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A Framework for the Selection of Material Handling Equipment Using Fuzzy FUCOM: A Case Study in the Automotive Industry

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ABSTRACT
Purpose: The selection of material handling equipment is a strategic decision for companies, as it requires significant capital and affects operational efficiency. In the design of an operational industrial system, the decision to select the most appropriate equipment should consider multiple competitive criteria together. This research aims to provide a systematic method for prioritizing the criteria involved in the selection of MHE for assembly lines in the automotive sector.
Methodology: This paper presents an application based on a real problem in a bus manufacturing plant. To gain insight into the experience and knowledge of the experts, the study was conducted from a phenomenological perspective and involved nine experts from different departments. The experts' evaluations were analysed via F-FUCOM.
Findings: Research results show that the purchase cost, loading and unloading speed of equipment and adaptability of equipment to plants are the three most important factors in the selection of material handling equipment.
Originality: In the automotive sector, expert opinion is rarely used in material handling equipment selection, and no case study on truck production exists in the literature, making this study an original contribution. In addition, the research is significant for its simultaneous evaluation of 14 criteria and the inclusion of insights from experts with diverse experiences.
Keywords: Material Handling Equipment, Automotive Industry, Equipment Adaptability, Strategic Equipment Selection, FUCOM.
JEL Codes: L62, M11, O32.

Bulanık FUCOM Kullanılarak Malzeme Taşıma Ekipmanı Seçimi için Bir Çerçeve: Otomotiv Endüstrisinde Bir Vaka Çalışması

ÖZET
Amaç: Malzeme elleçleme ekipmanları seçimi önemli bir sermaye gerektirdiği ve operasyonel verimliliği etkilediği için firmalar için stratejik bir karardır. Operasyonel bir endüstriyel sistemin tasarımında en uygun ekipman seçimi kararı için birçok rekabetçi kriterler birlikte değerlendirilmelidir. Bu çalışma, otomotiv sektöründeki montaj hatlarında kullanılacak malzeme elleçleme ekipmanlarının seçimine ilişkin kriterleri önceliklendirmek için sistematik bir yöntem sunmayı amaçlar.
Yöntem: Makalede otobüs üretim tesisindeki malzeme elleçleme sistemiyle ilgili gerçek dünya problemine dayalı bir uygulama sunulur. Uzmanların deneyimlerini ve tercihlerini anlamaya yönelik olarak, araştırma "fenomenoloji" bakış açısıyla yürütülmüş ve dokuz uzman üretimdeki farklı departmanlardan seçilmiştir. Uzmanların kriterlere yönelik değerlendirmeleri bulanık FUCOM ile analiz edilmiştir.
Bulgular: Çalışma bulguları, otomotiv sektöründe faaliyet gösteren üreticinin malzeme elleçleme ekipmanı seçim kararında satın alma maliyetinin, ekipmanın yüklü veya yüksüz hızının ve sisteme uyarlanabilir olmasının en belirleyici ilk üç faktör olduğunu göstermektedir.
Özgünlük: Çalışma otomotiv sektöründeki firmaların verimli bir üretim akışında gerekli malzeme elleçleme ekipmanı seçimini etkileyen kriterleri çok kriterli karar verme yaklaşımı ile değerlendirme imkânı sunmaktadır. Ayrıca 14 kriteri eş zamanlı değerlendirmesi ve farklı tecrübedeki uzmanların bilgilerine yer vermesi açısından araştırmanın önemli olduğu düşünülmektedir.
Anahtar Kelimeler: Malzeme Elleçleme Ekipmanı, Otomotive Endüstrisi, Ekipman Uyarlanabilirliği, Stratejik Ekipman Seçimi, FUCOM.
Jel Kodları: L62, M11, O32.

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1. INTRODUCTION

In the highly competitive automotive sector, customer demands are constantly increasing. Manufacturers seeking to respond to changes in consumer behaviour activate specific applications with new material choices, new designs or changes in business methods. The need to customize and change products frequently requires manufacturers to develop more flexible and adaptable production systems. Significant developments in automation technologies, changes in product portfolios and changes in plant design in the automotive sector have made equipment selection critical for manufacturers. Equipment used for different purposes must be considered and evaluated according to many criteria. Automotive production lines move raw materials, materials, parts and products in a continuous flow of assembly. Assembly systems are typically arranged in lines consisting of different workstations. Conveyors or other transport systems are very important in moving parts in the assembly of cars, buses, tractors, trucks and other vehicles. Products are processed along assembly lines and moved to the next station. In this sector, where the number of parts and processes is high, many materials and processes need to be considered when managing operations. Minimizing the number of processes and limiting the movement of objects in continuous production lines is critical to success. This focus is essential for companies seeking to improve efficiency, particularly in optimizing production functions. Removing unnecessary processes and movements in production processes minimizes time losses in terms of efficiency. This efficiency-focused change supports processes becoming more fluid by reducing bottlenecks in production lines.

Automated material handling equipment is an integral part of automated production systems in any industry. Especially in the automotive industry, where assembly is intensive, many situations require material handling, such as moving parts from one location to another and assembling them with other components. On the other hand, material handling is actively employed in various production facilities, ranging from textile and food manufacturers to the automotive and furniture sectors. In recent years, factories have increasingly favoured more advanced vehicles than traditional vehicles, such as forklifts, cranes, and conveyors (Hellman et al., 2019). Automated guided vehicles (AGVs) stand out as vehicles. AGVs are computer-controlled vehicles that rely on software and sensor technologies for movement, feature reliable smart systems, and operate without an operator. Owing to the more intensive use of these technologies in recent years, the need for research on this subject has become significant. AGVs have gained importance as smart material handling equipment that can easily adapt to the changing conditions of production systems (Agarwal and Bharti, 2022). Since material handling equipment (MHE) and AGVs contribute to the maximum cycle time in a production process (Zhe et al., 2017), selecting the most appropriate equipment is essential.

Owing to the continuous change in materials and products in the sector, the most suitable and flexible technologies should no longer be seen as a need but rather as a necessity. In facilities with high levels of automation, significant efforts are needed to develop technologies grounded in systems engineering (Skibniewski and Zavadskas, 2013). In the automotive industry, where material handling is often a cost-intensive activity, it is essential to evaluate transportation time, quantity, movements, and frequency. Consequently, selecting the most suitable material handling equipment for the task is necessary. Accurately identifying the appropriate MHE is critical for an operational production system. Selecting the most suitable equipment includes decisions aimed at reducing transportation distances, increasing transportation capacities, and improving space utilization in the facility (García-Cáceres et al., 2022).

Evaluating the situations that affect such a significant decision for manufacturers has also attracted the attention of some researchers. Researchers have conducted studies to address material handling challenges in production and to recommend the most suitable equipment for the production system. In the literature, research on material handling equipment has focused primarily on the equipment selection problem (Saputro et al., 2015). In a recent comprehensive literature review by Zolfani et al. (2023), they noted serious research and knowledge gaps in the literature and practice. It is known that in the automotive sector, the expert opinions are less common in making material handling equipment selection decisions compared to other sectors. However, there is a remarkable lack of case studies in the literature on truck production, which is one of the cornerstones of logistics systems. As a result of the literature review, no case studies addressing truck production processes were encountered. In this context, this study offers an original contribution in terms of case studies on truck production.

A review of existing studies reveals that researchers often focus on a limited set of criteria. Owing to the large number of criteria used in equipment selection, decision-making processes are costly and time-consuming (Goswami and Behera, 2021). For this purpose, the studies remain within a limited scope. Owing to the need to evaluate many criteria in equipment selection, material handling problems can be examined as multicriteria decision-making (MCDM) problems. However, a review of studies on this topic reveals that few studies have been conducted using MCDM methods. The limited attention that manufacturers have given to this critical issue has created a demand for a practical framework applicable to various sectors. Therefore, this study aims to address existing research gaps by evaluating a distinct set of criteria for selecting handling technologies to be used in the automotive industry. To achieve this aim, this study utilized a real-life case study to determine the most appropriate handling equipment for a manufacturer's assembly line. A key contribution of the study is that, while it addresses a specific problem faced by a manufacturer in the automotive sector, it also offers a framework that can benefit other manufacturers within the same industry. For companies in the automotive sector, where assembly is intensive, evaluating a unique set of criteria established by experts can streamline equipment selection decisions, saving time and costs.

Finally, this paper is organized as follows. Section 2 presents a general literature review on research conducted with MCDM in material handling equipment selection. Section 3 summarizes the fuzzy full consistency method (F-FUCOM) approach. The fourth section shares the research findings, drawing on the insights and expertise of industry professionals. The final section provides a general evaluation of the study findings and presents ideas for future research.

2. LITERATURE REVIEW

The appropriate selection of system technologies effectively affects the efficiency and productivity of companies. The selection and integration of the right technologies are important for ensuring operational efficiency. Businesses that focus on efficiency are more successful in achieving both competitive advantage and sustainable production goals. Therefore, the selection of the right system technologies is a critical factor for increasing efficiency. Many factors, including cost, capacity, performance and the technical characteristics of existing equipment, should be evaluated. The selection of material handling equipment is a highly complex and challenging task because of the various technologies and configurations involved (Park, 1996). Experts must possess comprehensive technical knowledge and the ability to perform systematic analyses for equipment selection decisions. This problem is quite costly and time-consuming because of both the large number of criteria and the many alternatives (Goswami and Behera, 2021). As Park noted, although selecting material handling equipment has always been challenging, it has become even more complex because of advancing technologies.

This difficulty in practice is also reflected in academic research. There are many different studies in the literature on equipment selection. Existing studies have focused primarily on the equipment selection problem (Saputro et al., 2015). Until 2015, only a few studies utilized MCDM methods to select material handling equipment (Hellman et al., 2019). Since 2015, a limited number of studies have been conducted on this subject. Determining the criteria in studies for the MHE decision has been addressed as a separate topic. In the literature, some researchers (Soufi et al., 2021) have reported that the criteria affecting equipment selection do not fully reflect reality or are limited. Researchers have mostly used safety, cost, maintenance, standardization, capacity, flexibility and space usage criteria. Since there are many criteria and many alternative equipment in the equipment selection problem, multicriteria decision-making methods are appropriate.

Hadi-Vencheh and Mohamadghasemi (2015) were the first to focus on weighing the criteria in the selection problem for material handling equipment and then conducted a case study using the Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method to select the best equipment. The authors analysed four primary criteria: technical, operational, strategic, and economic. The economic criteria were assessed on the basis of the purchasing cost, spare part cost, operational cost, maintenance cost, and salvage value. Moreover, researchers have assessed the operational criteria regarding speed, loading efficiency, capacity, feasibility, and volume. They examined the strategic main criteria in terms of flexibility, service, access to experts, spare part availability, relationship with production and, finally, the technical main criteria in terms of risk, repeatability, safety, maintenance and compatibility. After the study, the criteria identified in order of importance were purchasing cost, loading speed, operational cost, compatibility, capacity, maintenance cost, and flexibility. The least significant criteria were the equipment salvage value and feasibility.

Eka Saputro and Rouyendegh (2015) used the technique for order preference by similarity to an ideal solution (TOPSIS) and multiobjective mixed integer linear programming (MOMILP) as a hybrid approach to the material handling equipment selection problem. The researchers included both objective and subjective criteria, and these criteria were analysed via the analytical hierarchy process (AHP). They defined four main criteria: technical parameters, operational capability, compatibility and ease of maintenance. They also examined the technical parameters in terms of speed, power, loading capacity and lifting height; operational capability in terms of safety, ease of use, technical requirements, flexibility and task application; compatibility criterion in terms of space usage (width, storage, height, etc.); and ease of maintenance criterion in terms of spare part availability, technical support and maintenance training. According to the findings, the criteria ranked in order of importance were storage system, safety, ease of use, loading capacity, and equipment width. The least significant criteria among all the criteria were the lifting height and speed.

Ghorabaee (2016) developed an MCDM approach based on VIKOR with interval type-2 fuzzy numbers to select the best equipment in the material equipment selection problem. In this study, Ghorabaee included eight alternative tools and seven criteria. These criteria are flexibility, service contracts, stability, compatibility, human–machine interfaces, inconsistency with infrastructure and performance support features. In the study by Sen et al. (2017), the material handling equipment selection criteria were analysed via the fuzzy analytic hierarchy process (F-AHP) approach, which is based on optimization methods. In this study, there were 5 criteria, namely, a high power-to-weight ratio, ease of operation and maintenance, ease of installation, controllability and availability of spare parts. The most significant criterion was the availability of spare parts and controllability, whereas the least prioritized criterion was the high power-to-weight ratio.

Hellmann et al. (2019) proposed a framework based on failure mode and effects analysis (FMEA) and AHP for selecting the appropriate material handling system on the basis of a project in an injection molding facility in the USA. This framework incorporates both qualitative and quantitative criteria. One significant aspect of the study is that it was among the first to evaluate safety and reliability in the context of material handling equipment. Agarwal and Bharti (2022) used the AHP, decision-making trial and evaluation laboratory (DEMATEL) and TOPSIS methods to select the best AGV. The researchers included controllability, reality, cost, variety, reliability and flexibility criteria in the study. While controllability was the most significant criterion of the study, the cost criterion was the least significant criterion. The economic dimension was not evaluated much for this result with respect to the cost criterion because it is always a constraint.

Gaur and Ronge (2020) conducted a criterion evaluation for handling equipment to be purchased for the packaging and shipping department of a company operating in the textile sector. The researchers included seven criteria (cost, capacity, standardization, safety, maintenance, flexibility, and space utilization) in the study. They analysed the criteria with the AHP. Riaz et al. (2020) used fuzzy sets with multicriteria decision-making approaches for sustainable material handling equipment selection. Researchers have grouped the criteria under four main headings: technical, economic, operational and strategic. They studied the technical aspects in terms of convenience, maintainability, safety, and material aspects in terms of operating cost, maintenance cost, and purchase cost; the operational aspects in terms of fuel consumption, speed of movement and capacity; and the strategic aspects in terms of flexibility, level of training required and warranty. Verma et al. (2020) proposed the AHP-TOPSIS model to measure and evaluate the types of equipment for small-scale industries in Punjab. Tangible and nontangible criteria were assessed in the study.

Mohamadghasemi et al. (2020) used a version of type-2 fuzzy sets (T2FS) called Gaussian interval type-2 fuzzy sets in selecting material handling equipment. The authors first weighed all the criteria and subcriteria and then evaluated the alternatives according to the subcriteria. This methodology was applied in a real case study. Convenience, maintainability, safety, risk and continuity were classified as technical dimensions, whereas operating cost, maintenance cost, purchasing cost, and labor cost were classified as economic dimensions. In addition, capacity, movement speed, loading speed, reality and fuel consumption were evaluated as operational dimensions, and flexibility, spare part availability, warranty, training and relations with the manufacturer were evaluated as strategic dimensions. According to the research findings, the operational dimension was the most prominent criterion, followed by the economic dimension. While compatibility was the most significant criterion in the technical dimension, the least significant criteria were continuity and risk. The most significant criteria in the economic dimension were the purchasing cost and maintenance cost, whereas the labor cost was the least significant criterion. In the operational dimension, the loading speed and capacity criteria were prominent, whereas fuel consumption was the least significant criterion. Finally, while the most significant criteria in the strategic dimension were flexibility and spare part availability, the least significant criteria were relationships with the manufacturer and training.

Goswami and Behera (2021) aimed to determine the best alternative among three different materials for handling equipment. They used entropy to determine the importance of the criteria and preferred the additive ratio assessment (ARAS) and complex proportional assessment (COPRAS) for the best alternatives. The study includes criteria such as equipment speed, capacity, ease of access, controllability, and flexibility. Soufi et al. (2021) studied the selection of material handling equipment in production facilities. They preferred the AHP approach in criteria weighting and equipment selection, similar to many other studies. Soufi et al. (2021) presented a bibliometric study by examining 17 articles in the literature. According to their findings, the average number of criteria in the studies was 14. Fulzele et al. (2022), who conducted a similar study with the same method, also evaluated the relevant criteria to make a conveyor selection decision.

Zolfani et al. (2023) used an intuitionistic fuzzy MCDM integrated with the FUCOM and weighted aggregated sum product assessment (WASPAS) to evaluate new equipment for special storage operations. Researchers have aimed to reduce the idle costs of equipment and ensure the economic efficiency of logistics and storage operations. They used the criteria of capacity, equipment width, lifting height, equipment length, equipment width, engine power, speed, and acceleration. As a result, the width of the transport equipment, lifting engine power and lifting height were determined to be the most critical criteria because they affect the aisle width, space utilization, storage capacity and storage costs. Ulutaş et al. (2023) used the fuzzy best–worst method (F-BWM) to determine the criteria weights and the multiple criteria ranking with fuzzy alternating traces (MCRAT) method for forklift selection. The researchers used eight criteria (purchasing cost, lifting height, lowering and lifting speed, loading capacity, space requirement, manufacturer's image, and spare parts supply). According to the study findings, the most important criterion was the purchasing cost, followed by the loading capacity and lifting height, which are other significant factors. Additionally, the manufacturer's reputation emerged as the most critical criterion overall. Another study was conducted in the same year by Goswami and Behera (2023). The authors evaluated three alternatives and five criteria to conduct the equipment selection process. Three of the criteria were quantitative, whereas the other two were qualitative. The purchase cost, payload capacity, and repeatability error were quantitative criteria, whereas the human-machine interface (MMI) and programming flexibility were used as qualitative criteria. The researchers used a hybrid model combining fuzzy AHP to weight the criteria and COPRAS and ARAS to select alternatives.

Tadic et al. (2024) investigated new material handling equipment that would reduce material handling time, material losses, and costs in a construction materials manufacturing company. For this purpose, nine criteria and four different alternatives were evaluated. The nine criteria were investment cost, maintenance cost, operational cost, training of employees, productivity, flexibility, ability, eco-indicator, and employee safety. The researchers used the stepwise weight assessment ratio analysis (SWARA) method to evaluate the criteria. A study published in 2024 was written by Görçün et al. (2024). Görçün et al. (2024) used the interval-valued Fermatean fuzzy (IVFF) approach for the selection of telescopic forklifts through a case study in the textile industry. However, in their study, they presented a new IVFFS-based model that had not been used before and addressed the subject from a different method perspective. In addition, for the first time, selection criteria specific to telescopic forklifts were determined: carrying capacity, lift height, second-hand sale price, the unit price, maintenance cost, and fuel consumption. Under these criteria, the most suitable forklift among the five alternatives with different fuel types was selected. The most prominent criterion in the study was unit price. Chakraborty and Saha (2024) also used FUCOM and MOORA in the selection of material handling equipment in a warehouse. The researchers used 7 criteria: purchase cost, age (year of forklift production), working time, maximum load capacity, maximum lift height, environmental factors, and supply of spare parts.

Božić et al. (2025) evaluated four alternatives and twelve criteria to decide on material handling equipment in warehouse operations in the food industry. The study used the criteria of compatibility, operation frequency, layout, maintenance, purchasing cost, maintenance fees, operating expenditures, setup investments, eco indicators, waste generation, regulatory and safety standards and user friendliness. A new method combining simple aggregation of preferences expressed by ordinal vectors for multicriteria decision making (SAPEVO-M), fuzzy AHP and fuzzy combined compromise solution (FCOBRA) was used to rank the alternatives. The result of this study revealed that the AGV was the best alternative among the four alternatives.

Accordingly, a notable gap has been identified in the existing literature with respect to case studies. While there are few studies focusing on the automotive sector, which is characterized by intensive assembly processes, no case study has been found that specifically addresses truck manufacturing processes. From both this perspective and through the simultaneous evaluation of a distinct set of criteria related to technology selection within a single study, the research is expected to yield significant findings.

3. METHOD

The selection of material handling equipment is an area of operational research. Owing to the need to assess multiple factors, equipment selection decisions involve multicriteria decision-making. There are many multicriteria decision-making methods for solving equipment or machine tool selection problems. The purpose of MCDM is to support decision makers with several approaches among many alternatives. For selection, decision makers need to evaluate many criteria and know the weights of these criteria. Some criteria are “subjective”, and their weightings depend on decision makers’ thoughts. Some are “objective”, and their weight values depend on the calculated or analysed data.

Uncertainty is much greater in real business problems, so it is much more appropriate to use mathematical models and fuzzy variables together (Agarwal and Bharti, 2022). In this study, the fuzzy FUCOM was used to evaluate and analyse expert decisions. The method was first presented by Pamučar et al. in 2018. The FUCOM is used in many studies in the literature to make different decisions. FUCOM is preferred, especially to respond to various complex business problems. It has been used for personnel selection (Stević and Brković, 2020), weighting the criteria for deciding on the location of a logistics platform from a sustainability perspective (Ayadi et al., 2021), evaluating human resource information systems provided by different suppliers (Esangbedo et al., 2021), selecting routes for the transportation of hazardous materials (Milošević et al., 2021), evaluating determinants that improve business performance (Sharma et al., 2021) and selecting the locations of logistics centers (Yazdani et al., 2020).

When looking at the studies in 2022 and 2023, researchers used FUCOM to solve different business problems. The FUCOM was preferred by researchers in decisions such as improving security in thin sheet casting and rolling units of a steel processing plant (Dhalmahapatra et al., 2022), evaluating obstacles to adopting circular supply chain management in pharmaceutical industries (Khan and Ali, 2022), selecting the most suitable painting robot for the automobile industry (Kumar et al., 2022), evaluating supplier selection criteria (Ayough et al., 2023), determining the most suitable blockchain technology for the logistics sector (Görçün et al., 2023), prioritizing express packaging recycling models (Ling et al., 2023), evaluating the criteria for selecting the most suitable third-party logistics company in a food production company (Nila and Roy, 2023) and selecting handling equipment to be used in special warehousing operations (Zolfani et al., 2023).

There are several significant reasons why FUCOM was preferred in this study. As equipment selection is a strategic decision, various criteria should be considered. FUCOM was selected to manage this complexity effectively, given the nature of the problem and the numerous criteria involved. While two-way comparisons are made in the BWM and AHP methods used in criterion weighting, FUCOM eliminates this problem (Pamučar et al., 2018), and a small number of operations are sufficient. The method reduces the possibility of error due to the small number of comparisons and limitations in calculating the optimum values of the criteria (Sofuoğlu, 2020). Another significant reason is that it reduces concerns about consistency due to the presence of different decision makers. The ability to calculate deviations in FUCOM and the straightforward acceptance of its consistency were key factors in this decision. To verify the research model, multiple criteria decision-making methods need to calculate the error values of the weight vectors. The deviation from maximum consistency can be easily identified by calculating the error size for the weight vector obtained via FUCOM (Yazdani et al., 2020).

The method can be outlined in four steps as follows: (Pamučar et al., 2018)

Step 1: After the criteria are listed, decision makers rank them according to their preferences. The criteria are ranked from the highest importance to the lowest (Equation 1).

$$C_{\mathrm{j}(1)} > C_{\mathrm{j}(2)} > \cdots > C_{j(k)} \tag{1}$$

Step 2: All decision makers compare the criteria according to the scale in Table 1. The fuzzy importance of the criteria is expressed by $\widetilde{w}_{C_{j(k)}}$, and the fuzzy comparison importance is expressed by$\varphi_{k/(k+1)}$. The fuzzy comparison importance value is obtained by the ratio of the weight values of two criteria, as shown in Equation 2.

$$\varphi_{k/(k+1)} = \frac{w_{c_{j(k+1)}}}{w_{c_{j(k)}}} \tag{2}$$

Table 1. Comparison scale

Scale	*1*	*3*	*5*	*7*	*9*	*2,4,6,8*
Value Definition	Equal	Medium	Strong	Very Strong	Absolute Superior	Intermediate Values

Step 3: The values of the weight coefficients must satisfy the condition that the relationship between the weight coefficients of the criteria $C_{\mathrm{j(k)}}$ and $C_{\mathrm{j(k+1)}}$ is the same as their comparative importance $\varphi_{k/(k+1)}$. Equation 3 represents the first condition that must be met in the model.

$$\frac{w_k}{w_{k+1}} = \varphi_{k/(k+1)} \tag{3}$$

The second condition is that the final values of the weight coefficients must meet the transitivity condition in order. Equation 4 shows this requirement. In addition, Equation 4 yields Equation 5, which is in line with Equation (3).

$$\varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} = \varphi_{k/(k+2)} \tag{4}$$

$$\frac{w_k}{w_{(k+1)}} \otimes \frac{w_{(k+1)}}{w_{(k+2)}} = \frac{w_k}{w_{(k+2)}} \tag{5}$$

Equation 6 is attained by simultaneously applying Equations 4 and 5.

$$\frac{w_k}{w_{(k+2)}} = \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} \tag{6}$$

The minimum deviation (χ=0) is equivalent to the maximum consistency. For this purpose, the conditions of Equation 3 and Equation 6 are necessary. If expressed in terms of the deviation value, Equation 7 must be fulfilled, which is the critical aspect of this method.

$$\left|\frac{w_k}{w_{(k+1)}} - \varphi_{k/(k+1)}\right| \leq \chi \text{ and } \left|\frac{w_k}{w_{(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)}\right| \leq \chi \tag{7}$$

The final model is formulated as shown in Equations 8-12. Solving the model yields the weight values of the criteria.

$$min\ \chi \tag{8}$$

s.t.

$$\left|\frac{w_k}{w_{(k+1)}} - \varphi_{k/(k+1)}\right| \leq \chi \quad \forall j \tag{9}$$

$$\left|\frac{w_k}{w_{(k+2)}} - \varphi_{k/(k+1)} \otimes \varphi_{(k+1)/(k+2)} =\right| \leq \chi \quad \forall j \tag{10}$$

$$\sum w_j = 1\ j = 1, 2, ..n \tag{11}$$

$$w_j \geq 0\ \forall j \tag{12}$$

4. APPLICATION

This study aims to assess key criteria in a production facility before selecting the most suitable material handling equipment. In a bus manufacturing center, handling technology greatly facilitates various activities, such as transporting tires, assembling doors onto the product, and installing windows. These technologies are especially beneficial for transporting and handling large or heavy components. The research was carried out at a company that plans to invest in equipment for handling specific materials in assembly processes, involving interviews with experts actively working in the factory. In this real case study involving a company, managers are currently researching AGV selection among material handling technologies. Selecting AGV equipment has long been regarded as a challenging task because of the numerous constraints present in production systems (Agarwal and Bharti, 2022). Here, it is essential to consider many performance criteria. Initially, the criteria were established through field scanning and confirmed in collaboration with the experts in the sample.

4.1. Decision Makers

During the data collection process, expert opinions were considered in selecting the technology for a bus manufacturing company. The experts are the status of the decision makers in the study. The decision makers are the employees of the production or quality department of the company and the managers in the highest positions (see Table 2). This study utilizes a purposeful sample by selecting individuals with relevant knowledge and experience to gather qualitative data. The study was conducted independently, with each member of the expert group consisting of nine people. Expert opinions are the most significant element in weighing the criteria in the study. The study, aimed at understanding expert experiences and knowledge, was conducted from a "phenomenology" perspective. The experts participated in structured interviews via various meeting applications on virtual platforms.

Table 2. Information about the experts

Experts	*Title of the Experts*	*Seniority in the company*
E_1	COO- Chief Operating Officer	15 years
E_2	Production Director	7 years
E_3	Factory Manager	9 years
E_4	Production Manager	5 years
E_5	Process Improvement Manager	4 years
E_6	Technical Services Manager	6 years
E_7	Quality Director	7 years
E_8	Quality Manager	4 years
E_9	Process Improvement Manager	6 years

4.2. Criteria

Table 3. Criteria in the study and their sources

C_n	*Criteria name*	*Explanation*	*Related resources*
C_1	Purchasing cost	In the case of a new investment decision for businesses, the purchasing costs of a piece of equipment are a significant determinant. Many equipment purchasing costs also include equipment installation costs.	Mohamadghasemi et al. (2020, Pamučar and Ćirović (2015), Prasad et al. (2015), Riaz et al. (2020), Soufi et al. (2021), Ulutaş et al. (2023)
C_2	Maintenance-Repair Activities and Cost	Periodic maintenance of the equipment (oil change, chains, hydraulics, etc.) must be carried out by the technical requirements and warranty process. The ease of equipment maintenance can also be linked to its cost.	Gaur and Ronge, (2020), Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020), Pamučar and Ćirović (2015), Sen et al. (2017), Soufi et al. (2021), Riaz et al. (2020)
C_3	Operational cost	Operational cost refers to the expenses associated with running a new machine, component, piece of equipment, or facility. In addition, this cost category includes expenses such as energy costs and fuel consumption associated with equipment use in production.	Agarwal and Bharti, (2022), Mohamadghasemi et al. (2020), Pamučar and Ćirović (2015), Riaz et al. (2020), Soufi et al. (2021)
C_4	Lifetime	This criterion is related to the lifespan of the manufacturer's equipment and the number of products it can process.	Pamučar and Ćirović (2015)
C_5	Movement speed with/without load	This criterion refers to the speed at which the equipment can be reached within a specific timeframe. The fact that the equipment directly affects the time required for a process also affects the duration of the operations.	Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020), Pamučar and Ćirović (2015), Riaz et al. (2020), Soufi et al. (2021), Ulutaş et al. (2023), Zolfani et al. (2023)
C_6	Maximum lifting capacity	This criterion indicates the maximum weight that a piece of equipment can lift, measured in tonnes.	Hadi-Vencheh and Mohamadghasemi (2015), Pamučar and Ćirović (2015), Ulutaş et al. (2023), Zolfani et al. (2023)
C_7	Maximum bearing capacity	This criterion denotes the maximum load that a piece of equipment can handle, expressed in tons. The manufacturer is expected to demonstrate a strong capacity to adapt to changes in production volume in response to fluctuating demands.	Agarwal and Bharti (2022), Gaur and Ronge (2020), Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020); Pamučar and Ćirović (2015), Riaz et al. (2020), Soufi et al. (2021), Ulutaş et al. (2023), Zolfani et al. (2023)
C_8	Operational flexibility	This criterion is also known as multifunctionality. The ability of the equipment to perform different operations within the facility is critical for equipment selection.	Agarwal and Bharti (2022), Gaur and Ronge (2020), Ghorabaee (2016), Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020), Riaz et al. (2020), Soufi et al. (2021)
C_9	Process automation	This criterion is associated with the easier, faster and safer movement of parts in the system in a way that facilitates human intervention in material handling equipment. The level of automation required for the physical task is also evaluated in terms of the control capabilities of the equipment.	Agarwal and Bharti (2022), Ghorabaee, (2016), Sen et al. (2017), Soufi et al. (2021)
C_{10}	Adaptability	This criterion pertains to the equipment's ability to integrate into the system in a compatible manner. The equipment may require redesigning to integrate effectively with other subsystems and the entire system. The adaptability criterion encompasses the ease of integrating the equipment into a business's information system.	Agarwal and Bharti (2022), Ghorabaee (2016), Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020), Prasad et al. (2015), Riaz et al. (2020), Soufi et al. (2021)

Table 3. (*Contined*)

C_{11}	Safety	Ensuring the safety of operators, equipment and products is a crucial criterion in equipment selection. This criterion is considered in terms of the ability to safeguard against unauthorized access, malware, and other physical or digital security threats that may arise within a company's production system.	Agarwal and Bharti (2022), Gaur and Ronge (2020), Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020), Riaz et al. (2020), Soufi et al. (2021)
C_{12}	Continuity	This criterion is also referred to as reliability in some sources. Continuity criterion assesses whether newly added equipment can perform the desired functions of existing production without interruption under specific conditions.	Agarwal and Bharti (2022), Ghorabaee, (2016), Mohamadghasemi et al. (2020)
C_{13}	Ergonomic	This criterion evaluates the equipment's impact on the occupational health and safety of workers. The vibration and noise produced by the equipment, the space available for operator movement, and the ease of use can be assessed, particularly from an ergonomic perspective.	Gaur and Ronge (2020), Ghorabaee (2016), Hadi-Vencheh and Mohamadghasemi (2015), Soufi et al. (2021), Ulutaş et al. (2023), Zolfani et al. (2023)
C_{14}	Service quality	Companies require manufacturers that they can easily contact in the event of equipment failure or when they need support for spare parts. Access to an authorized service system is a critical criterion in equipment selection. Additionally, the equipment provided by the supplier is expected to come with a service guarantee for the company post sale.	Ghorabaee (2016), Hadi-Vencheh and Mohamadghasemi (2015), Mohamadghasemi et al. (2020), Pamučar and Ćirović, (2015), Riaz et al. (2020), Sen et al. (2017), Ulutaş et al. (2023)

When selecting material handling equipment, decision makers must consider the listed criteria qualitatively and quantitatively (Karande and Chakraborty 2013). Fourteen factors were analysed as the criteria included in the study (see Table 3). These criteria are purchasing cost, maintenance-repair cost, operational cost, lifetime, equipment speed (movement speed with/without load), maximum lifting capacity, maximum bearing capacity, operational flexibility, process automation, adaptability, safety, continuity, ergonomic and service quality. Additionally, the purchasing cost, maintenance-repair cost, and operational cost can be considered as subcriteria under the main criterion "Economic Factors"; equipment speed (movement speed with/without load), maximum lifting capacity, maximum bearing capacity, and lifetime can be evaluated as subcriteria under "Technical and Performance Factors"; operational flexibility, process automation, continuity, and adaptability can be categorized under "Operational Factors"; and safety, ergonomic, and service quality can be assessed under the main criterion "User-Centred Factors".

4.3. Results

The data obtained from the interviews and their analysis are listed below.

Step 1: All criteria listed in the table were ranked by the experts from most significant to least significant, as in Equation (1). Since each expert had a unique perspective, the data collection process was conducted separately for everyone. For example, the ranking of the first expert (E_1) according to Equation 1 is as follows:

C_1, C_5, C_{10}, C_3, C_9, C_7, C_{12}, C_{14}, C_2, C_{11}, C_{13}, C_4, C_8, and C_6.

The criteria were subsequently evaluated for the next criterion via the comparison scale (see Table 1). Table 4 presents the rankings and evaluations of all the experts regarding the criteria.

Step 2 and Step 3: Considering Table 4, Equation 3 $\varphi_{k/(k+1)} = \frac{w_{c_{j(k+1)}}}{w_{c_{j(k)}}}$ was used for the fuzzy comparison importance of the criteria $\varphi_{k/(k+1)}$. Then, Equation 4 was used for $\boldsymbol{\varphi_{k/(k+2)}}$.

Step 4: All criteria and the comparative priority data calculated in Equation 3 and Equation 4 were input into the Excel document. All the parameters were subsequently written to the Excel solver, adhering to the model in Equation 8.

Table 4. Table for comparison of criteria

For E_1														
Ranking	C_1	C_5	C_{10}	C_3	C_9	C_7	C_{12}	C_{14}	C_2	C_{11}	C_{13}	C_4	C_8	C_6
$\varphi_{k/(k+1)}$	1.00	2.00	1.50	1.00	1.333	1.00	1.25	1.00	1.20	1.166	1.142	1.125	1.111	-
$\varphi_{k/(k+2)}$	3.00	1.50	1.333	1.333	1.25	1.25	1.20	1.40	1.33	1.285	1.125	1.111	-	-
For E_2														
Ranking	C_1	C_{10}	C_5	C_3	C_7	C_9	C_{14}	C_{12}	C_{13}	C_{11}	C_2	C_8	C_6	C_4
$\varphi_{k/(k+1)}$	2.00	1.00	1.50	1.00	1.333	1.25	1.00	1.40	1.00	1.142	1.00	1.125	1.00	-
$\varphi_{k/(k+2)}$	2.00	1.50	1.50	1.333	1.667	1.25	1.40	1.40	1.142	1.142	1.125	1.125	-	-
For E_3														
Ranking	C_5	C_1	C_3	C_9	C_{12}	C_{10}	C_7	C_{13}	C_2	C_{14}	C_{11}	C_8	C_4	C_6
$\varphi_{k/(k+1)}$	1.00	2.00	1.00	1.50	1.667	1.00	1.20	1.166	1.00	1.142	1.125	1.00	1.00	-
$\varphi_{k/(k+2)}$	2.00	2.00	1.50	2.50	1.667	1.20	1.40	1.166	1.142	1.285	1.125	1.00	-	-
For E_4														
Ranking	C_1	C_{10}	C_5	C_3	C_{12}	C_{14}	C_2	C_7	C_{11}	C_9	C_{13}	C_4	C_8	C_6
$\varphi_{k/(k+1)}$	3.00	1.00	1.333	1.25	1.00	1.20	1.00	1.166	1.00	1.00	1.142	1.125	1.00	-
$\varphi_{k/(k+2)}$	3.00	1.33	1.667	1.25	1.20	1.20	1.166	1.166	1.00	1.142	1.285	1.125	-	-
For E_5														
Ranking	C_5	C_3	C_1	C_9	C_{14}	C_2	C_{10}	C_{12}	C_7	C_{11}	C_8	C_4	C_{13}	C_6
$\varphi_{k/(k+1)}$	3.00	1.00	1.333	1.25	1.00	1.20	1.00	1.166	1.00	1.00	1.142	1.125	1.00	-
$\varphi_{k/(k+2)}$	3.00	1.333	1.666	1.25	1.20	1.20	1.166	1.166	1.00	1.142	1.285	1.125	-	-
For E_6														
Ranking	C_1	C_{10}	C_5	C_3	C_9	C_{12}	C_7	C_{14}	C_2	C_8	C_{13}	C_6	C_{11}	C_4
$\varphi_{k/(k+1)}$	1.00	2.00	1.00	1.50	1.333	1.00	1.25	1.20	1.166	1.00	1.142	1.00	1.125	-
$\varphi_{k/(k+2)}$	2.00	2.00	1.50	2.00	1.333	1.25	1.50	1.40	1.166	1.142	1.142	1.125	-	-
For E_7														
Ranking	C_1	C_3	C_{10}	C_5	C_9	C_7	C_{12}	C_{14}	C_8	C_2	C_{11}	C_4	C_6	C_{13}
$\varphi_{k/(k+1)}$	2.00	1.50	1.00	1.666	1.00	1.20	1.00	1.166	1.00	1.142	1.00	1.125	1.00	-
$\varphi_{k/(k+2)}$	3.00	1.50	1.666	1.666	1.20	1.20	1.166	1.166	1.142	1.142	1.125	1.125	-	-
For E_8														
Ranking	C_1	C_{10}	C_5	C_3	C_{12}	C_7	C_9	C_{14}	C_2	C_{11}	C_4	C_8	C_6	C_{13}
$\varphi_{k/(k+1)}$	1.00	2.00	1.50	1.333	1.25	1.00	1.20	1.00	1.166	1.00	1.142	1.00	1.125	-
$\varphi_{k/(k+2)}$	2.00	3.00	2.00	1.666	1.25	1.20	1.20	1.166	1.166	1.142	1.142	1.125	-	-
For E_9														
Ranking	C_5	C_1	C_3	C_{10}	C_7	C_{12}	C_9	C_{14}	C_{11}	C_2	C_{13}	C_4	C_8	C_6
$\varphi_{k/(k+1)}$	3.00	1.333	1.00	1.00	1.25	1.00	1.40	1.00	1.142	1.00	1.125	1.00	1.00	-
$\varphi_{k/(k+2)}$	4.00	1.333	1.00	1.25	1.25	1.40	1.40	1.142	1.142	1.125	1.125	1.00	-	-

For example, for Expert 1:

$\left|\frac{C_1}{C_5}-1\right| \leq \chi$; $\left|\frac{C_5}{C_{10}}-2\right| \leq \chi$; $\left|\frac{C_{10}}{C_3}-1.5\right| \leq \chi$; $\left|\frac{C_3}{C_9}-1\right| \leq \chi$; $\left|\frac{C_9}{C_7}-1.33\right| \leq \chi$; $\left|\frac{C_7}{C_{12}}-1\right| \leq \chi$; $\left|\frac{C_{12}}{C_{14}}-1.25\right| \leq \chi$;

$\left|\frac{C_{14}}{C_2}-1\right| \leq \chi$; $\left|\frac{C_2}{C_{11}}-1.20\right| \leq \chi$; $\left|\frac{C_{11}}{C_{13}}-1.166\right| \leq \chi$; $\left|\frac{C_{13}}{C_4}-1.142\right| \leq \chi$; $\left|\frac{C_4}{C_8}-1.125\right| \leq \chi$; $\left|\frac{C_8}{C_6}-1.111\right| \leq \chi$

and

$\left|\frac{C_1}{C_{10}}-3\right| \leq \chi$; $\left|\frac{C_5}{C_3}-1.5\right| \leq \chi$; $\left|\frac{C_{10}}{C_9}-1.33\right| \leq \chi$; $\left|\frac{C_3}{C_7}-1.33\right| \leq \chi$; $\left|\frac{C_9}{C_{12}}-1.25\right| \leq \chi$; $\left|\frac{C_7}{C_{14}}-1.25\right| \leq \chi$;

$\left|\frac{C_{12}}{C_2}-1.20\right| \leq \chi$; $\left|\frac{C_{14}}{C_{11}}-1.40\right| \leq \chi$; $\left|\frac{C_2}{C_{13}}-1.33\right| \leq \chi$; $\left|\frac{C_{11}}{C_4}-1.285\right| \leq \chi$; $\left|\frac{C_{13}}{C_8}-1.125\right| \leq \chi$; $\left|\frac{C_4}{C_6}-1.111\right| \leq \chi$;

$\sum w_j = 1 \; j = 1,2,..n$

$w_j \geq 0 \; \forall_j$

As a simple linear programming problem, the target is min χ. Individual linear programming data were entered for each expert and solved via Excel Solver. Table 5 shows the criterion weights obtained after the evaluations of each expert and the criterion weights obtained by averaging these values.

Table 5 shows the final weight value of each criterion. The value of **χ** is 0 for each expert. This shows that the results are consistent. A promising result is that the weight values obtained are reliable. When the weights are examined, the criterion with the highest value is the "purchasing cost (C_1)", with a weight value of 0.1877. The purchasing cost has a weight value of 18.77% among all criteria for the equipment selection decision of the experts. The criterion with the second highest weight is "movement speed with/without load (C_5)" of the equipment, with a weight value of 0.1624; the criterion with the third highest weight is "adaptability (C_{10})", with a weight value of 0.1105; and the criterion with the fourth highest weight is "operational cost (C_3)", with a weight value of 0.0930. In other words, among all the criteria, "movement speed with/without load", with 16.24%, "adaptability", with 11.05%, and "operational cost", with 9.30%, are the other criteria with the highest weights.

Table 5. Final weights of all the criteria

Criteria	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	*Av. Weights*
C_1	0.262	0.245	0.215	0.292	0.097	0.206	0.273	0.224	0.099	0.1877
C_2	0.044	0.031	0.031	0.049	0.058	0.034	0.039	0.037	0.037	0.0400
C_3	0.087	0.082	0.108	0.073	0.097	0.103	0.137	0.075	0.075	0.0930
C_4	0.029	0.027	0.024	0.036	0.036	0.023	0.034	0.032	0.033	0.0304
C_5	0.131	0.123	0.215	0.097	0.292	0.103	0.091	0.112	0.298	0.1624
C_6	0.026	0.027	0.024	0.032	0.032	0.026	0.030	0.028	0.033	0.0512
C_7	0.065	0.082	0.043	0.049	0.042	0.052	0.055	0.045	0.075	0.0564
C_8	0.029	0.031	0.024	0.032	0.042	0.029	0.039	0.028	0.033	0.0318
C_9	0.065	0.061	0.108	0.042	0.073	0.069	0.055	0.045	0.060	0.0642
C_{10}	0.087	0.123	0.043	0.097	0.049	0.206	0.091	0.224	0.075	0.1105
C_{11}	0.037	0.035	0.027	0.042	0.042	0.026	0.034	0.032	0.043	0.0420
C_{12}	0.052	0.049	0.072	0.058	0.049	0.052	0.046	0.056	0.060	0.0548
C_{13}	0.033	0.035	0.036	0.042	0.032	0.029	0.030	0.025	0.037	0.0332
C_{14}	0.052	0.049	0.031	0.058	0.058	0.041	0.046	0.037	0.043	0.0461
χ	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Although there are no significant differences in the weights of these four criteria, notable differences emerge when the other criteria, are used indicating substantial variations in expert opinions. The criterion ranking is followed by "process automation (C_9)", with a weight value of 0.0642, and "maximum bearing capacity (C_7)", with a value of 0.0564. The criterion that is considered less significant than the other 13 criteria among all the criteria is "lifetime (C_4)".

Sensitivity Analysis

Sensitivity analysis is essential to interpret whether the solution is valid or not. This study used the weight variation approach to perform a sensitivity analysis of FUCOM. The scenario was applied for examinations of decision variables at different rates. The weight values reached in Table 5 for each criterion were changed at rates such as ±%10 and ±%20, and the results were analyzed to see how much they changed. This process was done for 14 criteria in the study. The columns containing the "Max" and "Min" weights indicate the highest and lowest weighted criteria weights among all criteria.

In the consistency interpretation, if there is no excessive change in the criterion weights with the highest and lowest weights, it is stated that mobel will be consistent and stable. According to Table 5, the criterion with the highest weight is "purchasing cost" (C_1) with a ratio of 0.1877. In the +%10 scenario of C_1, the new weight value is calculated as 0.2019, and the maximum value for this change is also seen as 0.2019 (see Table 6). This result again shows that C_1 maintains its dominance. In the -%10 scenario of C_1, the new weight value is calculated as 0.1715. This change again affected C_1 to be dominant compared to other criteria. On the other hand, according to Table 5, the criterion with the lowest weight is "lifetime" (C_4) with 0.0304. In the +%10 scenario of C_4, the new weight value is calculated as 0.0332. According to this increased rate, although the C_4 criterion is not the lowest weighted criterion, there was no significant imbalance in the weight distribution. In the -10% scenario of the Lifetime criterion, the new weight value reached 0.0273. In this scenario, the lowest weight criterion was 0.0273, which again affected C_4 to be the lowest priority compared to other criteria.

According to the sensitivity analysis results, the change of high weight criteria such as C_1 and C_5 was more effective than other criteria. However, the total weight distribution maintains its balance at 10% changes. In the sensitivity analysis in this study, changing the criterion weight by 10% changed the effect of the criterion on some factors. However, although the weights of other criteria changed, the total weight value of all criteria remained 1. While it is stated that the model is less sensitive to changes in the weights of criteria such as C_1, the decision making processes are reliable.

The criteria with smaller weights in the list, such as C_3, C_6, and C_9, will not affect the ranking too much. For example, in terms of other criteria, a 10% increase or decrease in C_2 increases or decreases the criterion's weight to 0.0437 and 0.0360, respectively. The difference between the max and min weights is insignificant here, which shows that the effect of C_2 is not very large and does not change the rankings too much. As a result, the fact that the ranking changes are minimal and the weights do not deviate too much indicates that the model is robust and balanced.

Table 6. Sensitivity analysis results

Scenario	*Criteria*	*New Weight*	*Total Weight*	*Max Weight*	*Min Weight*
+10% C_1	C_1	0.2019	1	0.2019	0.0297
-10% C_1	C_1	0.1715	1	0.1715	0.0309
+10% C_2	C_2	0.0437	1	0.1863	0.0302
-10% C_2	C_2	0.0360	1	0.1878	0.0304
+10% C_3	C_3	0.1010	1	0.1853	0.0300
-10% C_3	C_3	0.0842	1	0.1888	0.0306
+10% C_4	C_4	0.0332	1	0.1864	0.0316
-10% C_4	C_4	0.0273	1	0.1876	0.0273
+10% C_5	C_5	0.1751	1	0.1840	0.0298
-10% C_5	C_5	0.1480	1	0.1901	0.0308
+10% C_6	C_6	0.0558	1	0.1861	0.0301
-10% C_6	C_6	0.0461	1	0.1880	0.0304
+10% C_7	C_7	0.0615	1	0.1860	0.0301
-10% C_7	C_7	0.0509	1	0.1881	0.0305
+10% C_8	C_8	0.0347	1	0.1864	0.0302
-10% C_8	C_8	0.0286	1	0.1876	0.0286
+10% C_9	C_9	0.0699	1	0.1858	0.0301
-10% C_9	C_9	0.0579	1	0.1882	0.0305
+10% C_{10}	C_{10}	0.1198	1	0.1850	0.0300
-10% C_{10}	C_{10}	0.1002	1	0.1891	0.0306
+10% C_{11}	C_{11}	0.0458	1	0.1862	0.0302
-10% C_{11}	C_{11}	0.0378	1	0.1878	0.0304
+10% C_{12}	C_{12}	0.0597	1	0.1860	0.0301
-10% C_{12}	C_{12}	0.0494	1	0.1880	0.0305
+10% C_{13}	C_{13}	0.0363	1	0.1864	0.0302
-10% C_{13}	C_{13}	0.0299	1	0.1876	0.0299
+10% C_{14}	C_{14}	0.0503	1	0.1862	0.0301
-10% C_{14}	C_{14}	0.0415	1	0.1879	0.0304

5. CONCLUSION and DISCUSSION

Today, economic and technological changes are essential for innovation across various sectors. In response to these changes, companies may need to upgrade or replace their equipment technologically. This is a crucial problem and issue in production. Material handling equipment selection problems are crucial for businesses. In production, costs related to material handling activities constitute a significant portion of total production costs. Although the ratios vary in some sources, the share of handling costs in total can vary between 15% and 70% (Esmaeilian et al., 2016; García-Cáceres et al., 2022; Gavade, 2014). Failure to select the most appropriate equipment directly affects the total operation time, resource usage and service levels (Prasad et al., 2015). MHEs can effectively reduce physical effort and sometimes cognitive workload. Any innovation that positively affects the production process in the handling of materials is necessary and continuous to make operational management efficient. In this context, equipment selection decisions significantly influence the operational efficiency of enterprises (Esmaeilian et al., 2016; Ghorabaee, 2016; Prasad et al., 2015; Soufi et al., 2021).

Equipment selection problems are quite difficult and complex. Owing to the increasing variety of handling equipment, the extreme differences in their capacities, capabilities, economic values and other features make it difficult for manufacturers to make decisions. Improperly selected material handling equipment can seriously affect the performance and efficiency of the system (Prasad et al., 2015; Sen et al., 2017). The fact that the equipment has the appropriate capacity and capabilities in the production process is noteworthy in terms of operational efficiency. An incorrect equipment selection decision can cause various disruptions and problems in the workflow, leading to productivity losses. Choosing the right equipment necessitates technical knowledge and analysis in designing material handling systems, making it essential to structure it appropriately within the system (Park, 1996). Equipment selection problems, key strategic decisions for an organization, require detailed analysis and expert opinions. In this study, experts actively participate in both finalizing the criteria and the evaluation process.

This study aims to assess the criteria influencing the selection of new handling technology for assembly lines in the automotive sector and to establish a framework for manufacturers' technology selection. The criteria are well suited for real production challenges, as they are developed with literature support and incorporate expert opinions. The study includes insights from experts in different departments involved in the company's production process. The perspectives of managers, who evaluate situations from different angles, complement one another, leading to more realistic results for the research problem. In this study, expert evaluations of 14 criteria using linguistic variables were analysed via fuzzy FUCOM, with fuzzy logic addressing the uncertainty of information and ideas.

According to the findings of this study, the most effective criterion is the "purchasing cost". The level of investment in new technologies significantly influences the decision-making process of a company. Before collecting data, I expected that the purchasing cost would be one of the top three criteria with the highest weight. Correspondingly, the purchase cost of new equipment is identified as the priority criterion in the findings. The second key criterion influencing technology selection is "movement speed with and without load." The loading speed is crucial for production flow, as it affects operation times, with equipment speed directly influencing operational efficiency (Agarwal and Bharti, 2022), which may be a reason why decision makers use equipment speed as a very effective criterion after the purchase cost. The material flow that changes depending on the equipment speed reduces the waiting time during production, minimizes bottlenecks and ensures that operations are carried out without interruption. Equipment with high movement speed can significantly increase the level of productivity by reducing the production cycle time. Therefore, those who consider the speed dimension in equipment selection can approach a process that will maximize efficiency.

The third most significant criterion of the research is “adaptability”. A key concern regarding equipment changes in a company is whether the new equipment can be integrated into the existing system. According to experts, although the technical features of equipment are considered significant, its behavior within a system has become one of the three most significant criteria. This shows that the integration power of the new handling equipment is a very effective criterion. These three criteria in equipment selection constitute 46% of all the criteria. In other words, only 3 out of 14 criteria have a 46% effect on the material handling equipment selection decision. As a result, the purchasing cost, the speed of the equipment and the adaptability are the most effective criteria for this manufacturer.

The fourth most significant criterion of the study is the operational cost. In addition to the operational cost, two of the four most significant criteria for equipment selection, accounting for up 50%, are directly related to cost. Selecting the right equipment is crucial for businesses aiming to achieve significant cost savings (García-Cáceres et al., 2022). An efficient material handling system can greatly reduce operating costs (Sen et al., 2017). In addition to the purchase price of equipment, it is essential to consider the costs or cost savings that affect the business throughout the process. Rather than seeing the equipment selection decision as a one-time decision, it is recommended to see it as a strategic decision considering the costs that the equipment will cause to the company throughout its lifespan.

According to the research results, the fifth criterion with the highest weight is "process automation". In the selection of material handling equipment, especially AGVs, both cost and automatic production flow and controllability play significant roles (Agarwal and Bharti, 2022). Although the level of automation in factories increases with Industry 4.0 systems, it is expected that the control processes in production will also be maintained automatically. The automation of production processes, including control processes, is effective for both production efficiency and productivity. The increase in a company's productivity resulting from the heightened automation level of new equipment (Riaz et al., 2020) is a key factor in equipment selection.

The lowest weighted criterion of the study is the lifetime of the equipment. The fact that handling technologies have similar life spans probably did not highlight this criterion as a determinant. Another criterion with low weight is operational flexibility. The experts need to use new material handling equipment only at a certain location for the same reason, which may eliminate the expectation of using the equipment for different functions and purposes. One of the surprising results of the study is that the weights of the criteria of maintenance-repair operations and ergonomic features of the equipment are low. There may be several possible reasons for the low weight of the ergonomics dimension. One issue arises from the company's neglect of the harmony between its employees and the system. Another possibility is that the company excludes this dimension from the classification because it will already take it into account when establishing the system. This area requires thorough investigation.

Another is related to “maintenance-repair” activities. According to the experts, the variables related to equipment maintenance are not accepted as a determining factor for equipment selection. Timely maintenance of machinery and equipment is necessary so as not to disrupt the production flow and not to reduce operational efficiency. The frequency and complexity of maintenance periods may vary on the basis of the machine's technology. However, maintenance activities are not considered a highly decisive criterion by the decision-makers in this study. It is acceptable that there is not much difference in handling equipment due to routine maintenance procedures. Applying similar maintenance practices for equipment and knowing that costs do not change much in this direction may be appropriate for this result.

As shown in the study findings, factors such as equipment costs, carrying capacity, height, and flexibility significantly influence equipment selection. However, it is indisputable that some factors are more decisive in this decision. The findings of this study address the problem of a large company producing "buses" in the automotive sector. Owing to the high volume of production in the automotive industry, it is a significant strategic decision not to be late for technological innovations. On the other hand, the results may change in different cases due to some sectoral changes. The 14 criteria in the study may increase or decrease depending on the study in another sector or the company's problem. Exploratory studies can be conducted in different sectors by researchers interested in this subject by dealing with real cases. It is of interest to explore which dimensions are emphasized in different sectors and whether the findings of new research align with those in the automotive industry.

In this study, only the FUCOM was used for systematic weighting of the criteria. In future studies, using different criterion weighting methods and comparing the results may increase the reliability and validity of the results obtained. Therefore, using alternative MCDM techniques is suggested as a valuable research direction for further studies. Another issue is that the relative importance of each criterion has been revealed, and direct interactions between criteria have not been considered. Although examining the relationships between criteria is beyond the scope of this study, more comprehensive analyses should be conducted with methods that examine such relationships in future research. However, it may be useful to evaluate methods that address the relationships between criteria in future studies.

Conflict of interest
No potential conflict of interest was declared by the author.

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Compliance with Ethical Standards
For this study, the approval of the Scientific Research and Publication Ethics Committee of the Kırklareli University Rectorate was obtained with the decision dated 10.09.2024 and numbered E-35523585-199-133754.

Ethical Statement
The author declared that scientific and ethical principles have been followed in this study and that all the sources used have been properly cited.

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