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THE APPLICATION OF CRITIC-TOPSIS METHOD IN SOLVING THE MATERIAL HANDLING EQUIPMENT SELECTION PROBLEM

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ABSTRACT

Material handling equipment (MHE) is mechanical equipment required to transport materials or products between places. Selecting the best MHE is a crucial aspect of every industry due to a large amount of capital involved in the process. The idea behind Multi-Criteria Decision Making (MCDM) is it can address and deal with conflicting parts in the MHE selection process. The Criteria Importance Through Intercriteria Correlation (CRITIC) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods are proposed in this study to solve the MHE selection problem. This study aims to solve the MHE selection problem using the CRITIC-TOPSIS method. The CRITIC method is used to compute the criteria weights, while the TOPSIS method is applied to determine the ranking of MHE alternatives. Based on the findings, the ranking order for criteria is C = R > PR > AP > OSR > LCC > ETO = AV = AC > FIM > DIS. Meanwhile, the ranking order for the alternatives is Electric Pallet Truck > Hydraulic Pallet Truck > Hand Pallet Truck > Semi Electric Pallet Truck > Hydraulic Hand Pallet Truck. Of the five options of MHE, Electric Pallet Truck is the best option when using the CRITIC-TOPSIS method. In conclusion, the hybridization of the CRITIC-TOPSIS method is successfully used to solve the MHE selection problem.

Keywords: *CRITIC, MCDM, MHE Selection Problem, TOPSIS.*

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1. Introduction

Multi-Criteria Decision Making (MCDM) methods are widely used in various research applications to choose the best alternative when there are multiple criteria. This study proposed Criteria Importance through Intercriteria Correlation (CRITIC) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods. Diakoulaki *et al.* (1995) introduced the CRITIC method, one of the MCDM methods. CRITIC is a simple method that requires less computational effort. Analysis of correlations is used to determine the differences in criteria (Tuş & Aytaç Adalı, 2019). Meanwhile, TOPSIS is a method proposed by Hwang and Yoon (1981) to deal with complex real-world problems. The concept of the TOPSIS method is the best alternative chosen should simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Mitra & Kundu, 2018).

This study aims to identify and select the most appropriate material handling equipment (MHE), as inadequate and unsuitable MHE can lead to unprogressively work, inconvenience, and even fatal injuries to workers (Mitra *et al.*, 2015). MHE is mechanical equipment essential for every industry. Proper MHE selection is required to store, control, protect, and move products or materials at a greater speed through various manufacturing stages. Improper MHE selection can cause product loss and damaged material in the supply chain. This will likely affect the performance of your business. Thus, it is crucial to select the best MHE to ensure your business remains competitive. Therefore, the study proposed CRITIC and TOPSIS methods to solve the MHE selection problem. The CRITIC method aims to decide the criteria weights (Madic & Radovanovic, 2015), while the TOPSIS method's goal is to find the best optimal solution for a problem while focusing on some notable uniqueness of it. Nevertheless, the TOPSIS approach has a limitation since it does not account for the criteria weights (Tornyeviadzi *et al.*, 2021). Thus, to seek the best option, a combined decision-making method based on CRITIC and TOPSIS is used. This hybrid method is important because it considers a high level of uncertainty and increases the consistency of the evaluation process (Abdel-Basset & Mohamed, 2020).

To conclude, the hybridization of the CRITIC-TOPSIS method is proposed since this method is effective since holds the ability to analyze linguistic terms as well as multi-criteria data (Ighravwe & Babatunde, 2018).

2. Literature Review

The background theory and literature review of MCDM, the CRITIC, and the TOPSIS are discussed in this section.

2.1 Multi-Criteria Decision Making (MCDM)

MCDM methods have been used for several decades. MCDM is a method used to select the best alternative when multiple criteria are often in conflict (Velasquez & Hester, 2013). Generally, MCDM methods consist of five components which are the goal, a set of alternatives, the criteria, the decision-makers preference, and the result of judgment.

MCDM is categorized into two types which are Multi-Objective Decision Making (MODM) and Multi-Attribute Decision Making (MADM). MADM compromises the choice of the most effective alternatives from the feasible alternatives that are defined by numerous or conflicting criteria (Singh, 2014). This method is implemented to observe the efficient alternative among a finite number of alternatives. The MADM methods consist of Analytic Hierarchy Process (AHP), the TOPSIS, and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). For MODM, decision-makers got to obtain multiple objectives while these multiple objectives are non-commensurable and conflict with one another. The decision-makers must gather multiple objectives, optimize the objectives, and choose a solution (Daniel *et al.*, 2010). MODM methods consist of Goal Programming, Global Criteria Method, Weighting Method, and Parametric Method (Hwang & Masud, 1979). In addition, the MCDM method can also be hybridized with other methods to overcome the shortcomings of the method. For instance, AHP method is integrated with

Graph Theory Matrix Approach (GTMA) to solve the solid waste transhipment sites selection problem (Mior Abd Halim *et al.*, 2022).

2.2 Criteria Importance through Intercriteria Correlation (CRITIC)

CRITIC is introduced by Diakoulaki *et al.* (1995) to determine the objective weights of relative importance problems. It is a correlation method that assesses the information included in the parameters used to compare the alternatives using an analytical analysis of a decision matrix. The standard deviation of normalized criterion values by columns and the correlation coefficients of all pairs of columns are used to evaluate the criteria comparison (Madic & Radovanovic, 2015). The CRITIC method needs a few application steps but as a start, a set of *m* feasible alternatives, $A_i\,(i=1,2,3,...,m)$ and *n* evaluation criteria $C_j\,(j=1,2,3,...,n)$ need to be assumed in the problem (Madic & Radovanovic, 2015).

When using the CRITIC method, the criteria can be classified into objective weighting approaches and subjective weighting approaches (Xu *et al.*, 2020). Objective approaches are based on evaluating the weight of the criterion by applying data from the original decision matrix. While for subjective approaches, the decision maker provides their point of view on the significance of the criteria according to their preferences (Žižovic *et al.*, 2020). In this study, the data was obtained from a journal article by Satoglu and Türkekul (2021).

There are many reasons why the CRITIC method is advantageous. To begin with, the CRITIC method is a powerful technique to determine objective weights of criteria that organize both contradicting intensity of every criterion and conflict among criteria (Ghorabaee *et al.*, 2017). In addition, the CRITIC method is a popular tool for analyzing correlations between criteria and certain events (Xu *et al.*, 2020). Furthermore, CRITIC is a simple method that requires little computational effort and allows the decision-maker to express their opinion on the relative importance of the criteria (Diakoulaki *et al.*, 1995).

Table 1. The Application of CRITIC Method.

Author(s)	Title	Approach
Madic and Radovanovic, (2015)	Ranking of some most commonly used non-traditional machining processes using ROV and CRITIC methods	Combined Approach
Diakoulaki *et al.*, (1995)	Determining objective weights in multiple criteria problems: The CRITIC method.	Single Approach
Tuş and Aytaç Adalı, (2019)	The new combination with CRITIC and WASPAS methods for the time and attendance software selection problem	Combined Approach

Table 1 summarizes the previous literature on the CRITIC method in various decision-making problems. CRITIC method was used in solving MCDM problems such as selecting the most suitable Non-Traditional Machining Processes (NTMP) (Madic & Radovanovic, 2015), determining objective weights in situations with numerous criteria (Diakoulaki *et al.*, 1995), and selection of time and attendance software (Tuş & Aytaç Adalı, 2019).

However, when addressing MCDM problems, the CRITIC method has some drawbacks, such as the time required for the solution may be increased as the dimension of the matrix increases (Tuş & Adali, 2019). Furthermore, the CRITIC method does not convey the relative importance of meeting decision-makers objectives and it just displays some of the initial data's properties (Siksnelyte-Butkiene *et al.*, 2020).

2.3 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS is the MCDM method developed by Hwang and Yoon (1981). The concept of the TOPSIS method is the best alternative chosen should simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. This method can be used in dealing with and solving a complex real problem as it can provide the ranking for each alternative (Mitra & Kundu, 2018).

In the TOPSIS method, every score received by each of the alternatives from the evaluation criteria is used in the formation of a decision matrix. The positive ideal solution and negative ideal solution can be determined by taking into consideration all the criteria. TOPSIS method can help to rank the alternative based on the optimal ideal solutions. TOPSIS takes the relative closeness to the ideal solution into account when computing the distances to both the ideal and negative-ideal solutions (Hwang & Yoon, 1981).

The critical input to the TOPSIS method is the allocation of criteria weights. The criteria weight can be based on subjective, objective, or a combination of weighting methods. The subjective weights are determined by the level of preference of the decision-makers, whereas the objective weights are determined by the data of the decision-making matrix (Mohamadghasemi *et al.*, 2020). The positive ideal solution (PIS) increases the beneficial criteria while decreasing the non – beneficial criteria, whereas the negative ideal solution (NIS) increases the non – beneficial criteria while decreasing the beneficial criteria (Kelemenis & Askounis, 2010).

There are many benefits of using the TOPSIS method. The TOPSIS method is accepted in all problems because its methodology acknowledges the greatest and least situations between sets of alternatives in planning (Ighravwe & Babatunde, 2018). Besides, this method has been acknowledged as one of the most famous mathematical models to regulate the best solution of an MCDM (Slebi-Acevedo et. al, 2019). Other than that, TOPSIS provides the decision-maker with the closest option, which is deemed to be the better based on the score provided by the judgment (Marzouk & Sabbah, 2021).

Table 2. The Application of TOPSIS Method.

Author(s)	**Title**	**Approach**
Mitra and Kundu (2018)	Application of TOPSIS for best domestic refrigerator selection	Single Approach
Mohamed *et al.* (2018)	Evaluation of E-learning approaches using AHP-TOPSIS technique	Combined Approach
Kazan and Ozdemir (2014)	Financial performance assessment of large-scale conglomerates via TOPSIS and CRITIC methods	Combined Approach

Table 2 above summarize the past literature on the applications of the TOPSIS method in decision-making problem. TOPSIS method is used in solving MCDM problems such as choosing the best domestic refrigerator for middle-class families in India (Mitra & Kundu, 2018), evaluating the E-learning approach in public universities (Mohammed *et al.*, 2018), and assessing the financial performance of large-scale conglomerates (Kazan & Ozdemir, 2014).

There will be several drawbacks to the TOPSIS method. First, this method does not provide the weight of the criteria (Mohammed *et al.*, 2018). Besides that, TOPSIS has a critical flaw since it does not provide a feasible alternative (Marzouk & Sabbah. 2021). Other than that, the disadvantage of TOPSIS is a significant deviation from the ideal solution in one indicator has a significant effect on the outcomes and when only the indicators of alternatives do not differ significantly, the method is appropriate to use (Siksnelyte-Butkiene *et al.*, 2020).

To solve the MHE problem, this study will employ a hybridization of the CRITIC-TOPSIS method. It is possible to improve the CRITIC-TOPSIS method's decision-making results by utilizing hybridization methods.

3. Methodology

This section presents the mathematical formulations of the CRITIC -TOPSIS method which will be implemented to solve the MHE selection problem.

3.1 Conceptual Model

Figure 1 illustrates the conceptual diagram of the implementation of the CRITIC-TOPSIS method. The criteria weights are computed using the CRITIC method. The weights are further used as the input for the TOPSIS method to rank the MHE.

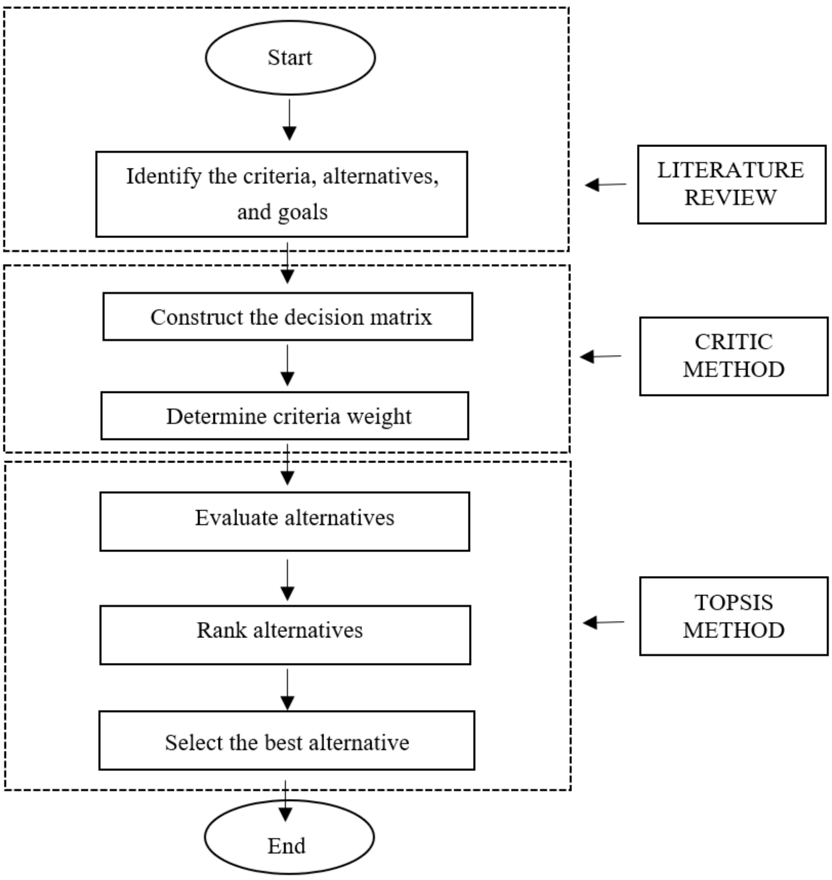

Figure 1. Conceptual Diagram.

3.2 Criteria Importance Through Intercriteria Correlation (CRITIC) Method Framework

The CRITIC method proposed by Diakoulaki *et al.* (1995) is used to determine objective weights for criteria. This method used correlation analysis to detect contrast among criteria (Yilmaz & Harmancioglu, 2010). The CRITIC method is based on decision matrix analytical testing for the purpose of finding out the information contained by criteria. The steps listed below show the procedure for determining the objective weights of criteria (Diakoulaki *et al.*, 1995, Isik & Adali, 2017):

Step 1: Develop the decision matrix, *X*.

The decision matrix is formed in this step by defining the set of *m* alternatives with respect to *n* criteria.

$$X = \left[X_{ij}\right]_{mxn} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \vdots & \vdots & \ddots & \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} ;\ (i = 1,2,...,m \text{ alternatives}, j = 1,2,...,n \text{ criteria}) \quad (1)$$

Step 2: Normalize the decision matrix.

The following equation can be used to normalize the decision matrix.

$$X^{*}_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \ ;\ (i = 1, 2, ..., m \text{ alternatives},\ j = 1,2,...,n \text{ criteria}) \quad (2)$$

where X^{*}_{ij} is the normalized performance value.

Step 3: Calculate the measure of the conflict.

Before calculating the measure of the conflict, the correlation between criteria must be calculated, to get the symmetric linear correlation matrix. Then, the measure of the conflict can be found using:

$$\sum_{k=1}^{n}(1 - r_{jk}) \ ;\ (j = 1, 2, ..., n \text{ criteria}, k = 1, 2, ..., n \text{ criteria}) \quad (3)$$

where r_{jk} is the correlation coefficient between the two criteria.

Step 4: Calculate the objective weight of the criteria, W_j.

To calculate the objective weight, W_j, the standard deviation of the criterion, σ_j must be computed, as well as the amount of information contained in *jth* criteria, C_j is needed. A higher value of C_j shows a greater amount of information in a criterion, so it will give a higher weight value. Below is the formula to compute the objective weight, W_j and the quantity of information, C_j.

$$C_j = \sigma_j \sum_{k=1}^{n} (1 - r_{jk}) \; ; (j = 1, 2, \ldots, n \text{ criteria}, k = 1, 2, \ldots, n \text{ criteria}) \quad (4)$$

$$W_j = \frac{C_j}{\sum_{j=1}^{n} C_j} \; ; (j = 1, 2, \ldots, n \text{ criteria}) \quad (5)$$

3.3 Technique for Order Preference by Similarity To Ideal Solution (TOPSIS) Method Framework

TOPSIS method is introduced by Hwang and Yoon (1981) and is one of the ways of making decisions. It is a goal-oriented method for identifying the option that is the most similar to the ideal solution. In general, when comparing the similarity of a design or option to the ideal and non-ideal levels, the distance between the design and the ideal and non-ideal solutions needs to be considered (Bhutia & Phipon, 2012). The steps of TOPSIS are listed below (Monjezi *et al.*, 2012):

Step 1: Construct a decision matrix, *D*.

The decision matrix $D = (x_{ij})_{m \times n}$ consists of *m* alternatives and *n* attributes. The equation below shows examples of the decision matrix.

$$D = \begin{matrix} & \begin{matrix} x_1 & x_2 & \cdots & x_n \end{matrix} \\ \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ \vdots & \vdots & & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \end{matrix} \; ; (i = 1, 2, \ldots, m \text{ alternatives}, j = 1, 2, \ldots, n \text{ criteria}) \quad (6)$$

Step 2: Normalized the decision matrix.
The normalization can be done by using the formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij^2}}} \; ; (i = 1, 2, \ldots, m \text{ alternatives}, j = 1, 2, \ldots, n \text{ criteria}) \quad (7)$$

Step 3: Compute the weighted normalized decision matrix, *V*.

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \cdots & v_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ v_{i1} & v_{i2} & & v_{ij} & & v_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_j r_{ij} & \cdots & w_n r_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ w_1 r_{i1} & w_2 r_{i2} & & w_j r_{ij} & & w_n r_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_j r_{mj} & \cdots & w_n r_{mn} \end{bmatrix} ; \quad (8)$$

$(i = 1, 2, \ldots, m \text{ alternatives}, j = 1, 2, \ldots, n \text{ criteria})$

Step 4: Determine the negative ideal solution, A^- and positive ideal solution, A^+.

$$\begin{aligned} A^+ &= \left\{ \begin{array}{l} \left(\max_i V_{ij} \mid j \in J\right), \left(\min_i V_{ij} \mid j \in J'\right),\ i = 1,2,...,m \text{ alternatives}, \\ j = 1,2,...,n \text{ criteria} \end{array} \right\} \\ &= \{V_1^+, V_2^+, \ldots, V_j^+, \ldots, V_n^+\} \\ A^- &= \left\{ \begin{array}{l} \left(\min_i V_{ij} \mid j \in J\right), \left(\max_i V_{ij} \mid j \in J'\right),\ i = 1,2,...,m \text{ alternatives}, \\ j = 1,2,...,n \text{ criteria} \end{array} \right\} \\ &= \{V_1^-, V_2^-, \ldots, V_j^-, \ldots, V_n^-\} \end{aligned} \tag{9}$$

where $J = \{ j = 1,2,...,n \mid j \text{ associated with beneficial criteria} \}$

$J' = \{ j = 1,2,...,n \mid j \text{ associated with non-beneficial criteria} \}$

Step 5: Calculate the separation measures by using *n*-dimensional Euclidean distance.
The separation for each alternative from the positive ideal solution is given as follows:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \;;\ (i = 1,2,...,m \text{ alternatives}, j = 1,2,...,n \text{ criteria}) \tag{10}$$

Therefore, the separation from the negative ideal solution is:

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \;;\ (i = 1,2,...,m \text{ alternatives}, j = 1,2,...,n \text{ criteria}) \tag{11}$$

Step 6: Compute the relative closeness to the ideal solution, CC_i.
To determine the relative closeness to the ideal solution, the relative closeness of the alternative A_i is defined as follows (Hwang & Yoon, 1981):

$$\begin{aligned} &CC_i = \frac{S_i^-}{\left(S_i^+ + S_i^-\right)}, 0 < CC_i < 1 \quad (i = 1,2,...,m \text{ alternatives}, j = 1,2,...,n \text{ criteria}) \\ &CC_i = 1 \quad if \quad A_i = A^+ \\ &CC_i = 0 \quad if \quad A_i = A^- \\ &\text{As } S_i^- \geq 0 \text{ and } S_i^+ \geq 0, \text{ so } CC_i \in [0,1]. \end{aligned} \tag{12}$$

Step 7: Rank the preference order.
The ranking is determined by the CC_i values. The higher the relative closeness value to ideal solution, the higher the rank, and thus the greater the alternative's results. The greatest alternative is the one that is closest to the positive ideal solution.

3.4 The Implementation of CRITIC-TOPSIS Method

Real-life data on MHE (Satoglu & Türkekul, 2021) is used in this study to select the best MHE. There were eleven criteria and five alternatives in this study. The criteria were ease to operate (ETO), application (AP), load-carrying capacity (LCC), power required (PR), flexibility in material (FIM), cost (C), availability of spare parts (AV), on-site repair (OSR), area constraints (AC), risk (R), and distance to be moved (DIS) while the alternatives were hand pallet truck (HPT), hydraulic hand pallet truck (HHPT), hydraulic pallet truck (HYPT), electric pallet truck (EPT), and semi electric pallet truck (SEPT). ETO, AP, LCC, FIM, AV, OSR, AC, and DIS are beneficial criteria while PR, C, and R are non-beneficial criteria. Three decision makers conducted a focus group discussion to determine the criteria, alternatives, a pairwise comparison matrix of criteria, and rating of the selected MHE.

3.4.1 CRITIC Method

In this study, the CRITIC method is used to determine the criteria weights. Below shows the implementation of the CRITIC method in selecting the MHE (Satoglu & Türkekul, 2021).

Step 1: Develop the decision matrix.

The decision matrix consists of 5 alternatives (Alt) with respect to the 11 criteria (Cri) defined. ETO, AP, LCC, FIM, AV, OSR, AC, and DIS are beneficial criteria, while PR, C, and R are non-beneficial criteria. Table 3 below shows the decision matrix for the MHE selection problem.

Table 3. Decision Matrix for Selection of Material Handling Equipment (MHE).

Cri / Alt	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
HPT	4	3	4	5	5	5	5	3	5	5	5
HHPT	2	3	3	3	3	3	3	3	3	3	3
HYPT	2	3	4	3	4	3	3	3	3	3	4
EPT	2	3	3	4	3	3	3	5	3	3	4
SEPT	2	4	3	3	3	3	3	3	3	3	3
Maximum	4	4	4	3	5	3	5	5	5	3	5
Minimum	2	3	3	5	3	5	3	3	3	5	3

Step 2: Normalize the decision matrix.

Equation (2) is used to normalize the decision matrix. Table 4 below shows the normalized decision matrix.

Table 4. Normalized Decision Matrix.

Cri / Alt	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
HPT	1	0	1	0	1	0	1	0	1	0	1
HHPT	0	0	0	1	0	1	0	0	0	1	0
HYPT	0	0	1	1	0.5	1	0	0	0	1	0.5
EPT	0	0	0	0.5	0	1	0	1	0	1	0.5
SEPT	0	1	0	1	0	1	0	0	0	1	0
Maximum	4	4	4	3	5	3	5	5	5	3	5
Minimum	2	3	3	5	3	5	3	3	3	5	3

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Step 3: Calculate the measure of the conflict.

Table 5 below shows the symmetric linear correlation matrix analyzed using Microsoft Excel. To obtain a measure of the conflict, the symmetric linear correlation matrix must be calculated first, and Equation 3 is used to obtain the measure of the conflict.

Table 5. Correlation Coefficient Values of Paired Criteria.

Cri	**ETO**	**AP**	**LCC**	**PR**	**FIM**	**C**	**AV**	**OSR**	**AC**	**R**	**DIS**	**Measure of the conflict**
ETO	1	-0.2500	0.6124	-0.8750	0.8750	-1.0000	1.0000	-0.2500	1.0000	-1.0000	0.8018	9.0858
AP	-0.2500	1	-0.4082	0.3750	-0.3750	0.2500	-0.2500	-0.2500	-0.2500	0.2500	-0.5345	11.4428
LCC	0.6124	-0.4082	1	-0.4082	0.9186	-0.6124	0.6124	-0.4082	0.6124	-0.6124	0.7638	8.9301
PR	-0.8750	0.3750	-0.4082	1	-0.6875	0.8750	-0.8750	-0.2500	-0.8750	0.8750	-0.8686	12.7143
FIM	0.8750	-0.3750	0.9186	-0.6875	1	-0.8750	0.8750	-0.3750	0.8750	-0.8750	0.8686	8.7753
C	-1.0000	0.2500	-0.6124	0.8750	-0.8750	1	-1.0000	0.2500	-1.0000	1.0000	-0.8018	12.9142
AV	1.0000	-0.2500	0.6124	-0.8750	0.8750	-1.0000	1	-0.2500	1.0000	-1.0000	0.8018	9.0858
OSR	-0.2500	-0.2500	-0.4082	-0.2500	-0.3750	0.2500	-0.2500	1	-0.2500	0.2500	0.1336	11.3996
AC	1.0000	-0.2500	0.6124	-0.8750	0.8750	-1.0000	1.0000	-0.2500	1	-1.0000	0.8018	9.0858
R	-1.0000	0.2500	-0.6124	0.8750	-0.8750	1.0000	-1.0000	0.2500	-1.0000	1	-0.8018	12.9142
DIS	0.8018	-0.5345	0.7638	-0.8686	0.8686	-0.8018	0.8018	0.1336	0.8018	-0.8018	1	8.8353

Step 4: Calculate the objective weight of criteria, W_j.

Table 6 shows the normalized decision matrix with standard deviation, σ_j. The standard deviation is calculated using Microsoft Excel.

Table 6. Normalized Decision Matrix with Standard Deviation.

Cri / Alt	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
HPT	1	0	1	0	1	0	1	0	1	0	1
HHPT	0	0	0	1	0	1	0	0	0	1	0
HYPT	0	0	1	1	0.5	1	0	0	0	1	0.5
EPT	0	0	0	0.5	0	1	0	1	0	1	0.5
SEPT	0	1	0	1	0	1	0	0	0	1	0
Standard deviation, σ_j	0.4472	0.4472	0.5477	0.4472	0.4472	0.4472	0.4472	0.4472	0.4472	0.4472	0.4183

Table 7 below shows the quantity of information contained in jth criteria, C_j that is computed using Equation (4) and the criteria weight, W_j using Equation (5).

Table 7. Weights of the Selection Criteria.

Criteria	C_j	W_j	Ranking
ETO	4.0632	0.0779	7
AP	5.1172	0.0981	4
LCC	4.8910	0.0938	6
PR	5.6858	0.1090	3
FIM	3.9243	0.0752	10
C	5.7752	0.1107	1
AV	4.0632	0.0779	7
OSR	5.0979	0.0978	5
AC	4.0632	0.0779	7
R	5.7752	0.1107	1
DIS	3.6958	0.0709	11

The findings show that the ranking order for criteria is C = R > PR > AP > OSR > LCC > ETO = AV = AC > FIM > DIS. The most preferred criterion is cost (C), and the least preferred criterion is the distance to be moved (DIS).

3.4.2 CRITIC-TOPSIS Method

The weights for criteria obtained from the CRITIC method are further used as the input in the TOPSIS method. The ranking for MHE will be determined by using the CRITIC-TOPSIS method. The procedures below show the implementation of the CRITIC-TOPSIS method.

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Step 1: Construct a decision matrix.

Table 8 below shows the decision matrix.

Table 8. Decision Matrix.

Cri / Alt	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
Weight	0.0779	0.0981	0.0938	0.109	0.0752	0.1107	0.0779	0.0978	0.0779	0.1107	0.0709
HPT	4	3	4	5	5	5	5	3	5	5	5
HHPT	2	3	3	3	3	3	3	3	3	3	3
HYPT	2	3	4	3	4	3	3	3	3	3	4
EPT	2	3	3	4	3	3	3	5	3	3	4
SEPT	2	4	3	3	3	3	3	3	3	3	3

Step 2: Normalize the decision matrix.

Table 9 shows the normalized decision matrix. The normalized decision matrix is constructed using Equation (7).

Table 9. Normalized Decision Matrix.

Cri / Alt	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
Weight	0.0779	0.0981	0.0938	0.109	0.0752	0.1107	0.0779	0.0978	0.0779	0.1107	0.0709
HPT	0.7071	0.4160	0.5208	0.6063	0.6063	0.6402	0.6402	0.3841	0.6402	0.6402	0.5774
HHPT	0.3536	0.4160	0.3906	0.3638	0.3638	0.3841	0.3841	0.3841	0.3841	0.3841	0.3464
HYPT	0.3536	0.4160	0.5208	0.3638	0.4851	0.3841	0.3841	0.3841	0.3841	0.3841	0.4619
EPT	0.3536	0.4160	0.3906	0.4851	0.3638	0.3841	0.3841	0.6402	0.3841	0.3841	0.4619
SEPT	0.3536	0.5547	0.3906	0.3638	0.3638	0.3841	0.3841	0.3841	0.3841	0.3841	0.3464

Step 3: Compute the weighted normalized decision matrix.

The weighted normalized decision matrix is given in Table 10 below. The weighted normalized decision matrix is constructed using Equation (8).

Table 10. Weighted Normalized Decision Matrix.

Cri / Alt	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
Weight	0.0779	0.0981	0.0938	0.109	0.0752	0.1107	0.0779	0.0978	0.0779	0.1107	0.0709
HPT	0.0551	0.0408	0.0488	0.0661	0.0456	0.0709	0.0499	0.0376	0.0499	0.0709	0.0409
HHPT	0.0275	0.0408	0.0366	0.0397	0.0274	0.0425	0.0299	0.0376	0.0299	0.0425	0.0246
HYPT	0.0275	0.0408	0.0488	0.0397	0.0365	0.0425	0.0299	0.0376	0.0299	0.0425	0.0327
EPT	0.0275	0.0408	0.0366	0.0529	0.0274	0.0425	0.0299	0.0626	0.0299	0.0425	0.0327
SEPT	0.0275	0.0544	0.0366	0.0397	0.0274	0.0425	0.0299	0.0376	0.0299	0.0425	0.0246

Step 4: Determine the negative ideal solution, A^- and positive ideal solution, A^+.

Table 11 indicates the negative ideal solution, A^- and positive ideal solution, A^+ computed using Equation (9).

Table 11. Negative and Positive Ideal Solution.

Cri / A^+ / A^-	ETO	AP	LCC	PR	FIM	C	AV	OSR	AC	R	DIS
A^+	0.0551	0.0544	0.0488	0.0397	0.0456	0.0425	0.0499	0.0626	0.0499	0.0425	0.0409
A^-	0.0275	0.0408	0.0366	0.0529	0.0274	0.0709	0.0299	0.0376	0.0299	0.0709	0.0246

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Step 5: Calculate the separation measures by using n-dimensional Euclidean distance.

Table 12 below shows the separation measure for each MHE alternative. The separation measure is computed using Equations (10) and (11) for positive and negative ideal solutions respectively.

Table 12. Separation Measure for each MHE alternatives.

Alt / S^+ / S^-	HPT	HHPT	HYPT	EPT	SEPT
S^+	0.0558	0.0558	0.0502	0.0496	0.0541
S^-	0.0498	0.0423	0.0457	0.0480	0.0444

Step 6: Compute the relative closeness to the ideal solution, CC_i.

Table 13 shows the relative closeness coefficient to the ideal solution, CC_i . The relative closeness coefficient, CC_i is computed using Equation (12).

Table 13. Relative Closeness Coefficient, CC_i .

Alt / CC_i	HPT	HHPT	HYPT	EPT	SEPT
CC_i	0.4716	0.4312	0.4765	0.4918	0.4508

Step 7: Rank the preference order.

Table 14 below, shows the ranking for each alternative based on the performance score.

Table 14. MHE Ranking.

Alternatives	CC_i	**Ranking**
Hand Pallet Truck (HPT)	0.4716	3
Hydraulic Hand Pallet Truck (HHPT)	0.4312	5
Hydraulic Pallet Truck (HYPT)	0.4765	2
Electric Pallet Truck (EPT)	0.4918	1
Semi Electric Pallet Truck (SEPT)	0.4508	4

The ranking order for alternatives is Electric Pallet Truck > Hydraulic Pallet Truck > Hand Pallet Truck > Semi Electric Pallet Truck > Hydraulic Hand Pallet Truck. The most preferred MHE is Electric Pallet Truck and the least preferred MHE is Hydraulic Hand Pallet Truck.

4. Results and Discussion

In this study, empirical data about the selection of MHE (Satoglu & Türkekul, 2021) is used to demonstrate the application of the CRITIC – TOPSIS method. The CRITIC method is used to obtain the criteria weight, while the TOPSIS method is used to rank the alternatives.

4.1 Weights and Rank of the Criteria

In this section, the criteria weights obtained using the CRITIC method along with the criteria weights obtained by Satoglu and Türkekul, (2021) and the ranking for the criteria will be analyzed. Figure 2 shows the criteria weights produced using the CRITIC method, while

Table 15 shows the ranking and the criteria weights produced by the CRITIC method in addition to the ranking and the criteria weights from Satoglu and Türkekul, (2021).

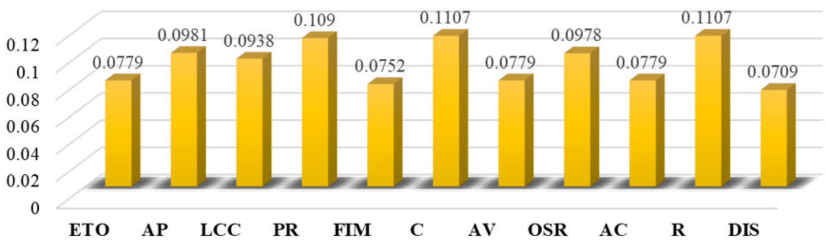

Figure 2. Criteria Weights.

Table 15. Criteria Ranking.

Criteria	CRITIC method		Criteria	AHP method (Satoglu & Türkekul, 2021)	
	Criteria weights	Rank		Criteria weights	Rank
C	0.1107	1	C	0.272	1
ETO	0.0779	7	ETO	0.200	2
R	0.1107	1	R	0.137	3
AP	0.0981	4	AP	0.095	4
LCC	0.0938	6	LCC	0.082	5
PR	0.1090	3	PR	0.053	6
FIM	0.0752	10	FIM	0.033	8
AV	0.0779	7	AV	0.032	10
OSR	0.0978	5	OSR	0.039	7
AC	0.0779	7	AC	0.032	9
DIS	0.0709	11	DIS	0.026	11

Satoglu and Türkekul (2021) calculated the weights of criteria using the AHP method. Table 15 displays the ranking of the criteria weights based on the preference of the decision-makers. The ranking order of the criteria is C > ETO > R > AP > LCC >PR > OSR > FIM >AC >AV > DIS. Cost (C) had been selected as the best criterion in the study (Satoglu & Türkekul, 2021). When the CRITIC method is used, the result also shows that Cost (C) is the most preferred criterion. The ranking order of the criteria is C = R > PR > AP > OSR > LCC > ETO = AV = AC > FIM > DIS. As a result of using the CRITIC method, Cost (C) is chosen as the most preferred criterion while the least preferred criterion is Distance to be moved (DIS). The Cost criterion was chosen as the most preferred criterion because the equipment maintenance procedure needs a lot of money, and the equipment is expensive (Satoglu & Türkekul, 2021).

4.2 Weights and Rank of the Alternatives

In this section, the ranking of MHE based on the CRITIC-TOPSIS method and the ranking obtained from an article by Satoglu and Türkekul, (2021) will be discussed. Figure 3 below indicates the weights of the material handling equipment.

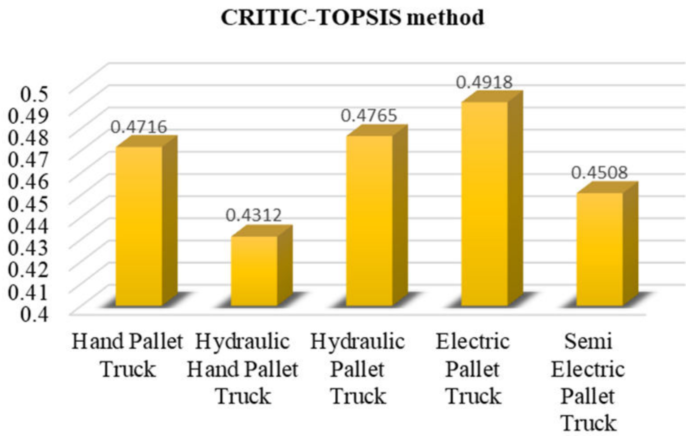

Figure 3. Weights of MHE.

The ranking of the alternatives is determined by the value of the relative closeness to the ideal solution, CC_i. The best alternative is the one that is closest to the positive ideal solution while being the furthest away from the negative ideal solution (Monjezi *et al.*, 2012). Table 16 shows the ranking of MHE using the CRITIC-TOPSIS method as well as the ranking from an article by Satoglu and Türkekul, (2021).

Table 16. The Ranking of MHE.

Alternatives	CRITIC – TOPSIS method		AHP-MOORA method (Satoglu & Türkekul, 2021)
	CC_i	Ranking	
Hand Pallet Truck, (HPT)	0.4716	3	1
Hydraulic Hand Pallet Truck, (HHPT)	0.4312	5	4
Hydraulic Pallet Truck, (HYPT)	0.4765	2	2
Electric Pallet Truck, (EPT)	0.4918	1	5
Semi Electric Pallet Truck, (SEPT)	0.4508	4	3

In this study, the CRITIC-TOPSIS method is used to solve the MHE selection problem, while Satoglu and Türkekul (2021) applied the AHP-MOORA method in their research. Table 16 shows the ranking of MHE using the CRITIC-TOPSIS method, and the ranking from Satoglu and Türkekul, (2021) is different. Based on the CRITIC – TOPSIS method, the findings show that the ranking order for alternatives is Electric Pallet Truck > Hydraulic Pallet Truck > Hand Pallet Truck > Semi Electric Pallet Truck > Hydraulic Hand Pallet Truck. The outcome revealed that Electric Pallet Truck is the most preferred MHE, and Hydraulic Hand Pallet Truck is the least preferred MHE. According to Satoglu and Türkekul (2021), the chosen MHE is a Hand Pallet Truck, while the Electric Pallet Truck is not recommended. The ranking order for the alternatives may be different since the AHP method used the comparative judgment of the decision maker to build a pairwise comparison matrix (Jadhav & Sonar, 2009), while the CRITIC method gains information from a decision matrix to determine the importance of criteria (Babatunde & Ighravwe, 2019).

5. Conclusions and Recommendations

MHE is an important equipment in every industry that requires materials to be stored or transported between places. Selecting the best MHE is crucial, as the development and production of the industry can become faster and more secure. Improper selection of MHE will lead to unprogressively work and may affect the business since it can reduce the productivity of your business. In this study, the objective is to solve the MHE selection problem by using the CRITIC-TOPSIS method. The findings revealed that the best alternative is Electric Pallet Truck.

In conclusion, the CRITIC-TOPSIS method can be used to solve MCDM problems because this hybrid method considers a high level of uncertainty and increases the consistency of the evaluation process (Abdel-Basset & Mohamed, 2020). However, it is recommended to apply the Distance Correlation-based CRITIC (D-CRITIC) method with the TOPSIS method since it could produce more valid criteria weights and ranks. That is because the D-CRITIC method yielded a higher average distance correlation, a higher average Spearman rank-order correlation, and a lower symmetric mean absolute percentage error (Žižovic *et al.*, 2020).

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Author Contribution

Author1 prepared a part of the literature review for the CRITIC and TOPSIS methods, designed the conceptual diagram, wrote the research methodology for the CRITIC method, implemented the CRITIC method, and interpreted the result by ranking the criteria. Author2 created the abstract, prepared the literature review for Multi-Criteria Decision Making and TOPSIS method, wrote the research methodology for the TOPSIS method, implemented the hybridization of the CRITIC-TOPSIS method, and provided conclusions and recommendations for the article. Author3 did the introduction, prepared a part of the literature review for the CRITIC method, interpreted the results by ranking the alternatives, and wrote the acknowledgment. Author4 prepared a part of the literature review, wrote, and checked the methodology, and oversaw the article writing.

Conflict of Interest

The authors have no conflicts of interest to declare.

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