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Multi-criteria decision-making for equipment selection: A review

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Abstract: The selection of equipment is a fundamental decision for the business's future. Several methodologies have been proposed to assist in this kind of decision, one of them being the Multiple Criteria Decision-Making (MCDM) methods. This study's objective is to identify the main multicriteria methods that are applied in decision-making regarding equipment selection. A systematic review of the literature was conducted using the *Methodi Ordinatio* to rank the articles. It was identified that the Analytic Hierarchy Process (AHP) method was the most used method in equipment selection, appearing in more than half of the analyzed articles (24 studies). To better integrate MCDM decisions, the authors intend to study a multicriteria model through the sustainable approach.

Keywords: Equipment selection. Decision-making. MCDM. Sustainability. Environment.

1. Introduction

Efficiency improvement relies on both quantitative and qualitative data, making equipment selection crucial for business success (Palanisamy et al., 2020). Oversized equipment can harm cash flow and lead to idleness, while undersized equipment risks quality issues (Sitorus et al., 2019). Given the complexity of equipment selection, which involves significant investment and multiple conflicting criteria, it is vital to choose the most suitable option to avoid extra costs (Sitorus & Brito-Parada, 2020).

Several frameworks, including Multiobjective Optimization and MCDM methods, have been developed to address equipment selection, allowing for both subjective and objective assessments (Hafezalkotob et al., 2018; Kumar et al., 2017). This manuscript aims to identify the main MCDM methods used in equipment selection and their variations.

The remainder of this manuscript includes a literature review, a description of the methods, an analysis of MCDM applications in equipment selection, and the final conclusions.

2. Theoretical background

2.1 Equipment selection

Selecting new equipment is a complex and time-consuming process that requires advanced knowledge and experience, making it challenging for engineers, managers, and salespeople (Ayag & Ozdemir, 2006). Proper equipment selection is crucial as incorrect choices can negatively impact performance and productivity, especially in competitive environments (Dagdeviren, 2008). The standard procedure involves matching equipment requirements with available options, prioritizing lower acquisition and maintenance costs (Tabucanon et al., 1994; Liu et al., 2021). Correct equipment selection reduces costs, improves layout, and boosts efficiency and productivity (Tabucanon et al., 1994).

Equipment selection also directly affects global competitiveness by enhancing production, labor flexibility, and system adaptability, making it a strategic decision (Tuzkaya et al., 2010). Given the wide variety of equipment available, choosing the best option is challenging (Chan et al., 2001). Beyond financial and technical aspects, environmental impacts and energy consumption should also be considered (Patyk & Bodziony, 2022). Since equipment purchase decisions involve conflicting criteria, relying on statistical or mathematical techniques, such as MCDM methods, enhances decision reliability and quality (Ulutas et al., 2020).

2.2 Multi-criteria decision making

Multi-criteria optimization involves finding the best solutions based on multiple criteria, often requiring compromise due to conflicting and non-measurable factors (Bazzazi et al., 2011). Human judgments can be vague, making it difficult to assign exact numerical values to preferences, so fuzzy approaches with linguistic terms are used to handle imprecision (Bazzazi et al., 2011).

As the number of possible solutions increases, the complexity of decision-making grows due to limitations in objectives, criteria, and alternatives (Jenkins & Keisler, 2022). MCDM, developed within Operations Research, provides mathematical tools to support subjective evaluation, helping decision-makers rank and classify alternatives (Stanujkic et al., 2017).

Recent reviews show a significant increase in the use of MCDM methods. Yannis et al. (2020) reviewed MCDM in transport decision problems, while Kumar et al. (2017) focused on sustainable renewable energy. Both studies found the Analytic Hierarchy Process (AHP) to be the most commonly used MCDM method.

3. Materials and methods

A systematic review of the literature was developed in four steps to achieve the objective of the article: (I) eligibility criteria, (II) selection of database and definition of search strategies, (III) data collection and selection process, (IV) application of the InOrdinatio method. The flow diagram in Figure 1 illustrates the process and the result obtained from each research phase.

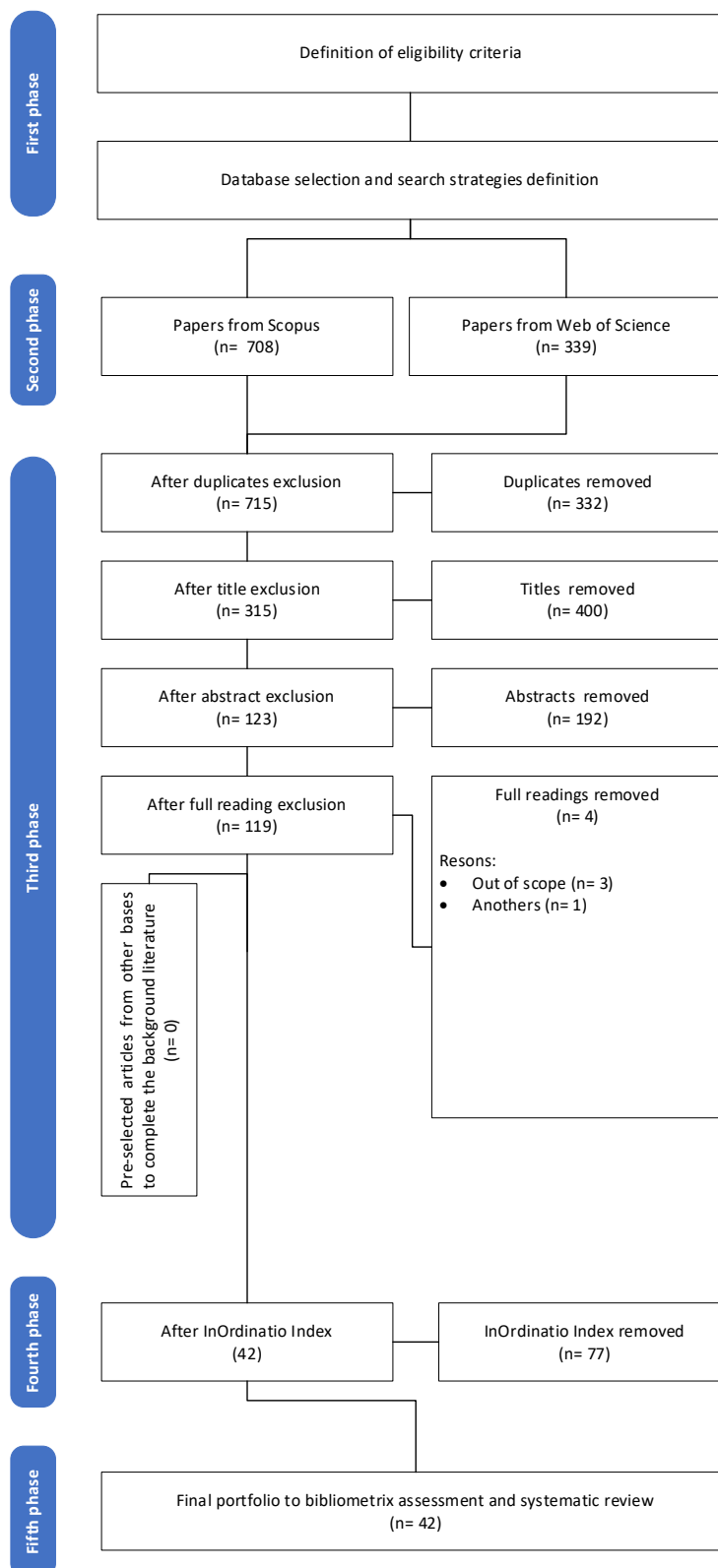


Figure 1 – Overview of Research Methods

3.1 Eligibility criteria

To obtain the final portfolio, inclusion and exclusion criteria were defined to be applied during the selection process, as shown in Table 1. The eligibility criteria ensure a

higher consistency assisting the screening of the studies and decreasing the number of studies outside the scope of the study.

Table 1 - Eligibility criteria

Item	Description
Inclusion criteria (IC)	
IC 1	Multicriteria equipment selection
IC 2	Using one or more MCDM tool
IC 3	Use of sustainable criteria during the equipment selection
Exclusion criteria (EC)	
EC 1	Duplicate studies
EC 2	InOrdinatio Index ≤ 0

3.2 Selection of database and search strategy

Scopus and Web of Science are the most significant databases with the most relevant sources about different themes. Therefore, these databases were chosen to obtain the studies using the string search shown in Table 3 with the keywords and Boolean operators of Table 2 and considering the search strategy in Table 3.

Table 2 - Search Strings

First axis	Boolean operator	Second axis
("machine select*" OR "equipment select*" OR "machine procure*" OR "equipment procure*" OR "machine purchas*" OR "equipment AND purchas*" OR "machine provi*" OR "equipment provi*" OR "machine suppl*" OR "equipment suppl*")		
		("multicriteria" OR "multiattribute" OR "MCDM" OR "MCDA" OR "multi-criteria" OR "multi-attribute" OR "criteria" OR "attribute" OR "decision making" OR "decision-making")

After the search string, the results in each database are limited to (II) research article and review article, (III) simple search mode, and (IV) no time frame. As shown in the full strategy search in Table 3.

Table 3 - Search strategies

Limitations	Scopus	Web of Science
Language	"English"	"English"
Type document	" Research article and Review article "	" Research article and review article "
Research field	"Article title, Abstract, Keywords"	"Topic"

Document mode	Search	"Simple"	"Simple"
Time		"No time frame"	"No time frame"

3.3 Data collection and selection process

The articles were filtered considering the eligibility criteria to ensure that all papers in the portfolio were relevant to this study. Duplicates in both databases were deleted using Mendeley software features and manually excluded by the authors. The data were collected in early June 2022.

3.4 Applying the *InOrdinatio* Index

As the *Methodi Ordinatio* (PAGANI *et al.*, 2015) explains, each paper has an *InOrdinatio* index calculated by the formula shown in Eq. 1. Papers with *InOrdinatio* lower than "0" were excluded after the application of eligibility criteria to ensure that only the most relevant research is included in the portfolio.

$$InOrdinatio = \frac{IF}{1000} + a \times [10 - (Research\ Year - Publish\ Year)] + (\sum Ci) \dots \dots \dots \quad Eq. 1$$

Where:

IF: *Impact Factor.*

a: *Weighting factor specified from 1 to 10 by the authors.*

Research Year: *Year when the research was conducted.*

Publish Year: *Year when the paper was published.*

Ci: *Number of citations.*

4. RESULTS AND DISCUSSION

4.1 A temporal Evolution of MCDM application in equipment selection

Over time, the applications of MCDM in equipment selection have become more diversified, with a substantial increase in methods and sectors of the industry being studied. The evaluation period of articles began in 2005 with two studies. In that year, Shapira and Goldenberg (2005) published a study that used the AHP to make the selection of the construction model. Kulak *et al.*, (2005) applied the Axiomatic Design (AD) to the selection of industrial equipment. Figure 2 shows that annual publications involving MCDM and equipment selection growth are remarkable. The year 2022 has only one publication, perhaps because data were collected in early June. The peak of publications was in 2021, which makes sense if we start with a general analysis of publications involving MCDM methods, as there has been an exponential evolution in the number of publications in recent years (BASÍLIO *et al.*, 2022).

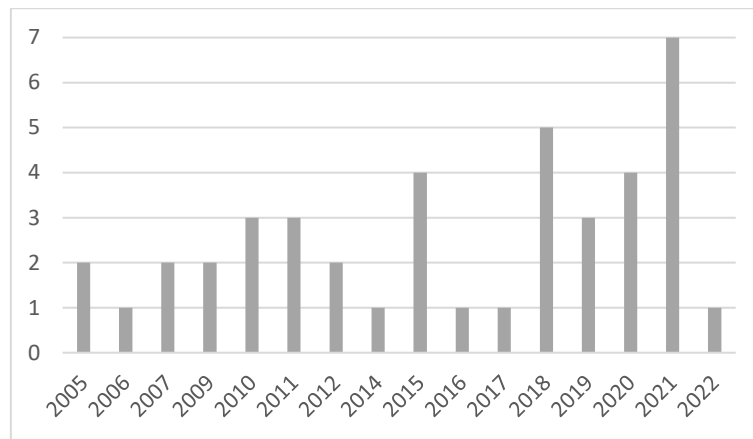


Figure 2 – Temporal evolution of MCDM application in equipment selection.

The rise in MCDM popularity is attributed to the development of new methods, such as Additive Ratio Assessment (ARAS) (Zavadskas & Turksis, 2010), Evaluation based on Distance from Average Solution (EDAS) (Ghorabae et al., 2015), and Combinative Distance-based Assessment (CODAS) (Ghorabae et al., 2016). This expansion has led to increased publications on multicriteria and equipment selection. The differences among MCDM methods lie in their applicability and approach: some rely on subjective data, while others require objective data for decision-making.

4.2 MCDM Approaches Applied to Equipment Selection

The analyzed methods vary widely, from complex fuzzy number adaptations (Sitorus & Brito-Parada, 2020) to combinations of multiple methods for comparison and sensitivity analysis. Multicriteria methods effectively capture various attributes needed for robust equipment selection decisions.

Figure 3 shows the number of times each approach appears, remembering that the approaches can be used together, so the numbers added together exceed the value of articles evaluated by the study. The term “fuzzy approach” denotes papers using fuzzy numbers. “Combined approach” refers to papers employing multiple methods, while “simple approach” involves using a single method. Within the “simple approach,” “simple approach with AHP or FAHP” indicates that over half of these papers used AHP, either in its original or fuzzy version.

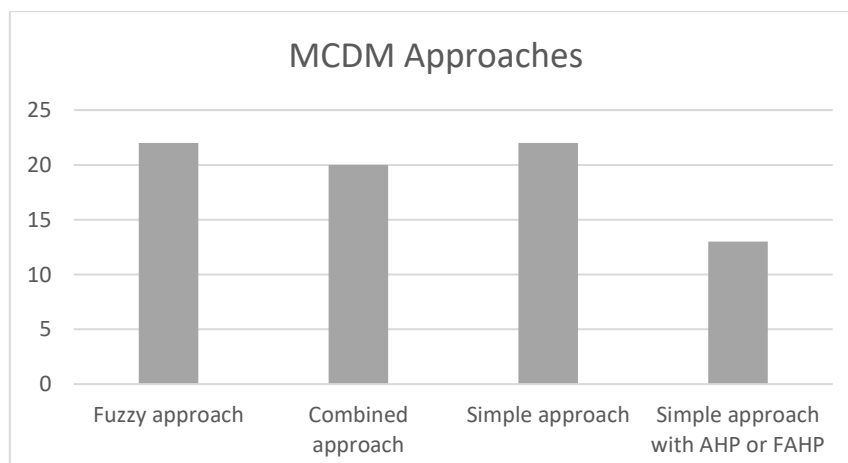


Figure 3 – Analysis of MCDM used in equipment selection.

In this regard, Goswami and Behera (2021) integrated the Entropy, ARAS, and COMplex PROportional Assessment (COPRAS) methods. Özcan and Çelik (2021) used Gray Relational Analysis (GRA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and COPRAS. Ersoy (2021) used Entropy to generate the criteria weights and compared the performance of TOPSIS, CODAS, and EDAS.

Alpay and Iphar (2018) compared the fuzzy number version of the TOPSIS and VišeKriterijska Optimizacija Kompromisno Rješenje (VIKOR) methods. Özgen *et al.*, (2011) compared PROMETHEE and TOPSIS. Ertuğrul and Öztaş (2015) used the Multi-Objective Optimization method based on Ratio Analysis (MOORA) and TOPSIS. Mathew and Sahu (2018) compared the CODAS, EDAS, MOORA, and weighted aggregated sum product assessment (WASPAS) methods. Lu *et al.*, (2022) used Entropy and Criteria Importance Through Intercriteria Correlation (CRITIC) to weigh the criteria and GRA-TOPSIS to rank the alternatives. However, 24 articles use the AHP. About 57% of the articles used some methodology that includes AHP, whether alone or combined with other methods. This considerable number of papers using AHP is related to the great popularity of the method, being the most used and popular among MCDM, regardless of the application area (Basílio *et al.*, 2022). The AHP is considered interdisciplinary because its mathematics is not very complex. It is the only method that can be used both for weighting criteria and ranking alternatives.

Another frequently used approach is the fuzzy theory, which is still widely used with MCDM methods, having a series of extensions and adaptations which allow researchers to obtain better results and approaches. Some fuzzy extensions and adaptations identified in the portfolio are the Fuzzy Axiomatic Design (FAD) used by Kulak *et al.*, (2005). Efe (2019) used the Fuzzy Cognitive Map (FCM) with the integration of the Intuitionistic Fuzzy Numbers (IFN), which are also used by Aloini *et al.* (2014). Sitorus and Brito-Parada (2020) used a stochastic fuzzy number formulated in a previous study (SITORUS *et al.*, 2019). Biscaia *et al.*, (2021) used a version of the bipolar trapezoidal fuzzy set integrated into the TOPSIS method, known as TrBF-TOPSIS. Camci *et al.*, (2018) used Fuzzy Hesitant Numbers (FHN). Most papers generally deal with AHP (for weighting the criteria) and some other tool for ranking alternatives.

Thirteen studies deal only with AHP or Fuzzy AHP (FAHP) for criteria weighting or ranking the alternatives, and six studies apply AHP or FAHP to weight the criteria and other tools like TOPSIS to rank the alternatives. To highlight the papers that applied these procedures, Dağdeviren *et al.*, (2009) used just the FAHP for weapon selection, and Dağdeviren and Yüksel (2008) applied AHP integrated with PROMETHEE to a machining equipment selection.

The AHP method is the most used MCDM in selecting equipment and decision-making in environmental sciences (BASÍLIO *et al.*, 2022). This study corroborates this information because 24 articles with the AHP approach were found, integrating fuzzy numbers or not.

4.3 Sectors of Equipment Selection

According to the analysis of the articles, the manufacturing sector is predominant in the applicability of MCDM for equipment selection. This fact is explained by the manufacturing sector, which employs several areas of engineering, such as management, mechanics, electrical, electronics, and others. Therefore, these professionals are more

familiar with MCDM and other mathematical approaches to decision-making. All areas surveyed in the research and their participation in the portfolio of articles are shown in Figure 4. The category “other sectors” embraces education, technology, house, and defense, with just one occurrence each.

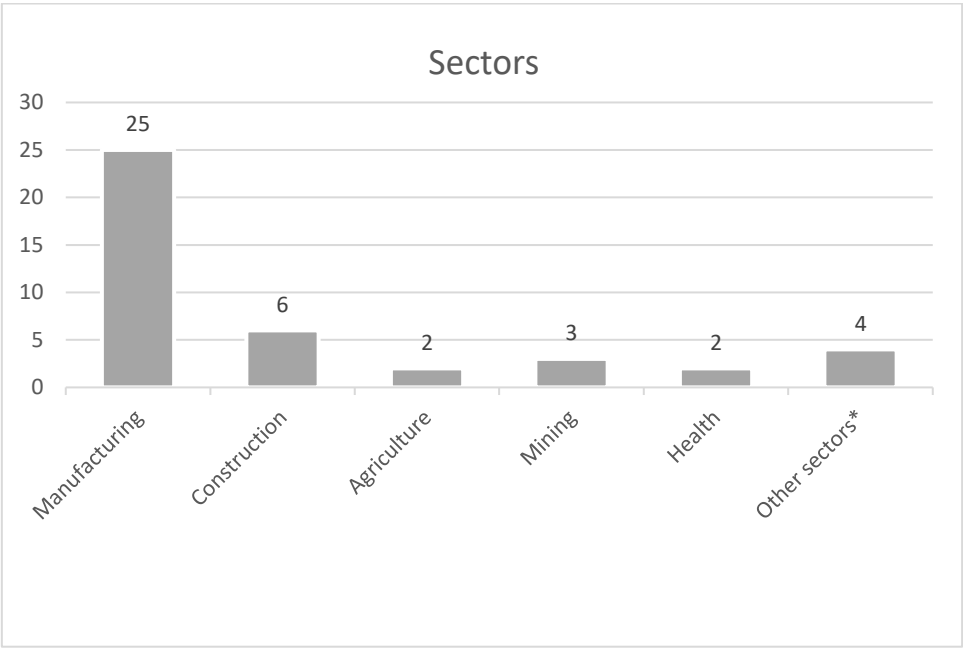


Figure 4 – Sectors of equipment selection.

4.4 Equipment in the Manufacturing Sector

Focusing the analysis of the results on the manufacturing sector, which represents 60% of the analyzed articles (with 25 studies), two types of equipment deserve more attention because of their large number of occurrences within this sector. Although most research brings decision analysis to various pieces of industrial equipment, 40% of the studies (17) focus on two types of equipment to be selected: Machining Equipment and Material Handling Equipment (MHE). Figure 5 shows a graph summarizing the types of manufacturing equipment that target decision-making processes involving MCDM.

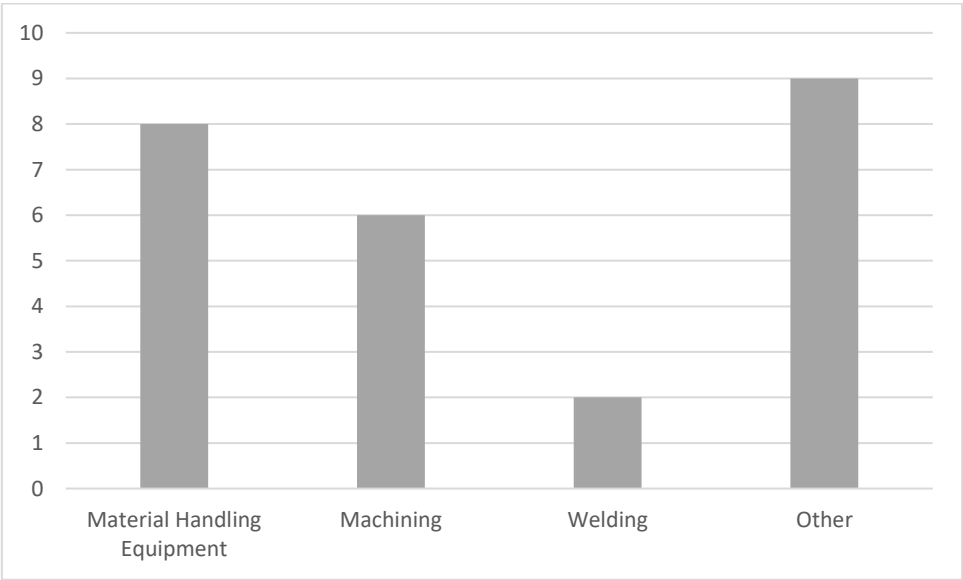


Figure 5 – Equipment selection in the manufacturing sector

* Education, technology, house, and defense, with just one appearance each.

Dağdeviren and Yüksel (2008) combined AHP and PROMETHEE for selecting milling machines. Palanisamy et al. (2020) used BWM for additive manufacturing machine selection. Camci et al. (2018) applied Hesitant FAHP for CNC router selection in SMEs. Cioca et al. (2019) proposed AHP and Fuzzy Inference Systems for reducing risks in purchasing Five-Axis CNC Machining Centers. Kabak and Dağdeviren (2017) ranked CNC Routers using ANP and GRA.

Regarding MHE selection, Mathew and Sahu (2018) solved two MHE problems using CODAS, EDAS, WASPAS, and MOORA methods for conveyor and AGV selection. Horňáková et al. (2021) and Chakraborty and Banik (2006) applied AHP for MHE selection in industrial enterprises. Goswami and Behera (2021) integrated ARAS and COPRAS for AGV selection. Ulutaş (2020) proposed WEBDA and PSI for stacker selection. Yavuz (2015) combined Yager's method and AHP for loader selection, while Lashgari et al. (2012) used Fuzzy AHP and Fuzzy TOPSIS for mine transport equipment. Finally, Onut et al. (2009) proposed Fuzzy ANP and Fuzzy TOPSIS for MHE selection.

The focus on the manufacturing sector in this study is due to its high competitiveness and the presence of highly qualified human resources, driven by globalization (Dağdeviren & Yüksel, 2008). The diversity of machining processes, brands, and services, involving numerous variables and geometries, further justifies the widespread use of MCDM models for selecting machining equipment, given their ability to handle multiple options and flexibility.

The use of MCDM in selecting Material Handling Equipment (MHEs) is widespread due to factors such as costs, size, material weight, distance, and speed (Mathew & Sahu, 2018). The variety of industry tasks drives numerous studies proposing MCDM methodologies for MHE selection.

Selecting Material Handling Equipment (MHESP) is crucial for companies, as it directly impacts productivity and manufacturing. This makes MHESP a strategic and complex decision due to many alternatives and conflicting objectives (Tuzkaya et al., 2010). Proper equipment selection is also a significant logistics challenge (Ulutaş et al., 2020).

5. CONCLUSIONS

This work developed a systematic and critical review of the literature about the selection of equipment through the MCDM, being able to contribute with authors who can seek information in the selection of equipment, especially the industrial ones. The most used MCDM for equipment selection is the AHP; this method is also intensively used in several areas. The primary area in these studies is the industrial sector, with machining and MHE problems.

There is a growing use of multicriteria methods for equipment selection, with integrated tools aimed at combining optimal performance. The manufacturing sector is a key area for equipment selection, which can be explained by the multicriteria methods being more familiar to engineering professionals. Within the manufacturing sector, Material Handling Equipment selection has led the analyzed studies, indicating that many studies aim to address logistics and storage issues.

The limitation of this study is due to the established time range. For future research, we suggest using bibliometric analysis to examine co-citation and author collaboration. Additionally, we also recommend investigating sustainability criteria in the literature, addressing it from a more modern and current perspective.

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