Multi-Criteria Decision Making Approaches for Warehouse Layout and Design: a Literature Survey

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MULTI-CRITERIA DECISION MAKING APPROACHES FOR WAREHOUSE LAYOUT AND DESING: A LITERATURE SURVEY

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Abstract *– Warehouse layout and design is a major input in terms of the total costs of the enterprise, as well as playing a key role in increasing the level of competition of the enterprise. Decision problems are encountered at the tactical and operational level in warehouse management, which is of high importance. With the literature review studies, it is emphasized that Multi-Criteria Decision Making (MCDM) applications should be handled as highly qualified or multi-purpose problems and that the problems should be compatible with real life problems. It has uncertain conditions because the real-life problems are taken into account and the criteria contain contradictory features. In this case, it becomes a difficult task to choose the best location for the product / raw materials. For this reason, the aim of this study is to examine the MCDM applications in the field of warehouse layout and design comprehensively. This literature study has been carried out with relevant keywords on different international databases. In the literature review, it has been determined that the most used techniques in the field of warehouse layout and design, which are carried out by applying the MCDM methods, are the Analytical Hierarchy Process (AHP), ELECTRE TRI and PROMETHEE, and it has been found that MCDM methods are used as an integrated manner in order to deal with the advantages to be obtained by using more than one MCDM method in its field. In addition, the suggestions were presented to researchers for further studies.*

Keywords – Literature Survey, Multi-Criteria Decision Making, Warehouse Design, Warehouse Layout

INTRODUCTION

Over the past two decades manufacturing has become more complex because of competition, great varieties and technological advances. Nowadays, the basis of competition has changed, so ensuring not only cost effectiveness but also customization (Kumar et al., 2016). While businesses are competing in the market with the price, quality and technological infrastructure of their final products, they may also face the risk of not being on the shelf with the sales and stock management they apply (Sever, 2006).

Warehouses generally are refered to the storage of raw materials and all products and is used in work in process (Yerlikaya, 2020). In his study, Yerlikaya (2020) states that warehousing activities are the activities in which the most time and money are spent among all the activities of the enterprise. Warehouse facility design and layout are considered as important logistics activities, in addition, warehouse selection is among the important steps in order to realize the most efficient activities (Amin et al., 2019).

Warehouse activity is an element of fundamental importance in the integration of the logistics channel, and it is regarded as an extension of production (Silva et al., 2015). It aims to achieve an efficient use of space that facilitates the separation of applications and minimizes the cost of order picking (Gu et al., 2007). Different criteria should be considered for product placement and classification in the warehouse; these criteria are size, weight, volume, demand, cost, distance etc. Considering all these criteria at the same time and placing the products in the most appropriate place is a difficult activity (Gu et al., 2007).

The criteria used in the fields of facility layout, design and facility location selection are determined according to the type and content of the problem. The explanation related to these studies is explained as in Table 1. Using Table 1., it can be seen which criteria are included in which study.

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The criteria in Table 1 were encoded with letters and entered in the table; A Distance, B Adjacency Score, C Shape Ratio, D Flexibility, E Accessibility, F Maintenance, G Closeness Gap Value Cluster, H Process Capacity, I Performance Measures, J Productive Area Utilization, K Quality, L Human Issues Cluster, M Throughput Time, N Product Indicators, O Work in Process, P Machine Utilization, R Material Handling Vehicle Utilization and Handling Cost, S Productivity, T Layout Reconfigurability, U Cost, V Reliability, W Flow.

Multi-Criteria Decision Making (MCDM) method has been used to make complex decisions, and allows for the consideration of multiple criteria, both measurable and also non-measurable, combining quantitative and qualitative criteria (Ilbahar et al., 2018). For all scientific researches, the decision making process is a planned path of solving problems (Sehra et al., 2016). MCDM methods can gather historical data and expert opinions (Pohekar and Ramachandran, 2004). The master purpose of MCDM is to evaluate and maybe choose the best one from several alternatives based on criteria (Afshari et al., 2016).

Table 1. Criteria used in MCDM processes (adapted from Besbes et al., 2018)

Authors	Abdul-Hamid al (1999)	Jafaryeganeh et al (2020)	Shang (1993)	Yang et al (2000)	Yamg and Kuo (2003)	Abdi (2005)	Ertay et al (2006)	Yang and Hung (2007)	Kuo et al (2008)	Abdi (2009)	Singh and Singh (2011)	Maniya and Bhatt (2011)	Shahin and Poormostafa (2011)	Lateef, Ateekh (2013)	Shokri et al (2013)	Hawari et al (2014)	Wang et al (2016)
A					x		x	x	x			x	x		x		x
B					x		x	x	x			x	x		x		x
C					x		x	x	x			x	x		x		x
D	x		x	x	x		x	x	x		x	x	x		x	x	x
E					x			x	x			x	x		x		x
F					x			x	x			x	x		x		x
G																x	
H				x													
I		x															
J																x	
K						x	x			x							
L			x							x	x					x	
M														x			
N														x			
O			x	x													
P														x			
R							x										
S	x			x													
T						x				x							
U	x					x				x							
V						x											
W											x						

Amin et al (2019) revealed the areas of use, advantages and disadvantages of some of the MCDM processes in their studies, and in this study, the most frequently used processes are given in Table 2.

Table 2. Explanation about the some MCDM processes (Amin et al., 2019)

Some MCDM processes	**Application Areas**	**Advantages**	**Disadvantages**
ELECTRE	Location and transportation problems etc.	It takes some uncertainties into accounts	Results are difficult to interpret.
AHP	Location selection, supply chain strategy etc.	Suitable for low number of alternatives and criteria, easy to understand.	Not suitable for too many alternatives and criteria.
ANP	Application limitations are unknown.	They also reveal the relationship between the criteria.	The solution takes too much time.
TOPSIS	Supply chain and logistics, energy etc.	Suitable for a large number of alternatives and criteria.	Az sayıda alternatif ya da çok sayıda kriter için uygun değildir.
Grey Theory	It can be used when there is missing data.	It needs accurate information.	It’s not give an optimal solution.
PROMETHEE	The field of application is quite wide.	It is easy to use.	There is no exact method for determining weights.
Simple Additive Weighting (SAW)	Business management, Financial problems etc.	It has simple method steps.	Sometimes its solution may not be understandable.

METHODOLOGY

The main goal of this paper is to review the literature concerning the application of MCDM methods in the field of warehouse layout. The Web of Science (WoS) Core Collection Database was chosen to identify papers in the period of 1977–2021.

In the publication research, a large number of studies that did not specialize in the warehouse were found, in this case, the framework of the research was expanded a little more and citations were made about the facility layout.

Scanning via Elsevier; (29.07.2021) 47.980 papers with the keyword of “Facility Layout”, Find articles with these terms: 306 publications with “Layout” and “MCDM” search.

Scanning via Science Core Collection; (29.07.2021) Between 1977 year and 2021 year, 12.487 papers with the keyword of (((((ALL=(MCDM)) AND ALL=(MCDM WAREHOUSE LAYOUT)) OR ALL=(WAREHOUSE DESIGN)) OR ALL=(INVENTORY REPLACEMENT)) OR ALL=(SHELF AASIGNMENT)) OR ALL=(STORAGE ALLOCATION)

PRIMARY REVIEW RESULT

A summary content as in Table 3 was prepared for the analysis of similar studies. The main reason for including this table in the study is to sample the publications that do not work directly on warehouse layout and design.

In addition to the studies in Table 3, more important studies are included under the Detailed Review Result title.

Table 3. Summary information about some of the analyzed studies

Author and Year	Methods	Inputs	Specialization in Warehouse Layout/Management
Colak et al (2016)	Analytical Hierarchy Process (AHP)	Criteria: Stock Turnover Rate, Transport Distance Quantity Alternatives: 47 raw materials	☑
Arunyanart and Pruekthaisong (2018)	AHP, Data Envelopment Analysis (DEA)	9 different layout alternatives for 7 departments of the company	
Indap (2018)	AHP	Criteria: Cost, Volume and Height Utilization, Ease of Loading, Stock Turnover Rate Shelf Systems: Back to Back Shelving, Narrow Aisle Racking System, Automated storage and retrieval systems	☑
Micale et al (2019)	ELECTRE TRI, TOPSIS	Criteria: weight, area, demand, profitability and number of customers	☑
Demircioglu ve Ozceylan (2021)	Fuzzy Analytical Network Process (Fuzzy ANP)	Criteria: Consumption Amount, Availability in Finished Product, Access Status, Storage Conditions, Analysis, Delivery Adequacy Alternatives: 9 raw materials	☑
Fontana and Calvante (2013)	ELECTRE TRI	Characteristics of products	☑
Hawari et al (2014)	ANP	6 criteria determined for 18 business areas of the business (Criteria: Closeness gap value, Expansion flexibility, Routing flexibility, Volume flexibility, Productive area utilization, Human issues)	
Vukasovic et al (2021)	The Fuzzy Full Consistency Method, The Fuzzy Evaluation based on Distance from Average Solution	78 products, 4 criteria (Criteria: Quantity, Unit price, Annual Procurement Costs and Demand)	☑
Alsyouf et al (2011)	SAW	12 criteria, 3 locations	

Nitkratoke and Aengchuan (2019)	Fuzzy AHP	33 different product brands, 4 criteria (Criteria: Ordering Cost, Selling volume, Perishability, Opportunity Cost)	☑
Fontana et al (2020)	ELECTRE TRI	50 products, 4 criteria (Criteria: Popularity, Maximum inventory, Profit, Sensitivity)	☑

DETAILED REVIEW RESULT

In this section, the literature review is given in more detail and specific to the studies.

Each method of MCDM follows different procedures in determining criterion weights, normalization techniques and alternative ranking (Jahan and Edwards, 2015). Hybrid evaluation method; The first step is to uncover the criteria and alternatives. The second step is to perform tradeoffs between criteria using pairwise comparisons. The third step is to calculate the criteria priority vector, normalize the relevant weights, and calculate the consistency ratio.

If the consistency rate is below 10%, the logical consistency of the binary matrix is considered to be sufficient (Ribeiro vd., 2011). Silva et al. (2015) proposed a multi-criteria decision model for assigning and ranking products to shelf locations in a warehouse. Fontana and Nepomuceno (2016) proposed a multi-criteria decision model to realize the product classification and solve the storage location assignment problem in a multi-layered warehouse.

In his study, Yerlikaya (2020) determined 3 criteria, since assigning products to storage areas creates many time problems, especially when there is uncertainty in product demands. These 3 criteria are demand, profitability and sensitivity. In the mentioned study, a decision matrix was created with a fuzzy number for 3 criteria. The decision matrix is expressed with linguistic values. Net flow values were also listed with the fuzzy PROMETHEE method. According to the order of importance of the obtained product, the storage areas were assigned. So, it is proposed to rank the products with the Fuzzy PROMETHEE method under qualitative criteria (demand, sensitivity, profitability) for warehouse systems where the demand is uncertain and assign them to the best storage locations according to this rank.

Jafaryeganeh et al (2020) have proven that it is possible to solve a multi-objective design problem based on different objectives as an MCDM problem. An oil tanker has been included in the review because it has a similar use to a warehouse. This design problem has objectives, constraints, and design variables. Purposes; minimization of pollution prevention parameter, cargo capacity (maximizing available space) and structural safety parameter (maximizing); constraints, regulations and other limitations. The importance of the criteria was determined by the objective weights of the Shannon entropy technique. Alternative rankings were evaluated by MCDM methods.

In Amin et al (2019) studies, MCDM process was used to select the best warehouse according to all criteria determined among 5 warehouses. The criteria that guide the selection were obtained by means of a questionnaire.

Besbes et al (2018) could not find a general model to cover all companies in their study; because each company differs on the basis of the sector in which it operates, in the product variety, in the context of available technologies and economic conditions. Using AHP and TOPSIS, the following conclusion was reached; distance, adjacency, space, work flow and material handling cost.

In the studies of Fontana and Nepomuceno (2016), products are categorized in many companies, the only problem is to assign them to the warehouse shelves. However, in some warehouses, products should be categorized, their weights should be determined according to the criteria determined according to the groups they are in, and shelf assignment processes should be completed. In this study, 4 criteria were determined, and it is desired to evaluate them simultaneously. In other words, while providing one criterion, the other criterion should not be compromised. For this reason, the Electre TRI method was chosen. These criteria are as follows; product weight, area size, demand size, product's contribution to the firm.

Silva et al (2015) çalışmalarında Storage of products which increases the speed of delivery and the competitiveness of enterprises. Bu çalışmanın amacı a multicriteria decision support model for ranking products and assigning them to warehouse storage locations. Warehouse activity is an element of fundamental importance in the integration of the logistics channel, and it is regarded as an extension of production. It aims to achieve an efficient use of space that facilitates the separation of applications and minimizes the cost of order picking (Gu et al, 2007). Different criteria should be considered for product placement and classification in the warehouse; these criteria are size, weight, volume, demand, cost, distance etc. It is a difficult activity to consider all these criteria at the same time and to place the products in the most appropriate place. In this study, two of the MCDM methods were used as hybrids. The areas determined for storage with the SMARTER and lexicographic methods were evaluated as an alternative. The criteria are listed as follows: Number of Customers, Inventory Turnover Rate, Area Size.

In the studies of Kumar et al (2016), facility layout design selection is examined by taking the opinions of experts. An application was made in a company with a Flexible Manufacturing Systems infrastructure. There are 5 criteria, 5 alternatives and 4 experts.

Table 4. Criteria for FLDs

Subjective Criteria	**Objective Criteria**
• Size and Shape of the Departments (C_1) • Distance between Facilities (C_2) • Quality of the Products (C_3) • Lighting, Ventilation and Identification Colours used (C_4)	Total Investment Cost (C_5)

In this paper there is an attempt to propose a FLD selection algorithm that is based on a combination of hierarchical structure analysis and Fuzzy Set Theory. A measure called 'Fuzzy Facilities Layout Index (FFLI)' is proposed in this paper that handles fuzziness or vagueness inherent in the evaluation process and to provide a standard for selecting the most appropriate FL of the alternatives without losing sight of the importance of various criteria in FL selection process. The criteria: Many potential FL attributes Availability of Skilled workforce, Size & Shape of the Departments, Distance between facilities, Quality of production, various cost components involved, Lighting & Ventilation etc are considered for the selection of a right kind of FL for a particular type of production process.

In the real-world, attributes so selected to help decision making regarding FL design selection can be categorised into: **(1) Subjective issues (**These factors have qualitative definition and based solely on an individual's (expert) perception and ratings) such as availability of skilled workforce, size & shape of the departments, distance between facilities, quality of production etc;

(2) Objective issues (These factors are defined in real quantitative terms) such as Investment cost, MH costs, Operating Costs, Improvement Costs etc. The basis for that can be found in (Tompkins and White, 1984). Also they introduced a method whereby the selection criteria regarding facilities were classified into 3 main categories: (1) Critical Factors, (2) Subjective Factors, (3) Objective Factors.

CONCLUSION

Operational performance or by managerial performance may not be the right choice for the warehouse manager. Thus, the proposed model was able to balance these approaches and provide a more significant overall performance.

This paper proposes a multi-criteria assignment approach to solve the storage location assignment problem (SLAP), in class-based storage (CBS) policy, to improve the warehouse operations, as well as inventory management. This model considers the ELECTRE III method, a well-known multi-criteria decision aiding (MCDA) method, to construct a medium-sized valued outranking relation, and a multi-objective evolutionary algorithm (MOEA) to exploit the outranking relation to derive a recommendation. The model compares the classes to define their allocation in the warehouse, and it finds a SLAP solution that can be used for inventory management, balancing the operational and tactical factors, allowing considering warehouse manager preferences, client requirements and stock keeping unit (SKU) characteristics simultaneously. The results of the simulated case showed the robustness of the proposed model for improving the order picking system performance.

The benefits from this FLD on the issues of Size and Shape of the Departments, Distance between Facilities, Quality of the Products manufactured, Lighting, Ventilation and Identification colours used outweigh the cost as it is evident from the ratings given by the experts.

If progress is to be made by obtaining opinions from experts, more than one person with different expertise should be interviewed. Otherwise, its reliability will be low due to its dependence on the opinion of experts.

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