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García-Cáceres, Rafael Guillermo; Torres-Hernández, Germán Guillermo; Delgado-Tobón, Arnoldo Emilio

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Taxonomy of Material handling equipment selection methods at distribution centers

Taxonomía de los métodos de selección de equipos de manipulación de materiales en los centros de distribución

[1] *Rafael Guillermo García-Cáceres*
Full Professor, School of Industrial Engineering, Faculty Seccional Sogamoso, Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia. e-mail: rafael.garcia01@uptc.edu.co

[2] *Germán Guillermo Torres-Hernández*
Researcher, Department of Industrial Engineering, Pontificia Universidad Javeriana, Bogotá, Colombia
e-mail: torres.german@javeriana.edu.co

[3] *Arnoldo Emilio Delgado-Tobón*
Professor, Faculty of Engineering, Universidad Militar Nueva Granada, Bogotá, Colombia
e-mail: arnoldo.delgado@unimilitar.edu.co

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Abstract

The current paper presents a taxonomy of material-handling-equipment for distribution centers, based on a Systematic Literature Review of previous works on both Material Handling Equipment in real picking-intensive logistics contexts and the Decision Support Systems [DSS] employed to solve this type of problem. The current review work intends to sort the literature on the topic through a Material Handling Equipment taxonomy supported on a Systematic Literature Review. A historical appraisal of the problem is complemented by the corresponding synthesis, conclusions and future research perspectives. The current study presents an overall view of Material Handling Equipments in real picking-intensive logistics contexts and Decision Support Systems employed to solve this type of problem. New research perspectives and future recommendations aim at a more thorough integration with expert systems (or any more efficient hybrid method) for candidate equipment assessment and final selection. This could be done by using MCDM techniques like to Stochastic Multicriteria Aceptability Analysis [SMAA].

Keywords: Review; Distribution center design; Material handling equipment selection.

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[1] Industrial Engineering, Universidad Pedagógica y Tecnológica de Colombia, Colombia, Doctor in engineering, Universidad de los Andes, Colombia.

[2] Industrial Engineering, Máster in industrial engineering, Pontificia Universidad Javeriana, Colombia.

[3] Mechanical Engineering, Universidad Nacional de Colombia, Colombia, Máster Mechanical Engineering, Universidad de los Andes, Colombia.

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Resumen

El presente artículo presenta una taxonomía de equipos de manipulación de materiales para centros de distribución, basada en una revisión sistemática de la literatura de trabajos previos tanto sobre equipos de manipulación de materiales en contextos logísticos reales de picking intensivo como sobre los Sistemas de Soporte de Decisiones [DSS] empleados para resolver este tipo de problema. La revisión pretende ordenar la literatura sobre el tema a través de una taxonomía sobre Equipo de Manipulación de Materiales apoyada en la Revisión Sistemática de Literatura. Una valoración histórica del problema se complementa con las correspondientes síntesis, conclusiones y perspectivas de investigación futura. El presente estudio presenta una visión general de los Equipos de Manipulación de Materiales en contextos logísticos reales de picking intensivo y DSS empleados para resolver este tipo de problemas. Las nuevas perspectivas de investigación y las recomendaciones futuras apuntan a una integración más completa con sistemas expertos (o cualquier método híbrido más eficiente) para la evaluación de equipos candidatos y la selección final. Esto podría hacerse mediante el uso de técnicas de MCDM como el Análisis Estocástico de Aceptabilidad Multicriterio [SMAA].

Palabras Clave: Revisión; Diseño de centros de distribución; Selección de equipos de manipulación de materiales.

1. Introduction

The current levels of Supply Chain [SC] competitiveness are challenging companies to develop elevated production and distribution standards, while keeping low inventory levels throughout their operational structure. In addition, they are managing larger and more varied numbers of Stock Keeping Units [SKU], which implies higher restocking frequencies and shorter response-to-the-customer times (Van Den Berg and Zijm, 1999). This situation imposes the need for high performance layout standards in the design of DCs, which in this way consolidate as key SC facilities.

DCs play a central role in business success or failure, since their adequate operation is critical in determining SC speed, accuracy, reliability, profitability and productivity (Baker and Canessa, 2009; Gu *et al.,* 2007; Frazelle, 2003; Frazelle, 2002; Gray *et al.,*1992; Holzapfel *et al.,* 2016).

Material Handling Equipment Selection [MHES] has been identified by Riopel *et al.* (2005) as a typical DC decision, among other 48 logistic decisions. In turn, García-Cáceres and Escobar-Velasquez (2016) have described 123 different SC issues and a series of classified relations among different components which include both MHES and DCs. DC functioning is not only one of the most important SC problems and design decisions, but also a very scarcely treated one, as it has been shown in two successive reviews covering 50 scientific contributions to the literature on logistics and SCs (Gu *et al.,* 2007, Gu *et al.,* 2010).

This work intends to sort the literature on the topic through a MHES taxonomy supported on a Systematic Literature Review, which is detailed below.

2. Methodology

This work is supported in the Systematic Literature Review (SLR) (Xiao and Watson, 2019) which comprise four steps:

Literature Search. The literature search finds materials for the review; therefore, a systematic review depends on a systematic search of literature. Channels for literature search. There are three major sources to find literature: (1) electronic databases; (2) backward searching; and (3) forward searching.

Data Extraction. The process of data extraction will often involve coding, especially for extending reviews. It is important to establish whether coding will be inductive or deductive (i.e., whether or not the coding will be based on the data or preexisting concepts)

Data Analysis and Synthesis. Once the data extraction process is complete, the reviewer will organize the data according to the review they have chosen.

Findings Report. The researchers should report the findings from literature search, screening, and quality assessment.

These steps are displayed below.

2.1. Literature Search

The literature consulted in this work dates back to 1977, due to the need to include classic works permanently taken into account in the

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literature on DCs and MHES, however, the vast majority of works are related to the last three decades. Many studies seem to take storage and material handling infrastructure for granted, which prevents considering the way they should be selected (Tejesh and Neeraja, 2018).

DCs are key nodes in supply chains wherein storage is time-limited and dominated by high turnover items, thus resulting in processes oriented towards the movement of materials and the productivity of the operation (Higginson and Bookbinder, 2005). In addition, they facilitate a continuous supply of large product amounts to the market, buffer both material flow and demand seasonality, shorten transport distances, allow promptly responding to the customer, consolidate and deconsolidate materials of different origins to be delivered to multiple customers, and facilitate value addition through maquila processes (Gu *et al.,* 2007; Baker and Canessa, 2009; Frazelle, 2002).

MHES has been studied since the 1970s through diverse approaches ranging from practical selection guides (Apple, 1977; Rudenko, 1971; Muther, 1981) to complex DSS. The literature review shows 62 different approaches to MHES directly or indirectly tackling the subject. Saputro *et al.,* (2015) conducted a review of 42 MHES papers, which they classified as related to Artificial Intelligence, Optimization, and MCDM, the latter accounting for approximately 33%.

The decision process is usually highly dependent on the experience and preferences of Decision Makers [DM], which makes it difficult to develop precise and objective selection criteria (Saputro *et al.,* 2015; Onut *et al.,* 2009; Gu *et al.,* 2010). According to Rouwenhorst *et al.,* (2000). This difficulty is mainly due to: a) the objective or utility function of the selection models is often complex and partially qualitative in nature; b) the set of alternatives is large, each of them having multiple attributes, which makes the determination of all possible solutions a very complicated task; c) the stochastic behavior of some variables such as useful life of equipment or performance rates; and d) the unpredictable behavior of the demand, which impacts DC capacity.

The review shows that the main MHES techniques in manufacturing and building contexts are AHP (Gray *et al.,* 1992; Skibniewski and Chao, 1992; Luong, 1998; Chan *et al.,* 2001; Bhattacharya *et al.,*2002; Shapira and Goldenberg, 2005; Chakraborty and Banik., 2006; Dağdeviren, 2008; Lin *et al.,* 2008; Komljenovic and Kecojevic, 2009; Momani and Ahmed, 2011; Kildienė *et al.,* 2014; Patel *et al.,* 2016; Varun *et al.,* 2017; Hafezalkotob *et al.,* 2018; Gaur and Ronge, 2020; Mathew *et al.,* 2020; Zakarya *et al.,* 2021); expert systems and Knowledge-Based Rules (Fisher *et al.,* 1988; Hosni, 1989; Matson *et al.,* 1992; Bookbinder and Gervais, 1992; Chu *et al.,*1995; Welgama and Gibson, 1995; Park, 1996; Fonseca *et al.,* 2004; Cho and Egbelu, 2005; Hassan, 2014; Chakraborty and Prasad, 2016); optimization and mathematical programming and analytical methods (Hassan *et al.,* 1985 ; Ziai and Sule, 1989; Velury and Kennedy, 1992; Welgama and Gibson, 1996; Lashkari *et al.,* 2004; Sujono and Lashkari, 2007; Ioannou, 2007; Santelices *et al.,* 2015); Simulation and Queuing Theory (West *et al.,* 1993); Raman *et al.,* 2009); and Hybrids, Metaheuristics, Axiomatic Design and other methods such as Fuzzy Logic, Techniques for Order Preference by Similarity to Ideal Solution (TOPSIS), FVIKOR algorithms, outranking methods (ELECTRE, PROMETHEE), Quality Function Deployment [QFD], and Weighted Utility Additive [WUTA], among others (Chittratanawat and Noble, 1999; Haidar *et al.,* 1999; Braglia *et al.,* 2001; Deb *et al.,* 2002; Kulak, 2005; Mirhosseyni and Webb, 2009; Onut *et al.,* 2009; Ulubeyli and Kazaz, 2009; Tuzkaya *et al.,* 2010; Athawale and Chakraborty; Valli and Jeyasehar, 2012; Lashgari *et al.,* 2012; Atanasković *et al.,* 2013; Sawant an Mohite, 2013; Yazdani-Chamzini, 2014; Mousavi *et al.,* 2014 ; Hadi-Vencheh and Mohamadghasemi, 2015; Khandekar and Chakraborty, 2015; Pamučar and Ćirović, 2015; Prasad *et al.,* 2015; Karande and Chakraborty, 2013; Cortés *et al.,* 2017; Hosseini and Seifbarghy,2016; Saputro and Erdebilli, 2016; Jiamruangjarus and Naenna, 2016; Tom *et al.,* 2020).

2.2. Data Extraction

As all the mentioned methods have strengths and weaknesses, their adequacy of use depends on the specific decision context

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to be managed. A brief synthesis of the applicability and critical points of the models presented in the literature has to do with:

a. equipment type, since these models have mainly focused on material conveyance, thus ignoring necessary equipment for storage, identification, communication, control and support in DCs.

b. objective: strong emphasis has been put on the traditional cost minimization, disregarding other user needs such as security, increased productivity, equipment utilization, and environmental impact and life cycle, among others.

c. subjectivity: the available techniques still do not treat it rigorously; it is usually associated to DM preferences and little attention is given to the endogenous estimation of criterion weights with respect to the utility function that evaluates equipment alternatives.

d. uncertainty: the stochastic nature of some equipment attributes is usually left aside;

e. many models are not capable of processing ordinal and cardinal criteria simultaneously.

f. stronger efforts are necessary for the development of systematic, comprehensive and consistent MHES tools with emphasis on their practical application, i.e., their manageability and easiness of use.

The current literature review shows that MHES studies focusing exclusively on logistics systems such as DCs are generally very limited in context, degree of specialization, specification of the attributes in question, and coverage of the available equipment alternatives. According to Khandekar and Chakraborty (2015), about 75% of the existing MHES methods consider only quantitative information, only the remaining 25% having the capability to process qualitative and quantitative information simultaneously. Since around 2007, there has been substantial increase in the application of other methods, and this trend is projected to spread around the world until 2022. In a review of 88 scientific publications and 25 MCDM methods, Jato-Espino *et al.,* (2014) focused on the construction sector, where they found that, alone or combined, AHP is the most frequently used technique.

In a typical industrial facility, material handling is estimated to represent 15% to 70% of the total cost of manufacturing and distributing a product. This implies that any improvement in this activity is likely to bring about not only increased efficiency in logistic and manufacturing flows, but significant savings in operation costs (Tompkins *et al.,* 2010).

In sum, the literature shows that MHES research is not only scarce and limited, but it lacks practical robustness as well (Saputro *et al.,* 2015; Hadi-Vencheh and Mohamadghasemi, 2015; Prasad *et al.*, 2015; Jato-Espino *et al.,* 2014; Gu *et al.,* 2010; Hassan, 2010; Gu *et al.,* 2007; Kulak, 2005; Welgama and Gibson, 1996; Welgama and Gibson, 1995; Ziai and Sule, 1989).

The literature review contains 87 articles from which 77.01% are Q1, 11.49% are Q2, 4.59% are Q3, 1.14% are Q4, and 5.74% are not part of SCOPUS when it comes to books. Table 1 shows the main publishers with their percentage of participation in the construction of the taxonomy.

Tabla 1. Editorials

Editorial	Percentage
Elsevier	49,42
Taylor and Francis Ltd.	12,64
John Wiley & Sons Inc	3,44
Emerald Group Publishing Ltd.	3,44
American Society of Civil Engineers (ASCE)	3,44
Springer London	3,44
Others	21,44
Total	100

Source: Authors' own elaboration.

2.3. Data Analysis and Synthesis and Findings Report

The current study presents an overall view of MHES in real picking-intensive logistics contexts and DSS employed to solve this type of problem. An appropriate MHES allows improving the performance of an organization through stronger financial operation, reduced response times and

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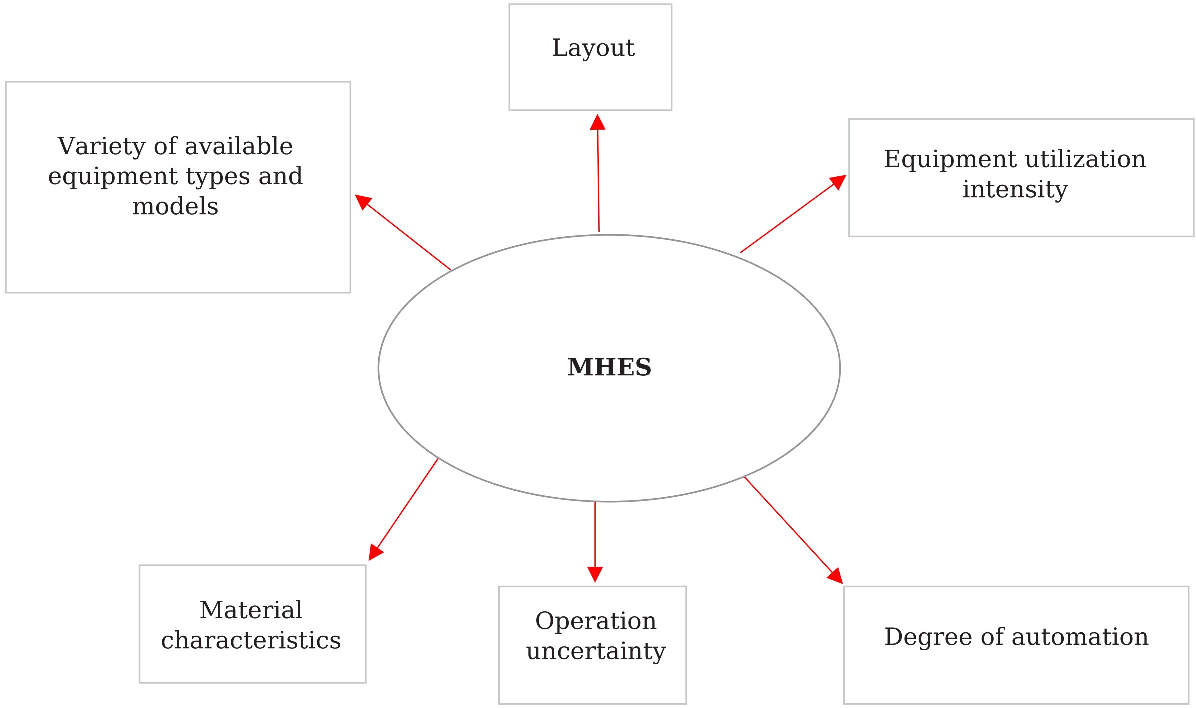
Figure 1. MHES decisión criterio



Source: Authors' own elaboration.

streamlined resource use. Having reviewed 62 works with different approaches to MHES, the current study aims to strengthen and facilitate DC design.

In spite of their importance, the literature has paid relatively little attention to DCs. The few theoretical developments regarding their functionality certainly contrast with those associated to other SC components, as is the case of factories (Van Den Berg and Zijm, 1999; Higginson and Bookbinder, 2005). The design of DCs is a highly complex task requiring comprehensive and systematic methods which have been poorly developed (Rouwenhorst *et al.*, 2000; Gu *et al.*, 2010; Baker and Canessa, 2009; Yener and Yasgan, 2019). This important planning activity, together with its pre-operative stages, requires fundamental decisions intended not only for the articulation of both layout and equipment selection, but for the adjustment of labor force, work and operative tactic conditions as well (Hassan, 2010; Rouwenhorst *et al.*, 2000). These decisions form a complex network of sequential and interdependent relations in which material handling should not be isolated, but integrated with the activities and resolutions of the rest of the organization. Said decisions determine: 1) MHES; 2) appropriate and sufficiently detailed layout; 3) operations strategy; 4) facility size and dimensionality; and 5) general structure or conceptual design of the material flow pattern. Out of the above, MHES and Layout determination are considered to be the most important issues in DC design (Lashkari *et al.*, 2004; Park, 1996; Hassan *et al.*, 1985; Temiz and Calis, 2017).

The Figure 1 shows the identified MHES decision criteriaI.

Finding the best combination of these and other factors involved in this process represents a complex decision problem (Onut *et al.*, 2009; Sule, 2001). But it is precisely the administration of this complexity what allows the MHES process to determine what and where the equipment needs are (Onut *et al.*, 2009).

In addition, the DMs could use this work for MHES processes at any logistics operation, with other equipment and

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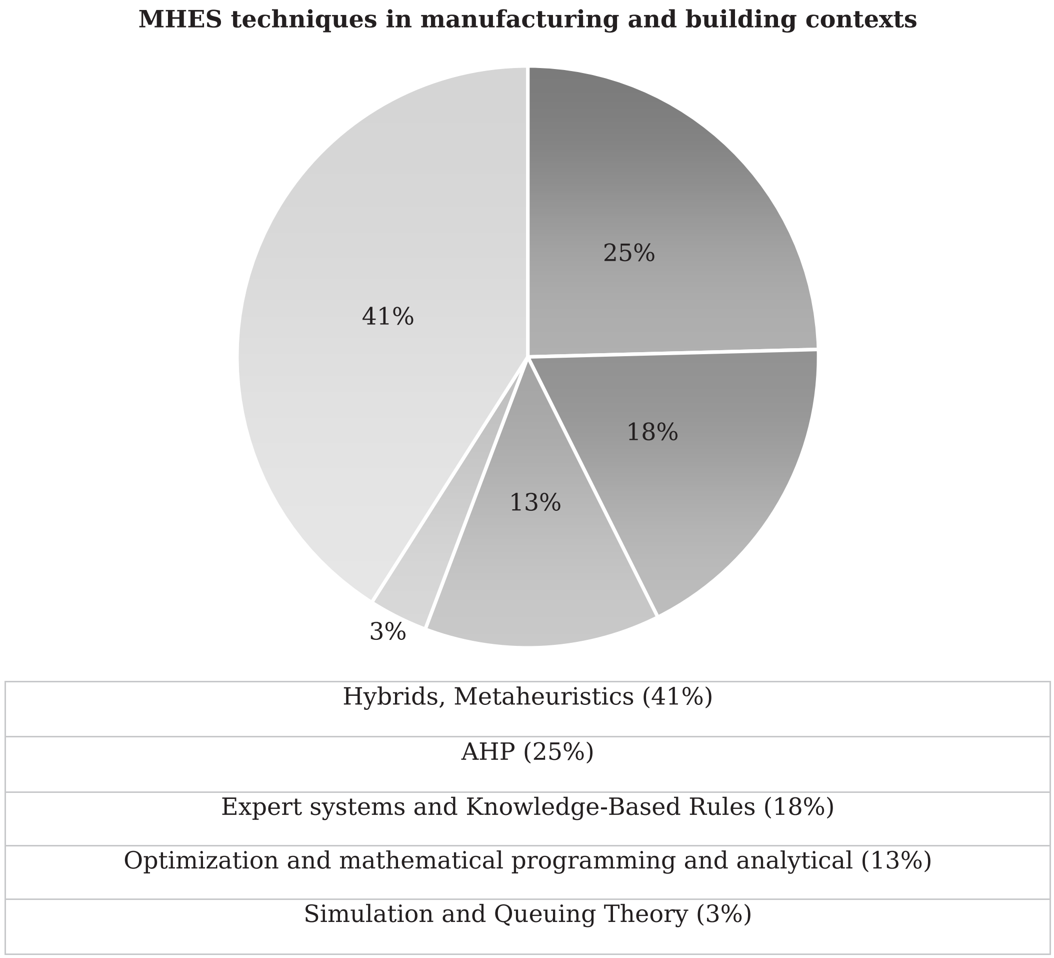
Figure 2. MHES techniques



Source: Authors' own elaboration.

criteria, and at manufacturing, services or construction industries as required. Recently, the integration of SMAA with other techniques has resulted in new methods aimed at strengthening the consistency of results and the management of uncertainty and preference information. Such is the case of SMAA-PROMETHEE (Corrente *et al.,* 2014) and SMAA-3 (Hokkanen *et al.,* 1998), both of which resulted from hybridization with the traditional outranking methods; and of SMAA-TOPSIS (Okul *et al.,* 2014) and SMAA-III (Tervonen *et al.,* 2009), the latter resulting from the combination with ELECTRE. Building on the work of Lahdelma *et al.* (2003), and Lahdelma *et al.* (2002), and more recently SMAA-M when the theoretical paradigm rules the decision process (García-Caceres, 2020). In this regard, the Figure 2 shows the synthesis of the percentages of the MHES techniques.

The review shows its theoritical and practical value allowing to identify the most used decision-making support techniques as well as the criteria, the key aspects, and the decision context of MHES, especially in the DCs proposing research perspectives.

A contradiction has been observed between research conducted on the design and operation of DCs and actual work practices observed in industry. Some authors coincide in highlighting the need for a more practical and consistent way of communicating and applying research results, so that they serve the purpose of designing real DCs (Gu et *al.,* 2010; Baker and Canessa*,* 2009; Gu *et al.,* 2007).

In this sense, simultaneously considering both the qualitative and quantitative aspects of the MHES process allows contemplating it together with complex Multi-Criteria Decision Making (MCDM) problems (Saputro *et al.,* 2015; Momani and Ahmed, 2011; Onut *et al.,* 2009; Dağdeviren, 2008), which have received far less attention than that of layout (Gu *et al.,* 2010).

The review show as an adequate MHES allows improving financial return, reducing response times, rationalizing the use of human resources and increasing the flexibility of the productive system (Tuzkaya *et al.,* 2010; Mirhosseyni and Webb, 2009; Chan *et al.,* 2001; Chu *et al.,* 1995; Matson *et al.,* 1992; Prasad *et al.,* 2015). Selecting proper equipment for the handling of materials involves making decisions aimed at reducing move distances, increasing the size of handled units, seeking opportunities for round trips during product storage or order picking, and improving cube utilization (Manzini, 2012).

As to MCDM, the literature review shows several theoretical and practical approaches to the topic in question. MCDM is a dynamic Operations Research scientific field in which diverse techniques have been developed (Jato-Espino *et al.,* 2014). Two large families correspond to Multiattribute Utility Theory (MAUT) based methods (Keeney and Raiffa, 1976) and Outranking methods such as ELECTRE (Elimination Et Choix Traduisant la Realité) (Roy, 1996), PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) (Brans and Mareschal, 2005), and SIR (Superiority and Inferiority Ranking method) (Xu, 2001). According to Tervonen *et al.* (2007), the former ones are supported by a stronger mathematical basis. The work of Pamučar and Ćirović (2015) stands out for the implementation of a new DEMATEL-MABAC (Multi-Attributive Border Approximation Area Comparison) method for the selection of forklifts in logistics centers.

New research perspectives and future recommendations aim at a more thorough integration with expert systems (or any more efficient hybrid method) for candidate equipment assessment and final selection. This could be done by using MCDM techniques like to Stochastic Multicriteria Aceptability Analysis – SMAA (Hokkanen *et al.,* 1998; Lahdelma and Salminen, 2001; Lahdelma *et al.,* 2002; 2003; García-Cáceres, 2020), ELECTRE, PROMETHEE, SIR, VIKOR, ANP, TOPSIS, fuzzy logic. Furthermore, if an integral MHES optimization is intended, Integral Analysis Method - IAM (García-Cáceres *et al.,* 2009) might come in handy for the case.

3. Conflict of interest

The authors declare no conflict of interest.

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