity
2	Very important	Very important	Very important	Very important	Very important
3	Extremely important	Somewhat important	Very important	Extremely important	Somewhat important
4	Very important	Very important	Very important	Very important	Neither important nor unimportant
5	Very important	Extremely important	Somewhat unimportant	Very important	Somewhat important
6	Somewhat unimportant	Somewhat unimportant	Very important	Somewhat important	Somewhat unimportant
7	Very important	Very important	Extremely important	Extremely important	Extremely important
8	Not at all important	Not at all important	Not at all important	Very important	Not at all important
9	Extremely important	Somewhat important	Extremely important	Very important	Extremely important
10	Very important	Somewhat important	Neither important nor unimportant	Somewhat important	Somewhat important
11	Very important	Not very important	Somewhat important	Very important	Somewhat important
12	Somewhat important	Somewhat important	Somewhat unimportant	Somewhat important	Somewhat important
13	Very important	Not very important	Very important	Very important	Somewhat unimportant
14	Somewhat important	Not very important	Very important	Very important	Somewhat unimportant
15	Very important	Neither important nor unimportant	Somewhat important	Extremely important	Extremely important
16	Very important	Not very important	Very important	Extremely important	Very important
17	Somewhat unimportant	Very important	Very important	Very important	Somewhat important
18	Neither important nor unimportant	Not very important	Somewhat unimportant	Somewhat important	Somewhat important
19	Very important	Somewhat important	Somewhat important	Very important	Somewhat important
20	Not very important	Not at all important	Somewhat important	Very important	Very important
21	Very important	Not very important	Very important	Somewhat important	Somewhat important
22	Very important	Somewhat important	Very important	Very important	Somewhat important
23	Extremely important	Not at all important	Not at all important	Extremely important	Extremely important
24	Somewhat important	Very important	Very important	Very important	Somewhat important
25	Somewhat important	Very important	Very important	Very important	Very important
26	Very important	Neither important nor unimportant	Somewhat unimportant	Very important	Somewhat important
27	Very important	Somewhat important	Neither important nor unimportant	Very important	Neither important nor unimportant
28	Somewhat unimportant	Somewhat unimportant	Neither important nor unimportant	Very important	Neither important nor unimportant
29	Very important	Very important	Somewhat important	Extremely important	Extremely important
30	Very important	Somewhat important	Very important	Extremely important	Extremely important
31	Very important	Somewhat important	Extremely important	Very important	Very important
32	Very important	Very important	Very important	Very important	Not at all important
33	Very important	Somewhat important	Very important	Somewhat important	Very important

Fig. 5. Results of the conducted survey shows the significance of each WQP

Survey Results														
Parameters / Respondants	Turbidity	Temperature	pH	Electrical conductivity (EC)	Alkalinity	Chloride	Sulphates	Magnesium	Potassium	Hardness	Total Dissolved Solids (TDS)	Total Suspended Solid (TSS)	Calcium	Sodium
R 1	6	6	6	6	6	6	6	6	6	6	6	6	5	5
R 2	7	5	7	6	5	7	7	2	7	7	5	6	6	6
R 3	6	6	6	6	4	4	4	4	4	4	1	4	4	4
R 4	6	7	6	3	5	6	6	5	5	6	6	7	5	5
R 5	3	3	5	6	3	6	4	5	5	5	5	6	5	5
R 6	6	6	7	7	7	7	7	7	7	6	7	7	7	7
R 7	1	1	6	1	1	1	1	3	5	5	5	5	5	5
R 8	7	5	6	7	7	6	6	7	7	5	7	7	7	6
R 9	6	5	5	4	5	7	5	5	5	5	6	6	5	5
R 10	6	2	6	5	5	5	5	5	5	7	6	6	5	6
R 11	5	5	5	3	5	5	5	5	5	5	5	5	6	5
R 12	6	2	6	6	3	6	2	2	2	1	7	6	5	5
R 13	5	2	6	6	3	6	5	5	4	3	7	7	4	4
R 14	6	4	7	5	7	6	5	6	6	6	7	7	6	6
R 15	6	2	7	6	6	7	4	3	3	6	7	4	3	3
R 16	3	6	6	6	5	6	6	6	6	6	7	5	6	6
R 17	4	2	5	3	5	5	5	5	5	6	5	3	4	4
R 18	6	5	6	5	5	5	6	5	5	6	6	5	5	5
R 19	2	1	6	5	6	7	5	5	5	6	5	5	5	5
R 20	6	2	5	6	5	5	6	5	5	6	7	6	7	7
R 21	6	5	6	6	5	6	4	5	5	6	7	5	5	4
R 22	7	1	7	1	7	7	7	7	7	7	7	7	7	7
R 23	5	6	6	6	5	6	6	6	6	6	5	5	6	6
R 24	5	6	6	6	6	6	6	6	6	6	6	6	6	6
R 25	6	4	6	3	5	5	2	7	5	4	3	5	7	6
R 26	6	5	6	4	4	7	5	5	6	4	7	6	5	6
R 27	3	3	6	4	4	4	6	6	5	6	6	5	7	6
R 28	6	6	7	5	7	7	7	7	7	6	6	6	6	7
R 29	6	5	7	6	7	6	6	5	7	6	6	5	6	7
R 30	6	5	6	7	6	6	6	3	3	3	7	7	2	2
R 31	6	6	6	6	1	6	6	6	3	5	6	5	6	6
R 32	6	5	5	6	6	7	7	6	6	6	5	5	5	5
Total	171	134	193	162	161	186	168	165	168	172	188	180	173	172

Fig. 6. Surveys' answers transformed into (1–7) values and calculation of the sum of each WQP.

In this section, the factor scale that was collected from the survey responses would be transformed into values from 1–7 (based on each response as shown in Table 4.

4 Relative Importance Index (RII) Calculation

Through the questionnaire results obtained by the participants that used the Likert scale (1–7), the values for each factor were collected separately and the total factor values were calculated to extract the RII values from each parameter as shown above in Fig. 6. The calculation of each parameter was as follows:

$$\textbf{Relative importance Index} = \textbf{WQP weight}/\textbf{Total WQP weights}$$

5 TOPSIS Method for Evaluating the WQ and Performance of WTPs

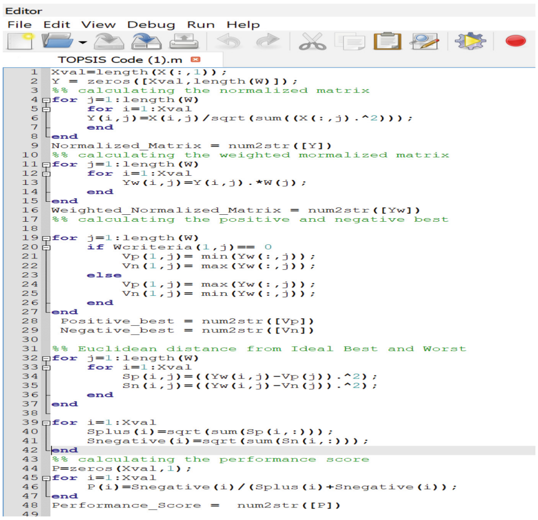
TOPSIS method is considered as a compensatory aggregation which is a technique for comparing sets of alternatives by identifying weights for each criterion, normalizing scores for each criterion, and calculating the geometric distance between each alternative and the ideal alternative, which is the alternative with the best score in each

$$\textbf{Relative importance Index} = {}^{\textbf{WQP weight}}/_{\textbf{Total WQP Weights}}$$

Relative Important Index (RII) Values of Water Quality Parameters															
Parameters / Respondant	Turbidity	Temperature	pH	Electrical conductivity (EC)	Alkalinity	Chloride	Sulphates	Magnesium	Potassium	Hardness	Total Dissolved Solids (TDS)	Total Suspended Solid (TSS)	Calcium	Sodium	
Total	171	134	193	162	161	186	168	165	168	172	188	180	173	172	2393
RII	0.071458	0.055996657	0.080651901	0.06769745	0.06728	0.0777267	0.0702048	0.068951107	0.07020476	0.07187631	0.07856247	0.07521939	0.07229419	0.07187631	1

Fig. 7. Relative Important Index (RII) values of each WQP. (TOPSIS weights)

criterion. TOPSIS is predicated on the notion that the criteria are rising or decreasing in a monotonous manner. As the parameters or criteria in multi-criteria situations are often of incongruent dimensions, normalization is normally essential to ensure that the results are comparable. The TOPSIS method would be carried out using the following developed programming code via Octave-7.1.0 (GUI) software as shown below in Fig. 8 below.




```
Xval=length(X(:,1));
Y = zeros([Xval,length(W)]);
%% calculating the normalized matrix
for j=1:length(W)
    for i=1:Xval
    Y(i,j)=X(i,j)/sqrt(sum((X(:,j).^2)));
    end
end
Normalized_Matrix = num2str([Y])
%% calculating the weighted mormalized matrix
for j=1:length(W)
    for i=1:Xval
        Yw(i,j)=Y(i,j).*W(j);
    end
end
Weighted_Normalized_Matrix = num2str([Yw])
%% calculating the positive and negative best

for j=1:length(W)
    if Wcriteria(1,j)== 0
        Vp(1,j)= min(Yw(:,j));
        Vn(1,j)= max(Yw(:,j));
    else
        Vp(1,j)= max(Yw(:,j));
        Vn(1,j)= min(Yw(:,j));
    end
end
 Positive_best = num2str([Vp])
 Negative_best = num2str([Vn])

%% Euclidean distance from Ideal Best and Worst
for j=1:length(W)
    for i=1:Xval
        Sp(i,j)=((Yw(i,j)-Vp(j)).^2);
        Sn(i,j)=((Yw(i,j)-Vn(j)).^2);
    end
end

for i=1:Xval
    Splus(i)=sqrt(sum(Sp(i,:)));
    Snegative(i)=sqrt(sum(Sn(i,:)));
end
%% calculating the performance score
P=zeros(Xval,1);
for i=1:Xval
    P(i)=Snegative(i)/(Splus(i)+Snegative(i));
end
Performance_Score =  num2str([P])
```

Fig. 8. Executing the code using Octave7.1.0(GUI) software

5.1 TOPSIS Methods Requirements and Steps Are

- **Decision Matrix\Dataset**

The first input requirement to implement TOPSIS via Octave software is the decision matrix which prepared by collecting the water quality tests' results from the Water National Laboratory (WNL) for the three WTPs over six months from Jan to June 2021 as shown in Figs. 9, 10 and WTPs output data for fourteen parameters presented in a table that shapes the decision matrix of this research.

Ministry of Municipalities and public Work
GDW\ Water National Laboratory

Governorate: AL-Anbar
Date of sampling: 2021/6/23
Sampled by:

Physical and chemical parameters Sample location	WTP-1 مشروع ماء الفلوجة القديم		WTP-2 مشروع ماء الفلوجة الجديد		WTP-3 مجمع ماء الرسالة (١)		MPL
Parameters in mg/L Unless other wise stated	Raw	Clean	Raw	Clean	Raw	Clean	
Turbidity, NTU	6.8	2.4	6.7	1.6	3.7	1	5
Temperature C	30	30	30	31	30	31	ACC
PH	8	7.8	7.6	7.8	7.9	8	6.5-8.5
E.C. µ S/CM 25 C	750	734	751	736	748	741	
Alkalinity (as $CaCO_3$)	112	116	116	116	120	116	125-200
Hardness (as $CaCO_3$)	337	341	345	337	333	337	500
Calcium (as Ca)	82	79	80	79	83	77	150
Magnesium (as Mg)	32	35	35	34	30	35	100
Chloride (as Cl)	86	93	90	92	88	93	350
Iron (as Fe)40	\	\	\	\	\	\	0.3
Aluminum (as Al)	\	\	\	\	\	\	0.2
Sulphates (as So_4)	235	230	231	241	238	244	400
Sodium (as Na)	62	64	61	62	60	62	200
Potassium (as K)	3.9	3.8	3.9	3.8	3.7	3.7	
T.D.S	504	500	514	498	506	504	1000
T.S.S	48	14	38	12	16	8	
Nitrate (as No_3)	\	\	\	\	\	\	50
Chromium (as Cr^{+6})	\	\	\	\	\	\	
Fluoride (as F)	\	\	\	\	\	\	

Fig. 9. Water quality tests result by the local Laboratory (WNL) for June 2021.

Decision Matrixes

Decision Matrix (January, 2021)

	Turb.	Tem.	pH	E.C	Alkalinity as $CaCO_3$	Cl	SO_4	Mg	K	Hardness	TDS	TSS	Ca	Na
WTP-1	1.3	21	7.8	855	112	94	203	52	2.7	307	587	4	76	56
WTP-2	1.4	21	7.9	856	118	92	198	30	2.8	306	588	5	74	58
WTP-3	1.8	21	8	857	13	93	196	31	3	307	577	4	75	55

Decision Matrix (February, 2021)

	Turb.	Tem.	pH	E.C	Alkalinity as $CaCO_3$	Cl	SO_4	Mg	K	Hardness	TDS	TSS	Ca	Na
WTP-1	1.2	20	8	858	112	94	206	30	3	307	586	4	74	57
WTP-2	1.3	20	8	856	120	92	204	30	2.8	307	588	4	74	59
WTP-3	1.9	20	8	854	112	94	196	59	2.9	307	576	4	75	56

Decision Matrix (March, 2021)

	Turb.	Tem.	pH	(EC)	Alkalinity as $CaCO_3$	Cl	SO_4	Mg	K	Hardness	TDS	TSS	Ca	Na
WTP-1	1.1	20	7.6	967	120	88	238	36	2.9	350	643	10	80	57
WTP-2	1.2	20	7.6	982	116	93	246	32	2.8	352	640	18	88	55
WTP-3	1	20	7.8	986	124	93	232	33	2.9	345	650	10	83	56

Decision Matrix (April, 2021)

	Turb.	Tem.	pH	E.C	Alkalinity as $CaCO_3$	Cl	SO_4	Mg	K	Hardness	TDS	TSS	Ca	Na
WTP-1	1.6	22	8	933	117	97	270	36	4	364	674	14	87	75
WTP-2	1.5	22	8	997	114	96	270	37	4.3	370	678	12	88	73
WTP-3	1.3	22	8.1	992	118	94	276	36	4.2	373	670	10	90	79

Decision Matrix (May, 2021)

	Turb.	Tem.	pH	E.C	Alkalinity as $CaCO_3$	Cl	SO_4	Mg	K	Hardness	TDS	TSS	Ca	Na
WTP-1	1.8	32	7.7	741	16	90	232	33	3.7	342	498	13	80	63
WTP-2	2.3	30	7.6	738	117	93	244	35	3.8	337	501	12	81	62
WTP-3	1.5	31	7.9	744	116	91	243	36	3.9	339	504	9	78	61

Decision Matrix

	Turb.	Tem.	pH	E.C	Alkalinity as $CaCO_3$	Cl	SO_4	Mg	K	Hardness	TDS	TSS	Ca	Na
WTP-1	2.4	30	7.8	734	116	93	230	35	3.8	341	500	14	79	64
WTP-2	1.6	31	7.8	736	116	92	241	34	3.8	337	498	12	79	62
WTP-3	1	31	8	741	116	93	244	35	3.7	337	504	8	77	62

Fig. 10. Decision Matrixes for Jan-June 2021.

- **Criteria weight determination**

This is the second input requirement for the TOPSIS method, in this step, the RII's weight values of each parameter obtained from the previous section would be formed in a table to be further handled for the other steps as shown above in Fig. 7. These weights were obtained per each of the studied parameters selected for our case study investigation and for the three selected WTP's.

- **Weighted Criteria Weights Identification**

To execute the MATLAB code below that will show the final scores of the TOPSIS method, the Octave software requires the third input which are weighted criteria weights that represent in our case the Beneficial & Non-Beneficial values for the WQPs. The beneficial & non-beneficial values were determined according to interviews done with experts to develop the WQPs' scales as shown in Fig. 10 below. When a lower value is desired = non-Beneficial; and if the high value is desired = Beneficial value, as explained in Fig. 12 (Fig. 11).

Levels	Parameters	Turbidity	Temperature	TDS	TSS	Electrical conductivity (EC)	pH	Alkalinity	Chloride	Sulfate	magnesium	Hardness	Calcium	Sodium	Potassium
Excellent	5	0-25	15 – 20	100-300	2	500	7	125-200	0.5PPM	200	1–20	0-60	10–50	10–50	1 – 20
good	4	26-5	11 – 14	301-500	4	600	6.8-7.2	120-205	0.8-1	220	20-30	61-120	50–100	50-100	20-30
poor	3	5.1-7	6 – 10<Tem >21-25	501-700	50	1000	6.5-6.7/7.3-7.5	115-210	2.5	350	50-80	121-180	100–140	150-180	50-80
very poor	2	7.1-8	1 – 5 <Tem >26-31	701-1000	50-100	1300	6-6.4 / 7.6-8.5	110-220	4	350-400	80-100	182-200	150	180-200	80 - 100
No suitable	1	>8	0<Tem>31	>1000	>100	> 1300	>=8.6/=<5.9	<110 &>220	>4	>400	> 100	> 200	> 150	> 200	> 100

Fig. 11. Water quality parameters scales

Beneficial & Non- Beneficial Values of each parameter	0	1	1	0	1	0	0	0	0	0	0	0	0	0

Fig. 12. Weighted criteria weights

After executing the TOPSIS method's code the following TOPSIS steps will be generated:

- **Normalization**

In this step, each weight selected for each parameter based on the three WTP's normally used to be handled with two mathematical equations

1 - **Firstly**, is the sum squared of each parameter obtained from the first step and based on Eq. 1.

$$\text{Sum Squared (i)} = \sum\nolimits_{1}^{j} \text{(parameter (i) fromWTP (j))2} \tag{1}$$

where j represents a counter for the number of WTP and i represent a counter for the selected parameters in this study to be handled with the TOPSIS-based method.

2 - **Secondly**, the squared root would be obtained from the values of the sum squared per each parameter in Eq. 3.1 and as seen in Eq. 2.

$$\text{Root (i)} = \sqrt{\text{Sum Squared } (\mathbf{i})} \tag{2}$$

However, this step of TOPSIS was generated by using the first part of the above MatLab code above shown in Fig. 8.

- **Determination of weighted normalized matrix (Normalized weight)**

This is the third step of the TOPSIS-based method, in this step the value of normalized weight would be obtained from the weight that was set for each parameter in step (1) and the Root values that were calculated from Eq. 2. This step can be calculated as in Eq. 3.

$$\text{Normalized Weight (NW) (i, j)} = \frac{\text{Parameter (I)} \textit{ from } \text{WTP (J)}}{\text{Root (I)}} \tag{3}$$

where the normalized weight would be calculated per each parameter (i) and each WTP (j). However, this step of TOPSIS was generated by using the second part of the above matlab code above shown in Fig. 8.

- **Determination of the positive & negative ideal solution**

In this fifth step the positive and negative values of the ideal solution are normally used to be calculated from the values that were obtained from Eq. 4 in the previous step. The calculation of these two values can be done as seen in Eqs. 5 and 6 respectively.

$$\text{V} + \text{(i)} = \text{MAX(Weighted NW (i, j))} \tag{4}$$

$$\text{V} - \text{(i)} = \text{MIN(Weighted NW (i, j))} \tag{5}$$

Noted that these two values would be calculated per each parameter (i) among the selected parameters. In this research, this step was generated by using the third part of the above MatLab code above shown in Fig. 8.

- **Ideal distance from positive/negative solution**

The distance in Euclidean space between all items in the ideal best and ideal worst rows. Where the ideal worst, and the worst distance are found. This step was also calculated using the same code.

- **Calculating TOPSIS method Scores and Ranking**

Now it has distance positive and distance negative with us, let's calculate the TOPSIS score for each row on basis of them. TOPSIS scores will be gained after running the designed code using the Octave GUI software. Then, Rank calculated using Microsoft Excel's *Rank formula to ranking the three WTPs performance over six months.

6 Results and Discussion

6.1 Research Survey

This survey has addressed 32 engineering and non-engineer staff from both chemical and biological educational backgrounds as well as other staff working in the drinking water sector. It is a part of scientific research. Where the specialists answered the main parameters that are as follows (Turbidity, pH, temperature, etc.). WQPs were measured using a Likert scale (1–7) to identify the weights of each parameter listed in the picture below in the opinion view. The answers of the participants were as follows;

First of all, the participants' opinions about the turbidity parameter were different, as it was between (somewhat important _ very important), which had evaluated according to the Likert scale (5–6). The overall total of the participants concerning the turbidity parameter was equal to 171, which is an appropriate value for the other factors studied through the questionnaire.

While, the participants' opinions about the temperature parameter were different, as it was between (neither important - somewhat important), which had been evaluated according to the Likert scale (4–5). The overall total of the participants who answers the temperature parameter was equal to 134, this result which is an appropriate value for the water temperature in the study area (Iraq) is generally normal, as it does not reach the boiling point or the freezing point in the drinking water sources in the Tigris and Euphrates rivers.

Also, the participants evaluated important parameters, including (electrical conductivity, Alkalinity, Chloride, Sulphates, Magnesium, Potassium, Hardness, Total Dissolved Solids, Total Suspended, Calcium, Sodium) the participants' opinions about the parameters varied between (somewhat important- very important), which had evaluated according to the Likert scale (5–6).

On the other hand, the participants' opinions about the pH parameter were different, as it was between (very important _ extremely important), which had evaluated according to the Likert scale (6–7). The overall total of the participants with respect to the pH parameter was equal to 193, which is the highest value for the other factors that were evaluated through the questionnaire, because pure water has a pH of about 7.0, making it neutral. Normal rainfall has a pH of 5.6 due to the presence of carbon dioxide in the air (slightly acidic). The pH of drinking water should be between 6.5 and 8.5 to be safe for home use and to meet the requirements of living organisms.

As shown in Fig. 6 of the results of the questionnaire, there was clear importance for certain elements such as pH, and turbidity, as they are considered among the most important criteria to examine when examining water quality, since any inappropriate change in its proportions causes a direct, rapid and dangerous health impact on human life.

6.2 Analyzing the Data of the Survey Using the Relative Importance Index (RII)

The calculation of each parameter was as follows:

$$\textbf{Relative importance Index} = \textbf{WQP weight}/\textbf{Total WQP weights}$$

The results of calculating the RII for the WQPs were as the following:
For Turbidity = 171/2393 = 0.0714;
Temperature = 134/2393 = 0.0559;
pH = 193/2393 = 0.0806;
E.C = 162/2393 = 0.0676;
Alkalinity = 161/2393 = 0.0672;
Chloride = 186/2393 = 0.0777;
Sulphates = 168/2393 = 0.0702;
Magnesium = 165/2393 = 0.0689;
Potassium = 168/2393 = 0.0702;
Hardness = 172/2393 = 0.0718;
Total Dissolved Solids.
(TDS) = 188/2393 = 0.0785;
Total Suspended Solid (TSS) = 180/2393 = 0.0752;
Calcium = 173/ 2393 = 0.0722;
Sodium = 172/ 2393 = 0.0718;

Sum of results for (RII) values of water quality parameters = 0.0714 + 0.0554 + 0.0806 + 0.0672 + 0.0777 + 0.0702 + 0.0689 + 0.0702 + 0.0718 + 0.0785 + 0.0752 + 0.0722 + 0.0718 = 1 (Sum of RII).

As shown, after collecting the corresponding values for fourteen parameters within the questionnaire about each water quality criterion and obtaining the weight of each measure by applying the RII arithmetic operation to the initial weights, the result was that the weights were more accurate for each criterion. These weights will used as final weights in the TOPSIS method and the evaluation of the three water treatment plants.

6.3 TOPSIS Method Execution to Evaluate the Performance of the Three WTPs:

The Normalized Matrix

In this step, the normalized matrix was calculated, where the three elements used in the octave program were defined, as shown in the Fig. 13 and Fig. 14.

Where: X = Decision Matrix
W criteria = Beneficial & Non-Beneficial values
W = weights.

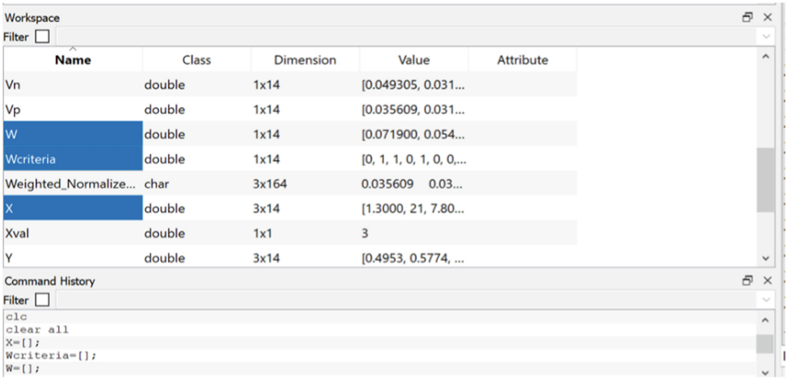


Fig. 13. Defining the elements in the octave program to calculate the normalized matrix

Normalized Matrix														
Normalized Matrix (January, 2021)														
WTP-1	0.49526	0.57735	0.57001	0.57668	0.68624	0.58354	0.58889	0.76963	0.54965	0.57798	0.58030	0.52981	0.58501	0.57379
WTP-2	0.53336	0.57735	0.57732	0.57735	0.72300	0.57112	0.57439	0.44402	0.57001	0.57609	0.58128	0.66227	0.56962	0.59429
WTP-3	0.68575	0.57735	0.58463	0.57802	0.07965	0.57733	0.56858	0.45882	0.61072	0.57798	0.57041	0.52981	0.57732	0.56355
Normalized Matrix (February, 2021)														
WTP-1	0.46222	0.57735	0.57735	0.57870	0.56362	0.58144	0.58865	0.41282	0.59702	0.57735	0.57997	0.57735	0.57475	0.57386
WTP-2	0.50074	0.57735	0.57735	0.57735	0.60388	0.56907	0.58293	0.41282	0.55722	0.57735	0.58195	0.57735	0.57475	0.59399
WTP-3	0.73185	0.57735	0.57735	0.57600	0.56362	0.58144	0.56007	0.81188	0.57712	0.57735	0.57007	0.57735	0.58252	0.56379
Normalized Matrix (March 2021)														
WTP-1	0.57577	0.57735	0.57229	0.57064	0.57714	0.55609	0.57557	0.61658	0.58398	0.57898	0.57614	0.43685	0.55162	0.58760
WTP-2	0.62811	0.57735	0.57229	0.57949	0.55790	0.58769	0.59492	0.54807	0.56385	0.58229	0.57346	0.78633	0.60678	0.56698
WTP-3	0.52342	0.57735	0.58735	0.58185	0.59637	0.58769	0.56106	0.56520	0.58398	0.57071	0.58242	0.43685	0.57230	0.57729
Normalized Matrix (April, 2021)														
WTP-1	0.62757	0.57735	0.57494	0.55280	0.58060	0.58535	0.57307	0.57201	0.55401	0.56950	0.57734	0.66742	0.56858	0.57195
WTP-2	0.58835	0.57735	0.57494	0.59072	0.56571	0.57931	0.57307	0.58789	0.59556	0.57889	0.58077	0.57208	0.57511	0.55670
WTP-3	0.50990	0.57735	0.58213	0.58776	0.58556	0.56724	0.58581	0.57201	0.58171	0.58358	0.57392	0.47673	0.58819	0.60246
Normalized Matrix (May, 2021)														
WTP-1	0.54823	0.59577	0.57479	0.57735	0.09666	0.56887	0.55874	0.54924	0.56203	0.58188	0.57389	0.65493	0.57969	0.58661
WTP-2	0.70052	0.55853	0.56732	0.57501	0.70681	0.58783	0.58764	0.58252	0.57722	0.57337	0.57734	0.60455	0.58694	0.57730
WTP-3	0.45686	0.57715	0.58972	0.57968	0.70077	0.57519	0.58523	0.59917	0.59241	0.57677	0.58080	0.45341	0.56520	0.56799
Normalized Matrix (June, 2021)														
WTP-1	0.78615	0.56473	0.57242	0.57500	0.57735	0.57942	0.55699	0.58285	0.58241	0.58189	0.57657	0.69653	0.58222	0.58957
WTP-2	0.52410	0.58356	0.57242	0.57656	0.57735	0.57319	0.58362	0.56620	0.58241	0.57507	0.57427	0.59702	0.58222	0.57114
WTP-3	0.32756	0.58356	0.58709	0.58048	0.57735	0.57942	0.59089	0.58285	0.56709	0.57507	0.58119	0.39801	0.56748	0.57114

Fig. 14. The normalized matrix for the study period over six months

The Weighted Normalized Matrix

In this step, the normalized matrix was calculated, where the Y_w element used in the octave program were defined, as shown in the Fig. 15 and 16.

Workspace

Filter

Name	Class	Dimension	Value	Attribute
Wcriteria	double	1x14	[0, 1, 1, 0, 1, 0, 0,...	
Weighted_Normalize...	char	3x164	0.035609 0.03...	
X	double	3x14	[1.3000, 21, 7.80...	
Xval	double	1x1	3	
Y	double	3x14	[0.4953, 0.5774, ...	
Yw	double	3x14	[0.035609, 0.031...	
i	double	1x1	3	
j	double	1x1	14	

Command History

Fig. 15. Defining the elements in the octave program to calculate the weighted normalized matrix

Weighted Normalized Matrix

Weighted Normalized Matrix (January, 2021)														
WTP-1	0.03541	0.03233	0.04600	0.03904	0.04618	0.04534	0.04134	0.05311	0.03859	0.04156	0.04561	0.03984	0.04230	0.04126
WTP-2	0.03814	0.03233	0.04659	0.03909	0.04866	0.04438	0.04032	0.03064	0.04001	0.04142	0.04569	0.04980	0.04118	0.04273
WTP-3	0.04903	0.03233	0.04718	0.03913	0.00536	0.04486	0.03992	0.03166	0.04287	0.04156	0.04483	0.03984	0.04174	0.04052
Weighted Normalized Matrix (February, 2021)														
WTP-1	0.033049	0.032332	0.046592	0.039178	0.037932	0.045178	0.041323	0.028485	0.041911	0.041511	0.045585	0.043417	0.041554	0.041260
WTP-2	0.035803	0.032332	0.046592	0.039087	0.040641	0.044217	0.040922	0.028485	0.039117	0.041511	0.045741	0.043417	0.041554	0.042708
WTP-3	0.052327	0.032332	0.046592	0.038995	0.037932	0.045178	0.039317	0.056020	0.040514	0.041511	0.044807	0.043417	0.042116	0.040537
Weighted Normalized Matrix (March 2021)														
WTP-1	0.041167	0.032332	0.046184	0.038632	0.038841	0.043208	0.040405	0.042544	0.040996	0.041629	0.045285	0.032851	0.039882	0.042248
WTP-2	0.044910	0.032332	0.046184	0.039232	0.037547	0.045664	0.041763	0.037817	0.039582	0.041867	0.045074	0.059132	0.043870	0.040766
WTP-3	0.037425	0.032332	0.047399	0.039392	0.040136	0.045664	0.039386	0.038999	0.040996	0.041034	0.045778	0.032851	0.041378	0.041507
Weighted Normalized Matrix (April, 2021)														
WTP-1	0.044871	0.032332	0.046398	0.037425	0.039074	0.045481	0.040230	0.039468	0.038891	0.040947	0.045379	0.050190	0.041108	0.041123
WTP-2	0.042067	0.032332	0.046398	0.039992	0.038072	0.045013	0.040230	0.040565	0.041808	0.041622	0.045649	0.043020	0.041581	0.040027
WTP-3	0.036458	0.032332	0.046978	0.039791	0.039408	0.044075	0.041124	0.039468	0.040836	0.041959	0.045110	0.035850	0.042526	0.043317
Weighted Normalized Matrix (May, 2021)														
WTP-1	0.039198	0.033363	0.046385	0.039086	0.006505	0.044201	0.039223	0.037897	0.039454	0.041837	0.045107	0.049251	0.041912	0.042177
WTP-2	0.050087	0.031278	0.045783	0.038928	0.047568	0.045674	0.041252	0.040194	0.040521	0.041225	0.045379	0.045462	0.042436	0.041508
WTP-3	0.032665	0.032320	0.047590	0.039245	0.047162	0.044692	0.041083	0.041343	0.041587	0.041470	0.045651	0.034097	0.040864	0.040838
Weighted Normalized Matrix (June, 2021)														
WTP-1	0.786150	0.564730	0.572420	0.575000	0.577350	0.579420	0.556990	0.582850	0.582410	0.581890	0.576570	0.696530	0.582220	0.589570
WTP-2	0.524100	0.583560	0.572420	0.576560	0.577350	0.573190	0.583620	0.566200	0.582410	0.575070	0.574270	0.597020	0.582220	0.571140
WTP-3	0.327560	0.583560	0.587090	0.580480	0.577350	0.579420	0.590890	0.582850	0.567090	0.575070	0.581190	0.398010	0.567480	0.571140

Fig. 16. Calculation of the weighted normalized matrix

Positive & Negative Bests calculations

In this step, the Positive & Negative Bests was calculated, where the elements (V_n and V_p) used in the octave program were defined, as shown in the Figs. 17, 18 below.

Workspace

Filter

Name	Class	Dimension	Value	Attribute
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	
Splus	double	1x3	[0.022597, 0.010...	
Vn	double	1x14	[0.049305, 0.031...	
Vp	double	1x14	[0.035609, 0.031...	
W	double	1x14	[0.071900, 0.054...	

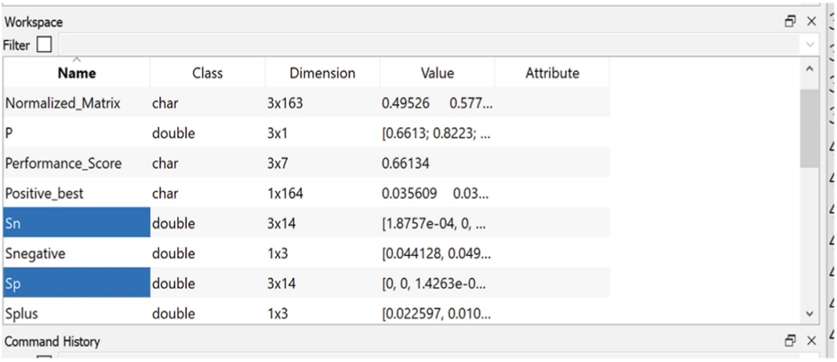
Fig. 17. Calculating the positive & negative bests

1	Caluculating the Positive and Negative Bests														
2	Positive and Negative Bests (January, 2021)														
3	Positive Best	0.035411	0.032332	0.047179	0.039041	0.048658	0.044376	0.039915	0.030637	0.038585	0.041421	0.044834	0.039842	0.041183	0.040519
4	Negative Best	0.049031	0.032332	0.046	0.039132	0.005361	0.045341	0.04134	0.053105	0.042873	0.041557	0.045689	0.049802	0.042296	0.042729
5	Positive and Negative Bests (February, 2021)														
6	Positive Best	0.033049	0.032332	0.046592	0.038995	0.040641	0.044217	0.039317	0.028485	0.039117	0.041511	0.044807	0.043417	0.041554	0.040537
7	Negative Best	0.052327	0.032332	0.046592	0.039178	0.037932	0.045178	0.041323	0.05602	0.041911	0.041511	0.045741	0.043417	0.042116	0.042708
8	Positive and Negative Best (March, 2021)														
9	Positive Best	0.037425	0.032332	0.047399	0.038632	0.040136	0.043208	0.039386	0.037817	0.039582	0.041034	0.045074	0.032851	0.039882	0.040766
10	Negative Best	0.04491	0.032332	0.046184	0.039392	0.037547	0.045664	0.041763	0.042544	0.040996	0.041867	0.045778	0.059132	0.04387	0.042248
11	Positive and Negative Bests (April, 2021)														
12	Positive Best	0.036458	0.032332	0.046978	0.037425	0.039408	0.044075	0.04023	0.039468	0.038891	0.040947	0.04511	0.03585	0.041108	0.040027
13	Negative Best	0.044871	0.032332	0.046398	0.039992	0.038072	0.045481	0.041124	0.040565	0.041808	0.041959	0.045649	0.05019	0.042526	0.043317
14	Positive and Negative Best (May, 2021)														
15	Positive Best	0.032665	0.033363	0.04759	0.038928	0.047568	0.044201	0.039223	0.037897	0.039454	0.041225	0.045107	0.034097	0.040864	0.040838
16	Negative Best	0.050087	0.031278	0.045783	0.039245	0.006505	0.045674	0.041252	0.041343	0.041587	0.041837	0.045651	0.049251	0.042436	0.042177
17	Positive and Negative Best (June, 2021)														
18	Positive Best	0.023421	0.032679	0.047378	0.038927	0.038856	0.044537	0.0391	0.039067	0.03981	0.041347	0.045137	0.029931	0.041029	0.041065
19	Negative Best	0.056209	0.031625	0.046194	0.039298	0.038856	0.045021	0.04148	0.040217	0.040885	0.041838	0.045681	0.052379	0.042095	0.04239

Fig. 18. The positive & negative bests calculations

The Euclidean Distance from Ideal Best & Worst best

In this step, the Positive & Negative Bests was calculated, where the elements (S_n and S_p) used in the octave program were defined, as shown in Figs. 19, 20.



Workspace

Filter

Name	Class	Dimension	Value	Attribute
Normalized_Matrix	char	3x163	0.49526 0.577...	
P	double	3x1	[0.6613; 0.8223; ...	
Performance_Score	char	3x7	0.66134	
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	
Splus	double	1x3	[0.022597, 0.010...	

Command History

Fig. 19. Defining the elements in the octave program to calculation the euclidean distance from ideal best & worst best

Euclidean Distance from Ideal Best and Worst			
(January, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.022752	0.010715	0.045609
Ideal Negative	0.044405	0.050099	0.023848
(Febreuary, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.0046106	0.0039694	0.03377
Ideal Negative	0.033649	0.03237	0.0034053
(March, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.0067184	0.027992	0.0036442
Ideal Negative	0.027038	0.0052022	0.027939
(April, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.016737	0.010156	0.004903
Ideal Negative	0.005101	0.0084926	0.016823
(May, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.044309	0.021354	0.0046718
Ideal Negative	0.012107	0.041279	0.04686
(June, 2021)			
	WTP-1	**WTP-2**	**WTP-3**
Ideal Positive	0.039842	0.020704	0.0027664
Ideal Negative	0.0024359	0.020306	0.039822

Fig. 20. Calculation the euclidean distance from ideal best & worst best

The Performance Score and Ranking of the Three WTPs

In this step, the Positive & Negative Bests was calculated, where the element (P) used in the octave program were defined, as shown in Fig. 21, 22.

Workspace

Filter

Name	Class	Dimension	Value	Attribute
Negative_best	char	1x164	0.049305 0.03...	
Normalized_Matrix	char	3x163	0.49526 0.577...	
P	double	3x1	[0.6613; 0.8223; ...	
Performance_Score	char	3x7	0.66134	
Positive_best	char	1x164	0.035609 0.03...	
Sn	double	3x14	[1.8757e-04, 0, ...	
Snegative	double	1x3	[0.044128, 0.049...	
Sp	double	3x14	[0, 0, 1.4263e-0...	

Fig. 21. Defining the elements in the octave program to calculation the performance score of the three WTPs

Performance Score & ranking of the WTPs Using RII Weights		
WTP	**Performance Score (January 2021)**	**Rank**
WTP-1	0.66121	2
WTP-2	0.82381	1
WTP-3	0.34335	3
WTP	**Performance Score (Febreuary 2021)**	**Rank**
WTP-1	0.87949	2
WTP-2	0.89077	1
WTP-3	0.091603	3
WTP	**Performance Score (March 2021)**	**Rank**
WTP-1	0.80097	2
WTP-2	0.15672	3
WTP-3	0.88461	1
WTP	**Performance Score (April 2021)**	**Rank**
WTP-1	0.23359	3
WTP-2	0.45541	2
WTP-3	0.77432	1
WTP	**Performance Score (May 2021)**	**Rank**
WTP-1	0.2146	3
WTP-2	0.65906	2
WTP-3	0.90934	1
WTP	**Performance Score (June 2021)**	**Rank**
WTP-1	0.057617	3
WTP-2	0.49515	2
WTP-3	0.93504	1

Fig. 22. Calculation the performance score & ranking the three WTPs

7 Conclusion and Recommendations

The water quality & the performance WTPs evaluation is globally and especially in Iraq facing a shortage in the research study in this field. In this study, an evaluation of three WTPs located in Fallujah city was conducted. A survey was designed with a specific question related to the water quality generally and the WQPs particularly to identify the significance or impact on the number of fourteen parameters like (Turbidity, Temperature, pH, electrical conductivity, Alkalinity, Chloride, Sulphates, Magnesium, Potassium, Hardness, Total Dissolved Solids, Total Suspended, Calcium, Sodium) who has a direct impact on the quality of drinking water. The survey was carried out and 32 answers with required data were collected from different experts working in the same field of study. This survey included several metrics, and each metric would be evaluated based on Likert 1–7 scale. These factors were: (extremely important, very important, somewhat important, neither important, not unimportant, somewhat unimportant, not very important, not at all important,). Then, the result of the survey scale valued and the sum for each parameter collect to generate the primary weights for these parameters. After that, The RII calculation were conducted on the primary weights to extract the weights that required for the TOPSIS method. Then, the MCDM\TOPSIS method executed using Octave-7.1.0 (GUI) software where three variables were created with represent the decision matrix which taken form the WQ testing results of these WTPs, the final weights which generated using RII, and the beneficial & on-beneficial values that identified using the water quality parameters scale. After identifying these three major elements required to run the code. TOPSIS method application has been done and the main steps of the TOPSIS method which are the normalized matrix, the weighted normalized matrix, the positive and negative bests, Euclidean distance from Ideal Best and Worst, and finally obtaining the final performance scores. The ranking formula was applied for the TOPSIS scores for three WTPS and showed that in the first two months (January & February) the WTP-2 was better than the WTP-1 and WTP-3 and for the last four months of the study period. The results of the overall performance scores and ranking of these WTPS using the weights generated via RII which showed that the first two months (January & February) the performance of WTP-2 was better than the WTP-1 and WTP-3; and for the last four months of the study period showed that the performance and efficiency of WTP-3 was enhanced and got the highest ranking while WTP-1 and WTP-2 have got the lower ranking.

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