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Decision Support for Material Handling Equipment Selection Using a Grey-TOPSIS Multi-Criteria Evaluation Model under Qualitative Indices

Dr. M. Prabhu[1], Dr. Saleem Basha[2,*], Dr. Abebe Ejigu Alemu[1], Dr. D. Cokilavany[3]

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ABSTRACT

The main objective of this research is to select an admirable Material Handling Equipment based on gleaned subjective properties. The researchers built a multi-index MHE evaluation module by connecting the general and momentous properties of material handling, which are in vogue in industrial and manufacturing firms and are driving the MHE selection arena. The present study pivots towards developing a competent approach that offers an efficient decision-support framework for managers of industrial and manufacturing firms to evaluate and benchmark the noteworthy MHE amongst available alternatives, operationalised through a built-analogous module. The Grey-TOPSIS approach, which is principally developed by fusing Grey Set Theory and the TOPSIS technique, is employed in this study to develop a conceptual framework for material handling equipment based on qualitative indices. The present study provided a platform that effectively grasped the experts' lingo and offered chains of subjective properties for evaluating MHEs. The presented approach is built on a multi-index MHE platform, making it easily adopted by firms that prefer an evaluated Material Handling System over their preferred indices. The application of grey set theory is presented in the technical domain of MHE, and the TOPSIS technique is used in this study. It is found that MHE encompasses certain input characteristics that, in turn, contribute to pollution and declining ecological performance; thus, the present study selects an admirable MHE alternative that can efficiently capture inputs that reproduce ecological performance as output. Firms can easily implement the proposed DSF because it is presented as a set of subjective MHE indices and can be technically applied in other decision-making fields that consider subjectivity.

1. Introduction.

Material Handling Equipment (MHE) are needed for scheduling manufacturing actions, satisfying warehousing requirements, meeting customer demands, meeting fabrication requirements, fulfilling assembly component requirements, etc. The commercial objective of increasing revenue can be achieved by selecting noteworthy Material Handling Equipment for industrial and manufacturing firms. MHEs are required in industrial and manufacturing plants to hold and transfer inventories in the form of loose or bulk inventories, from the indicated origin to their intended destination. Material handling can account for 30–75% of the total cost, and by developing a proficient material handling system, firms' operating costs can be reduced by 15–30% (Kulak, 2005). MHEs are used in numerous activities, e.g., dumping materials, storing inventory, and transferring materials in various ways across different manufacturing operations. MHEs are mechanical arms, which are exploited to transmit numerous varieties of raw materials, semi-finished products, and finished goods from one point to another. They are usually used for travelling within in-house or outdoor spaces within the plant

[1]Department of Logistics Management, International Maritime College Oman, National University of Science and Technology, Sohar, Sultanate of Oman.

[2]RIEU, University of Buraimi, Al Buraimi, Sultanate of Oman.

[3]Department of Mathematics, CEG, Anna University, Chennai 600025, Tamil Nadu, India.

*Corresponding author: Dr. Saleem Basha. E-mail Address: saleem.b@uob.edu.om.

or warehouse (Ataeepour and Baafi, 1999; Castillo and Peters, 2002; Furmans, 2015). They support numerous manufacturing activities, including changing the size, form, and shape of materials, as well as fabrication and assembly processes in the manufacturing plant. These mechanical arms emit smoke and gases that contribute to environmental pollution and pose a danger to society. Selecting appropriate MHE by measuring performance indices can help reduce environmental pollution and inform the development of ecological indices for MHE alternatives. Chakraborty and Banik (2006) defined chains of material-handling equipment indices and applied the Analytic Hierarchy Process (AHP) to determine the practical MHE based on their defined indices.

The firm can use this study to enhance environmental performance by adopting eco-friendly MHE criteria and alternatives in place of the proposed DSF. In this study, the general and momentous MHE properties are identified to develop a practical MHE appraisal module and to outline a logical approach to evaluating the performance of MHE alternatives. Egbelu and Tanchoco (1984) defined an Automatic Guided Vehicle (AGV) as material-handling equipment and categorised it as an Automatic Material Handling System (AMHS). They found that automated guided vehicles can be used effectively to transport goods over discrete distances. They studied the responses of AGVs in a job-shop manufacturing environment to assess their potential power. Sahu et al. (2017) highlighted the criteria for MHEs, considering fiscal and ecological aspects, and drafted an appraisal platform to select appropriate material-handling equipment. They appraised the arena of MHE and supplied some universal MCDM techniques that can be used to choose MHEs for a particular application.

Nguyen et al. (2016) modelled Multi-Criteria Decision Making (MCDM) podiums using fuzzy AHP and fuzzy ARAS (Additive Ratio Assessment) techniques to evaluate a conveyor system for material transfer. They identified factors related to ergonomics and restructuring ability and assessed their importance in the decision-making process for evaluating the conveyors' material-handling system. They found that a conveyor system can improve the performance of flexible manufacturing cells (FMCs) and defined sets of qualitative and quantitative criteria for evaluating potential MHE substitutes. Karande and Chakraborty (2013) developed a functional platform based on MCDM techniques to appraise the MH system. They adopted the companies' experts' advice for identifying the quantitative and qualitative standards for MHEs. They identified load capacity, reliability, energy consumption, cost, etc., as quantitative standards, while environmental hazard, environmental performance, safety, load, shape, type, etc. as qualitative standards, which are needed to fabricate a functional DSF about MHEs. Karande and Chakraborty (2013) applied the weighted-utility additive approach to the aforesaid standards to address decision-making problems about MHEs. Onut et al. (2009) suggested using fuzzy logic to resolve the MHE evaluation problem.

Mohsen and Hassan (2010) conducted a literature review to highlight the economic and green aspects of satisfying an MHE skeleton. They suggested developing the decision-maker's capabilities to approve the paramount MHE. Chan (2002) developed an intelligent material handling equipment selection system, i.e., a knowledge-based expert system called MHESA (Material Handling Equipment Selection Advisor), for selecting and configuring a material handling system. He used the AHP technique to determine the most favourable MHE. Tuzkaya et al. (2010) employed the fuzzy ANP (F-ANP) method to determine the weightings of the selection criteria for MHEs.

Additionally, they employed the fuzzy-PROMETHEE (F-PROMETHEE) method to evaluate MHE substitutes for a manufacturing company. In many manufacturing firms, robots are referred to as MHEs because they can transfer materials from one location to another. Datta et al. (2013) identified fiscal and environmental measures and presented a robust MCDM framework for benchmarking industrial robots. They highlighted the use of the MULTI - MOORA (Multi-Objective Optimisation by Ratio Analysis) technique. They implemented MULTI - MOORA within their built MCDM platform to identify the most suitable industrial Robot (MHE).

Additionally, Sahu et al. (2018c) presented an approach based on a fuzzy weighted geometric aggregation operator to appraise industrial robots (MHE). Sen et al. (2016) demonstrated the utility of PROMETHEE (preference ranking organisation method for enrichment evaluations) for solving robot selection problems, using both objective and subjective evaluation data.

Hadi-Vencheh and Mohamadghasemi (2014) defined fuzzy weights for MHE criteria based on opinion grades: very low, low, moderate, high, and very high importance. They applied the VIKOR technique to select the most favourable MHE substitute. Maniya and Bhatt (2011) employed AHP to identify the relative importance of elected measures for evaluating Automatic Guided Vehicles (AGVs) and to determine their relative significance. They discuss an Extended-Grey Relational Analysis (E-GRA) methodology to classify the noteworthy AGV alternatives. Deb et al. (2002) used fuzzy theory to model the performance of MHEs. They assembled an MCDM framework, along with fiscal and green measures, to assess the performance of material-handling equipment. Fuzzy theory is implicated in their work to define the appropriateness ratings assigned by decision makers.

Additionally, a literature review is conducted within the framework of grey set theory to assist in identifying and devising a comprehensive DSF that accommodates the inconsistent information provided by experts regarding indices. In this study, the authors have effectively applied grey set theory to reduce incomplete information provided by decision experts efficiently. The concept of grey theory is employed in this work to approximate probabilistic thinking, as it provides a probabilistic view of the system, which helps explore and derive necessary outcomes. Liu et al. (2014) and Wua and Liu (2009) explained the operational view of applying grey set theory to a system under vagueness and incomplete information. Sahu et al. (2012) extended the application of grey set theory in decision-making. They devised the grey-TOPSIS & Grey-COPRAS approaches, which they concurrently applied to address the supplier selection problem. The concepts of grey numbers are exploited in their work to develop decision models for green supply chain management. Liu et al. (2015a) employed grey theory to develop an appraisal index for defining supplier performance at the Commercial Aircraft Corporation of China Ltd (COMAC). They applied grey theory at the production and development stages and developed a grey cluster evaluation model to estimate the performance of five significant related vendors broadly.

Liu et al. (2015b) proposed a grey Verhulst model to improve the system's prediction accuracy, developed based on its existing characteristics. Hashemi et al. (2015) applied the grey relational analysis method, along with the Analytic Hierarchy Process (AHP), in a case study of the automotive industry to evaluate decision criteria for supplier selection. Sahu et al. (2014) employed grey concepts to develop an MCDM framework for benchmarking computerized numerical control machine tools. They represent the procedural steps for implicating their proposed study through a numerical case based on grey numbers. Guo (2007) modelled stopping times using grey differential equations and developed a methodical grey equation system for imperfectly repaired systems. Li et al. (2015) applied grey concepts and an improved grey clustering technique to develop a logical grey system theory for characterizing the system. Sahu et al. (2018a) amalgamated grey sets theory with the DEMATEL (Decision-Making Trial and Evaluation Laboratory) technique and extended its application by developing a Grey-DEMATEL approach to identify the significant enablers responsible for producing electronic waste through the replacement of working mobile phones. Luo et al. (2015) extended the applicability of grey theory and developed the theory of grey analysis to address the practical challenges encountered across numerous application fields. Guo and Guo (2009) extended the application of grey theory and provided an appropriate mathematical foundation for grey concepts by projecting grey modelling onto fuzzy credibility measure theory. Sahu et al. (2018b) applied a grey-based scorecard model to the chains of macro-micro parameters and their hierarchical structure to describe the performance and extent of fruit supply bazaars (FSBs). Wang et al. (2016) found that grey theory possesses strong capabilities to reduce uncertainty and inconsistency in the collected information.

The authors also reviewed the literature on TOPSIS techniques for devising a momentous DSF. James and Chen (2015) extended the application of the TOPSIS methodology and merged it with AHP to deliver an index-based approach for evaluating green suppliers. They presented a two-step procedure in which AHP is used in the first step to shape priority importance, and TOPSIS is used in the second step to decode supplier rankings. Sahu et al. (2016) employed a modified TOPSIS method with interval-valued fuzzy numbers to assess the importance of the TOPSIS methodology in selecting the most appropriate supplier firm with agile attributes. Mandic et al. (2015) presented the application of the TOPSIS technique by connecting it with fuzzy logic and interpolative Boolean algebra. They investigated whether decision makers can successfully incorporate their reasons into multi-attribute decision-making problems using interpolative Boolean algebra. The case of telecommunications equipment, which has numerous attributes, is solved by them to demonstrate the effectiveness of their work. Kannan et al. (2014) presented the application of the TOPSIS method to the decision-making process in supplier selection. They present a fuzzy-based methodology that integrates TOPSIS techniques to enhance decision-making for a Brazilian electronics company. They grouped the green measures from 12 existing suppliers to propose applying the Fuzzy-TOPSIS approach to decision - making. Zeng and Xiao (2016) amalgamated the TOPSIS technique with intuitionistic fuzzy sets to sort out the multiple-criteria decision-making dilemmas and presented the application case of the investment selection to demonstrate the applicability of their proposed approach. Matawale et al. (2016) verified the Fuzzy-MOORA and Fuzzy-TOPSIS schemes for selecting worthy suppliers by manufacturing firms. They illustrated the sequence of technical steps required to execute the Fuzzy-TOPSIS and Fuzzy-MOORA methods in an empirical case study. Metaxas et al. (2016) and Prabhu et al. (2020) combined the TOPSIS and AHP techniques with Fuzzy logic to evaluate performance. As a result, the authors found that the TOPSIS method produces robust results, and grey set theory can efficiently handle incomplete information. Thus, in the present work, the authors developed a DSF by integrating TOPSIS with grey set theory in the application domain of material handling equipment. Thus, the Grey-TOPSIS approach is employed in this study to develop a conceptual framework for material-handling equipment.

2. Problem Definition and Discussions.

System modelling can assist in precisely representing its prevailing behaviour (Yang and Tzeng, 2011). The authors found that the dynamic character of any system can be defined by modelling, and that modelling can be efficiently prepared by probabilistic thinking (Guo, 2007). Furthermore, probabilistic thinking helps recognise noteworthy possible choices, and it can be prepared using grey set theory. The variety of choices exists in modern approximation theory, which can be used to define probabilistic thinking, i.e., fuzzy thinking, grey thinking, other rough-set thinking, etc. (Guo, 2007). The conception of grey thinking is employed in this work to approximate probabilistic thinking. The authors found that significant work is needed to review and select appropriate handling equipment for admirable materials, which may include a Multi-Indices Decision Making (MIDM) platform under discrete and incomplete information.

Saputro et al. (2015) reported that the high diversity of MHE categories and types available for executing industrial work introduces complexity in decisions regarding MHE selection. It is found that MHEs are important to manufacturing and industrial firms, as they can significantly increase firms' revenues. Additionally, the majority of research has employed fuzzy set theory to address subjectivity in decision-making. It is also found that the researchers have conducted a low level of research, which has implicated grey set theory in the application domain of material handling equipment.

The authors found that decision-making and excellence in it are responsible for effective monitoring and utilization of the system (Čančer and Mulej, 2013; Sen et al., 2015; Qin and Liu, 2016; Yadav and Sharma, 2015; Nishad et al., 2025), and this can be done by building an effective DSF. Consequently, in this study, the authors framed a DSF using a mathematical computational procedure based on grey set theory to review the performance of MHEs under chains of gleaned subjective indices. The Grey-TOPSIS approach is employed in this study to develop a conceptual framework for MHEs using qualitative indices. The present study provided a platform that effectively grasped the experts' lingo and offered a chain of subjective indices for evaluating MHEs.

In numerous works, authors observed that researchers have adopted poor subjectivity and developed unsophisticated decision - making tools to expose the technical conception of appraising MHEs. Thus, the authors developed an appraisal platform and coupled it with grey set theory and the renowned TOPSIS methodology to practically handle imperfect information in selecting an admirable MHE. The developed Grey-TOPSIS approach demonstrates the ability to deliver admirable MHE. The presented approach is built on a multi-index MHE platform, making it easily adoptable by firms that prefer an evaluated MHS over their preferred indices. Additionally, the present framework can be utilized by firms to preserve ecological performance, which can be achieved only by identifying eco-friendly MHE criteria to be mounted over the proposed DSF, as demonstrated by the authors in this study.

3. Grey Sets Theory (*GysT*) and Its Mapping.

The information obtained from the working system is generally incomplete and vague; thus, to track it, non-deterministic datasets are formed. Non-deterministic data sets can help express the essence of complete information by capturing the incomplete ones. The degree of uncertainty or incompleteness can be assessed using Grey set theory. *GysT* assists in representing a course of information in the form of a grey degree. This *GysT* is a valuable means that can handle uncertainty in decision tribulations under discrete data and incomplete information (Liu et al., 2011; Mishra et al., 2013; Li et al., 2023). The fundamental concept of *GysT* is offered by Deng (1982); a few statements holding the relevant mathematical framework of *GysT* are as follows (Deng, 1982):

Statement 3.1: *GysT* is an option to represent the uncertainty and vagueness in the systems. Let X represent the universal set, then a grey set (Gys) of X is usually defined by two mappings:

$$\begin{cases} \bar{\mu}_{Gy}(x) : x \to [0,1] \\ \underline{\mu}_{Gy}(x) : x \to [0,1] \end{cases} \tag{1}$$

$\bar{\mu}_{Gy}(x) \geq \underline{\mu}_{Gy}(x), x \in X, X = R$, where $\bar{\mu}_{Gy}(x)$ and $\underline{\mu}_{Gy}(x)$ are the upper and lower membership functions in Gys, respectively. When $\bar{\mu}_{Gy}(x) = \underline{\mu}_{Gy}(x)$, then Gys becomes a fuzzy set; thus Gys possesses a state of fuzziness and can flexibly handle fuzziness situations.

Statement 3.2: A grey system holds uncertain information in the form of grey numbers and grey variables. *GysT* relocates the system's functional characteristics into mathematical behaviour as grey numbers (Xie et al., 2011).

Statement 3.3: In the grey set, the precise values are unidentified, while the upper and lower bounds are approximated. Generally, a grey set is indicated as $\left(\otimes Gys = G\Big|_{\underline{\mu}_{Gy}}^{\bar{\mu}_{Gy}}\right)$.

Statement 3.4: Gys is branded as a lower limit grey number if no more than the lower edge of Gys is probably approximated.

$$\otimes Gys = \left[\underline{\mu}_{Gy}, \infty\right] \tag{2}$$

Statement 3.5: Gys is branded as an upper limit grey number if no more than the upper edge of Gys is probably approximated.

$$\otimes Gys = \left[-\infty, \bar{\mu}_{Gy}\right] \tag{3}$$

Statement 3.6: If the lower and upper confines of Gys are approximated, in that case Gys is defined as an interval grey set ($\otimes Gys$).

$$\otimes Gys = \left[\underline{\mu}_{Gy}, \bar{\mu}_{Gy}\right] \tag{4}$$

Statement 3.7: For a $\otimes Gys = \left[\underline{\mu}_{Gy}, \bar{\mu}_{Gy}\right]$; the corresponding whitened value $Gys_{(\lambda)}$ can be found as follows (Liu and Lin, 2006):

$$Gys_{(\lambda)} = \lambda \underline{\mu}_{Gy} + (1-\lambda)\bar{\mu}_{Gy} \tag{5}$$

Here, λ is known as the whitening coefficient, as $\lambda \in [0,1]$; it depends on the proximity with the lower and upper confines.

Statement 3.8: The basic operations of grey sets $\otimes Gys^1 = \left[\underline{\mu}^1_{Gy}, \bar{\mu}^1_{Gy}\right]$ & $\otimes Gys^2 = \left[\underline{\mu}^2_{Gy}, \bar{\mu}^2_{Gy}\right]$ are expressed as:

$$\begin{aligned} \otimes Gys^1 + \otimes Gys^2 &= \left[\underline{\mu}^1_{Gy} + \underline{\mu}^2_{Gy},\ \bar{\mu}^1_{Gy} + \bar{\mu}^2_{Gy}\right] \\ \otimes Gys^1 - \otimes Gys^2 &= \left[\underline{\mu}^1_{Gy} - \underline{\mu}^2_{Gy},\ \bar{\mu}^1_{Gy} - \bar{\mu}^2_{Gy}\right] \\ \otimes Gys^1 \times \otimes Gys^2 &= \left[\underline{\mu}^1_{Gy}\underline{\mu}^2_{Gy},\ \bar{\mu}^1_{Gy}\bar{\mu}^2_{Gy}\right] \\ \otimes Gys^1 \div \otimes Gys^2 &= \left[\underline{\mu}^1_{Gy}, \bar{\mu}^1_{Gy}\right] \times \left[\frac{1}{\underline{\mu}^2_{Gy}}, \frac{1}{\bar{\mu}^2_{Gy}}\right] \end{aligned} \tag{6}$$

Statement 3.9: The signed distance amongst $\otimes Gys^1$ & $\otimes Gys^2$ can be computed by the signed difference between its centres using Equation 7 (Sahu et al., 2014):

$$\begin{aligned} d\left(\otimes GyS^1, \otimes GyS^2\right) &= \frac{\mu^1_{Gy} - \bar{\mu}^1_{Gy}}{2} - \frac{\mu^2_{Gy} - \bar{\mu}^2_{Gy}}{2} \\ &= \frac{1}{2}\left[\left(\mu^1_{Gy} - \mu^2_{Gy}\right) + \left(\bar{\mu}^1_{Gy} - \bar{\mu}^2_{Gy}\right)\right]. \end{aligned} \tag{7}$$

In the last few decades, firms have been pressured by legislation to address ecological deficits arising from their operations. Thus, the present framework can also be utilized by the firm to preserve ecological performance by identifying eco-friendly MHE criteria and alternatives to be incorporated into the decision support framework presented by the authors in this study.

4. Significance of the Present Work.

MHEs reciprocate an important role in designing a valuable manufacturing system (Kulak, 2005). Hadi-Vencheh and Mohamadghasemi (2014) found that MHEs' evaluation cases usually involve a finite number of substitutes, each surrounded by diverse quantitative or qualitative criteria or sub-criteria. Hadi-Vencheh and Mohamadghasemi (2014) disclosed that the material handling system has a significant impact on the efficiency of a manufacturing system. Thus, in this work, the authors served as the decision platform and highlighted the selection process for a noteworthy MHE alternative amongst favoured choices, operating under gleaned subjective indices. The subjective indices are derived from the literature review to evaluate the technical domain of MHEs using the MCDM technique and grey set theory. The authors found that MHEs are liable for contributing to environmental pollution and for generating fiscal gains for firms. It is also found that the researchers have performed low-level work, which has encircled MHEs within the Multi-Indices Decision Making (MIDM) process. It is also found that the present DSF, built under discrete and incomplete information, is subjective and unsophisticated. The authors found that significant work is needed to review and select the admirable MHE, which encompasses decision-making under imperfect information.

It is also found that MCDM techniques can handle decision dilemmas involving chains of indices. Thus, the authors identified the general and momentous indices and developed an appraisal platform in alliance with grey set theory and the renowned TOPSIS methodology to practically reduce imperfect information in selecting an admirable MHE. Purchasing MHE requires a robust decision-making framework, given the diverse functions required by industrial and manufacturing firms.

The constant requirements of industrial and manufacturing firms can be fulfilled by distinguishing the material-handling equipment available in the marketplace. Various types of material handling equipment are available in the marketplace and perform different functions. Thus, it will be beneficial to the firms if the available functions and alternative MHE are evaluated against their requirements. Thus, the present study provided a DSF for the concerned firms to select the best-suited MHE alternative for their firm. The authors consider a group of indices, i.e., handling cost, possession cost, control mechanism, logistics, nature of the movement, type of movement, travel arena, quantity of inventory, inventory characteristics, and type of inventory, in this study, where possession cost indicates the price of the material handling equipment that is going to be purchased by the related firms, which also includes installation and other miscellaneous charges required for implementing the purchased equipment into the firm. Moreover, inventory characteristics for MHE indicate the density, shape, and size of the inventory that needs to be transported by the purchasing MHE. The nature of the movement in MHE indicates the equipment's frequency and speed; the accompanying inventory needed to be transported by the purchasing MHE to the firms. The element logistics in MHE specifies the required loading logistics and the type of loading required to load the corresponding materials onto the purchasing MHE. Handling costs in MHE are distinguishing costs per unit; these have to be spent by the firms during the treatment of distinguishing inventories by the upcoming purchasing MHE over time. Types of movement in MHE include straight, overhead, and variable, among others, which are prerequisites for firms implementing a specific MHE for their working area. Travel arena responded to the direction type (either fixed or irregular) and the distance (i.e., in kilometres) to be travelled by the purchasing MHE to the firm. Quantity of Inventory responded to the amount of material required to be transported by the MHE to satisfy the scheduled daily activities. Type of Inventory indicates the type of substance, i.e., solid, fluid, etc., desired to be transported by the purchasing MHE. Control mechanism specifies the driving mechanism to be used by the purchasing MHE, e.g., automatic, manual, etc. This also indicates the obligation to meet human requirements when purchasing a manual MHE. The momentous MHE indices are described in this section to broaden the view of industrial and manufacturing firms when purchasing MHE to schedule their routine activities. The authors present a DSF to evaluate the decision-making process for MHE selection in this study.

5. G-TOPSIS (Grey-TOPSIS) Approach.

Onut et al. (2009) developed a fused MCDM methodology by combining the Fuzzy Analytic Network Process (FANP) and TOPSIS techniques to evaluate MHEs in the steel construction industry in Istanbul, Turkey. Hwang and Yoon (1981) proposed the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. This technique considers the Ideal Solution for computation and evaluation based on the positive and negative spheres of the decision problem. The positive sphere assists in minimizing the cost criteria and maximizing the benefit criteria, whilst the negative sphere assists in maximizing the cost criteria and minimizing the benefit criteria. In this study, the authors developed an appraisal platform and aligned it with grey set theory and the renowned TOPSIS methodology to practically handle imperfect information in selecting an admirable MHE.

In this study, to evaluate a decision-making problem, which encloses alternatives $(\xi_1, \ldots, \xi_m)$ and has indices $(\Omega_1, \ldots, \Omega_n)$, ratings and weights are assigned in the form of grey variables to the alternatives by decision makers $(\partial m|1, \ldots, \partial m|K)$. The structure of the grey decision-making problem accompanying the ratings and weights of alternatives $(\xi_1, \ldots, \xi_m)$ and indices $(\Omega_1, \ldots, \Omega_n)$ is represented by Equation 8, denoted by $G = (\otimes Gys_{ij})_{mn}$, where each element $\otimes Gys_{ij}$ aggregates the grey ratings assigned by the K decision-makers $(\partial m|1, \partial m|2, \ldots, \partial m|K)$ to alternative ξ_i with respect to index Ω_j:

$$G = \left(\otimes Gys_{ij}\right)_{mn}, \qquad i = 1,\ldots,m;\ j = 1,\ldots,n \tag{8}$$

The aggregated Grey-MIDM matrix for conceptualizing the G-TOPSIS approach $GysT$ is shown by Equation 9, where -$\otimes\hat{Gys}_{ij}$, the aggregated grey variables, are assigned to alternatives $(\xi_1,\ldots,\xi_m)$ having indices $(\Omega_1,\ldots,\Omega_n)$:

$$\hat{G} = \begin{bmatrix} \otimes\hat{Gys}_{11} & \otimes\hat{Gys}_{12} & \cdots & \otimes\hat{Gys}_{1n} \\ \otimes\hat{Gys}_{21} & \otimes\hat{Gys}_{22} & \cdots & \otimes\hat{Gys}_{2n} \\ \vdots & & \ddots & \vdots \\ \otimes\hat{Gys}_{m1} & \otimes\hat{Gys}_{m2} & \cdots & \otimes\hat{Gys}_{mn} \end{bmatrix} \tag{9}$$

The normalized grey decision matrix is disclosed by Equation 10. Normalization is required to preserve the equivalence property among indices.

$$^{norm^*}G = \begin{bmatrix} \otimes Gys^*_{11} & \otimes Gys^*_{12} & \cdots & \otimes Gys^*_{1n} \\ \otimes Gys^*_{21} & \otimes Gys^*_{22} & \cdots & \otimes Gys^*_{2n} \\ \vdots & & \ddots & \vdots \\ \otimes Gys^*_{m1} & \otimes Gys^*_{m2} & \cdots & \otimes Gys^*_{mn} \end{bmatrix} \tag{10}$$

The transformation of normalization is done based on the property of the indices. For a benefit characteristic, $\otimes Gys^*_{ij}$ should be expressed by employing Equation 11, and for a cost characteristic, $\otimes Gys^*_{ij}$ should be expressed by employing Equation 12.

$$\otimes Gys^*_{ij} = \left[\frac{\underline{\mu}_{Gy_{ij}}}{\mu_{Gy^{\max}_{ij}}}, \frac{\bar{\mu}_{Gy_{ij}}}{\mu_{Gy^{\max}_{ij}}}\right], \quad \text{such that} \quad \mu_{Gy^{\max}_{ij}} = \max_{1\le i\le m}\left\{\bar{\mu}_{Gy_{ij}}\right\} \tag{11}$$

$$\otimes Gys^*_{ij} = \left[\frac{\mu_{Gy^{\min}_{ij}}}{\bar{\mu}_{Gy_{ij}}}, \frac{\mu_{Gy^{\min}_{ij}}}{\underline{\mu}_{Gy_{ij}}}\right], \quad \text{such that} \quad \mu_{Gy^{\min}_{ij}} = \min_{1\le i\le m}\left\{\underline{\mu}_{Gy_{ij}}\right\} \tag{12}$$

Let $\beta_i = (\beta_1, \beta_2, \ldots, \beta_n)$ be the relative weight vector of the indices $(\Omega_1,\ldots,\Omega_n)$; that transforms the weighted normalized grey decision matrix. The weighted normalised grey decision matrix is depicted in Equation 13, which accounts for the relative importance of each decision attribute.

$$\delta^* = \begin{bmatrix} \otimes\delta_{11} & \otimes\delta_{12} & \cdots & \otimes\delta_{1n} \\ \otimes\delta_{21} & \otimes\delta_{22} & \cdots & \otimes\delta_{2n} \\ \vdots & & \ddots & \vdots \\ \otimes\delta_{m1} & \otimes\delta_{m2} & \cdots & \otimes\delta_{mn} \end{bmatrix} \tag{13}$$

Where $\otimes\delta_{ij} = \otimes Gys^*_{ij} \times \beta_i$, and β_i is the relative weight vector of the indices $(\Omega_1,\ldots,\Omega_n)$. The positive and negative ideal alternatives are accounted for from the matrix δ^* to decide the significant choice (Hwang and Yoon, 1981; Oztaysi, 2014). The positive ideal alternative (Pos^+) and the negative ideal alternative (Neg^-) evaluate the separation measure from Pos^+ and Neg^-, in the form of ℓ^*_i and ℓ^-_i (Sahu et al., 2016).

$$\begin{aligned} Pos^+ &= \left\{\left[\max_{1\le i\le m}\underline{\delta}_{i1}, \max_{1\le i\le m}\bar{\delta}_{i1}\right], \left[\max_{1\le i\le m}\underline{\delta}_{i2}, \max_{1\le i\le m}\bar{\delta}_{i2}\right], \ldots, \left[\max_{1\le i\le m}\underline{\delta}_{in}, \max_{1\le i\le m}\bar{\delta}_{in}\right]\right\} \\ &= \{\otimes\delta^+_1, \otimes\delta^+_2, \ldots, \otimes\delta^+_n\} \\ &= \left\{\left(\underline{\delta}^+_1, \bar{\delta}^+_1\right), \left(\underline{\delta}^+_2, \bar{\delta}^+_2\right), \ldots, \left(\underline{\delta}^+_n, \bar{\delta}^+_n\right)\right\} \end{aligned} \tag{14}$$

$$\begin{aligned} Neg^- &= \left\{\left[\min_{1\le i\le m}\underline{\delta}_{i1}, \min_{1\le i\le m}\bar{\delta}_{i1}\right], \left[\min_{1\le i\le m}\underline{\delta}_{i2}, \min_{1\le i\le m}\bar{\delta}_{i2}\right], \ldots, \left[\min_{1\le i\le m}\underline{\delta}_{in}, \min_{1\le i\le m}\bar{\delta}_{in}\right]\right\} \\ &= \left\{\otimes\delta^-_1, \otimes\delta^-_2, \ldots, \otimes\delta^-_n\right\} \\ &= \left\{\left(\underline{\delta}^-_1, \bar{\delta}^-_1\right), \left(\underline{\delta}^-_2, \bar{\delta}^-_2\right), \ldots, \left(\underline{\delta}^-_n, \bar{\delta}^-_n\right)\right\} \end{aligned} \tag{15}$$

$$\ell^+_i = \sum_{j=1}^{m}\sqrt{\frac{1}{2}\left[\left(\underline{\delta}^+_j - \underline{\delta}_{ij}\right)^2 + \left(\bar{\delta}^+_j - \bar{\delta}_{ij}\right)^2\right]} \tag{16}$$

$$\ell^-_i = \sum_{j=1}^{m}\sqrt{\frac{1}{2}\left[\left(\underline{\delta}^-_j - \underline{\delta}_{ij}\right)^2 + \left(\bar{\delta}^-_j - \bar{\delta}_{ij}\right)^2\right]} \tag{17}$$

$$Q^+_i = \frac{\ell^-_i}{\ell^+_i + \ell^-_i} \tag{18}$$

The relative closeness coefficient (Q^+_i) should be computed from Equation 18 to adorn the decision results, such that $0 \le Q^+_i \le 1$. In this work, the authors merged $GysT$ with conventional TOPSIS. The same is called G-TOPSIS and yields the necessary outcome. Additionally, this study highlights the case of MHEs to assess the behaviour and validity of the proposed G-TOPSIS approach. The Grey-TOPSIS approach demonstrates competence in delivering admirable MHE. The said approach is built on a multi-index MHE platform to be easily adopted by firms that prefer an evaluated MHS over their preferred indices.

6. Discussions and Implications.

Selection and configuration of a material handling system for the transportation and storage of materials require artificial intelligence in decision-making (Chan, 2002). Adopting appropriate MHE is important for effectively operating business activities. The concerned firms can define the appropriate MHE by capturing the related performance attributes. Significant MHE can also help reduce environmental pollution by considering ecological indices in the built MHE alternatives platform. Additionally, opting for the significant MHE can help increase firms' profits. Thus, in this study, the authors developed a multi-index MHE evaluation module that linked the general and momentous MHE indices for use by industrial and manufacturing firms. Tuzkaya et al. (2010) found a lack of systematic approaches in the field of MHEs and stressed the need to develop novel approaches to quantify intangible factors. The present study developed a robust approach that can offer managers of industrial and manufacturing firms an efficient DSF for evaluating and benchmarking the commendable MHE amongst available alternatives.

A DSF, combined with the TOPSIS approach and grey set theory, is presented to identify the most noteworthy MHE alternative amongst available chains effectively. The decision-makers should follow the steps below to execute the proposed DSF in their respective firms.

6.1. First Step: Identify the Significant MHE Characteristics.

Identify the significant MHE characteristics needed to undertake the required operations, such as production, transformation, assembly, fabrication, etc., by the selected MHE within the firms.

To implement the proposed DSF by managers, it is first necessary to recognise the significant MHE characteristics, which can help relate the obligatory daily activities to the required material handling equipment. Managers or decision-makers must first organise brainstorming sessions to define the key MHE characteristics essential for the material handling equipment to execute the firm's routine activities effectively. Brainstorming sessions should adapt the group decision-making process, which should be accompanied by experts, top authorities, or the board of directors, to produce a list of MHE characteristics relevant to their firms' routine activities. In this study, the authors provided a set of subjective MHE indices to help managers more effectively identify MHE characteristics in their firms.

6.2. Second Step: Categorise the Available Market MHE Alternatives.

Categorise the available market MHE alternatives that can efficiently operate under the required conditions, and relate them to the firm's material handling activities.

Next, it is required to identify the group of MHE alternatives available in the market that can be effectively worked with the existing firm's conditions and can incorporate the concerned firm's material handling activities. The same can be discussed during the same brainstorming sessions, in line with the opinion of the board of directors, top authorities, managers, etc. For this, the concerned firms should first procure details on the handling materials' sizes, lengths, and types to be handled by the installed MHE. The present study furnished a DSF based on a group of momentous subjective indices, which are discussed in Section 4.

6.3. Third Step: Implications of Grey Set Theory for Allocating Linguistic Views of Decision Makers.

Table 1: Priority importance linguistic weights of MHE indices.

Indices	(Ω_i)	*Weight* (β_i)	*Priority weights expressed in grey numbers*				
			$\partial m\|1$	$\partial m\|2$	$\partial m\|3$	$\partial m\|4$	$\partial m\|5$
Handling cost	(Ω_1)	(β_1)	*ML*	*H*	*M*	*M*	*H*
Possession cost	(Ω_2)	(β_2)	*VH*	*VH*	*H*	*H*	*ML*
Control mechanism	(Ω_3)	(β_3)	*M*	*VL*	*MH*	*MH*	*VH*
Logistics	(Ω_4)	(β_4)	*MH*	*M*	*VH*	*H*	*MH*
Nature of the movement	(Ω_5)	(β_5)	*VH*	*H*	*M*	*L*	*ML*
Type of movement	(Ω_6)	(β_6)	*H*	*L*	*VH*	*M*	*VH*
Travel arena	(Ω_7)	(β_7)	*ML*	*ML*	*MH*	*H*	*L*
Quantity of Inventory	(Ω_8)	(β_8)	*VH*	*H*	*VH*	*M*	*MH*
Inventory characteristics	(Ω_9)	(β_9)	*VL*	*MH*	*VH*	*M*	*VH*
Type of Inventory	(Ω_{10})	(β_{10})	*MH*	*H*	*L*	*H*	*VL*

Source: Authors.

Next, to efficiently handle brainstorming sessions and understand the perceptions of the concerned decision-makers, grey set theory is utilised. Grey sets theory is implicated in the allocation of decision makers' linguistic views, as numerous researchers have stressed the use of subjective criteria and linguistic methods for evaluating alternatives (Onut et al., 2009; Dong and Wan, 2016). The decision-makers' views on the importance weights of the MHE Indices are presented in Table 1. MHE alternatives, i.e., Industrial trucks, Belt Conveyor systems, Hoists & Cranes, Automatic Guided Vehicles (AGV), and Monorails, are employed in this study to model a DSF and represent the group of alternatives. The appropriateness linguistic ratings of the alternatives are acquired during brainstorming sessions. The same are disclosed in Tables 2-6. The rounds of brainstorming sessions are needed to collect decision-makers' perceptions of the indices and to organize the case into an MCDM matrix.

Table 2: Appropriateness linguistic ratings for Industrial trucks.

Indices	(Ω_i)	*Ratings* (α_i)	*Appropriateness ratings in grey numbers*				
			$\partial m\|1$	$\partial m\|2$	$\partial m\|3$	$\partial m\|4$	$\partial m\|5$
Handling cost	(Ω_1)	(α_1)	*MP*	*MP*	*F*	*F*	*F*
Possession cost	(Ω_2)	(α_2)	*G*	*F*	*G*	*MG*	*VG*
Control mechanism	(Ω_3)	(α_3)	*F*	*VG*	*MP*	*VG*	*G*
Logistics	(Ω_4)	(α_4)	*F*	*MP*	*MP*	*MG*	*F*
Nature of the movement	(Ω_5)	(α_5)	*VG*	*MG*	*VG*	*P*	*G*
Type of movement	(Ω_6)	(α_6)	*MP*	*P*	*MP*	*MG*	*F*
Travel arena	(Ω_7)	(α_7)	*G*	*P*	*G*	*G*	*G*
Quantity of Inventory	(Ω_8)	(α_8)	*VP*	*VG*	*F*	*P*	*VG*
Inventory characteristics	(Ω_9)	(α_9)	*G*	*MP*	*MG*	*MG*	*VP*
Type of Inventory	(Ω_{10})	(α_{10})	*MG*	*G*	*F*	*VG*	*MG*

Source: Authors.

Table 3: Appropriateness linguistic ratings for Belt Conveyor systems.

Indices	(Ω_i)	*Ratings* (α_i)	*Appropriateness ratings in grey numbers*				
			$\partial m\|1$	$\partial m\|2$	$\partial m\|3$	$\partial m\|4$	$\partial m\|5$
Handling cost	(Ω_1)	(α_1)	*MG*	*P*	*P*	*G*	*VP*
Possession cost	(Ω_2)	(α_2)	*MG*	*VG*	*MG*	*MG*	*VG*
Control mechanism	(Ω_3)	(α_3)	*MP*	*G*	*G*	*MP*	*MP*
Logistics	(Ω_4)	(α_4)	*G*	*F*	*VG*	*MG*	*MG*
Nature of the movement	(Ω_5)	(α_5)	*VP*	*MG*	*P*	*MG*	*G*
Type of movement	(Ω_6)	(α_6)	*VG*	*VG*	*F*	*MP*	*F*
Travel arena	(Ω_7)	(α_7)	*MP*	*MP*	*MG*	*MG*	*VG*
Quantity of Inventory	(Ω_8)	(α_8)	*MG*	*F*	*G*	*F*	*VG*
Inventory characteristics	(Ω_9)	(α_9)	*VG*	*P*	*G*	*VG*	*MG*
Type of Inventory	(Ω_{10})	(α_{10})	*G*	*VG*	*VG*	*MG*	*F*

Source: Authors.

6.4. Fourth Step: Transformation of Appropriateness Ratings and Priority Importance.

Transformation of appropriateness ratings and priority importance relating to the MHE alternatives.

The appropriateness linguistic ratings and priority importance's about the MHEs alternatives are acquired from decision makers based on their experience, knowledge and practices; thus it is required by the decision makers to visit the numerous manufacturing firms, where the scrutinized MHE alternatives are in operational mode, there, the decision makers

Table 4: Appropriateness linguistic ratings for Hoists & Cranes.

Indices	(Ω_i)	Ratings (α_i)	Appropriateness ratings in grey numbers				
			$\partial m\|1$	$\partial m\|2$	$\partial m\|3$	$\partial m\|4$	$\partial m\|5$
Handling cost	(Ω_1)	(α_1)	VG	G	G	P	G
Possession cost	(Ω_2)	(α_2)	VP	F	MG	F	F
Control mechanism	(Ω_3)	(α_3)	VG	G	MP	G	MG
Logistics	(Ω_4)	(α_4)	P	MG	VG	MG	VG
Nature of the movement	(Ω_5)	(α_5)	MG	VG	MP	F	MP
Type of movement	(Ω_6)	(α_6)	G	VP	P	F	VG
Travel arena	(Ω_7)	(α_7)	VP	F	VG	G	MP
Quantity of Inventory	(Ω_8)	(α_8)	MG	P	MG	MG	VG
Inventory characteristics	(Ω_9)	(α_9)	VG	VG	MP	G	MP
Type of Inventory	(Ω_{10})	(α_{10})	F	G	MG	G	VG

Source: Authors.

Table 5: Appropriateness linguistic ratings for Automatic Guided Vehicles (AGV).

Indices	(Ω_i)	Ratings (α_i)	Appropriateness ratings in grey numbers				
			$\partial m\|1$	$\partial m\|2$	$\partial m\|3$	$\partial m\|4$	$\partial m\|5$
Handling cost	(Ω_1)	(α_1)	VP	G	P	G	VG
Possession cost	(Ω_2)	(α_2)	MG	VG	F	MG	G
Control mechanism	(Ω_3)	(α_3)	F	VP	VG	VG	F
Logistics	(Ω_4)	(α_4)	G	MG	F	MP	MP
Nature of the movement	(Ω_5)	(α_5)	P	P	G	VG	G
Type of movement	(Ω_6)	(α_6)	VG	G	MG	P	MG
Travel arena	(Ω_7)	(α_7)	VP	F	F	MP	MP
Quantity of Inventory	(Ω_8)	(α_8)	MG	VG	G	VG	F
Inventory characteristics	(Ω_9)	(α_9)	G	G	MP	MG	F
Type of Inventory	(Ω_{10})	(α_{10})	F	MG	VG	VG	MP

Source: Authors.

can oversight the MHE performance and can best approximate the appropriateness ratings and priority importance relating the MHE alternatives; which are needed to be transformed in the form of appropriateness grey ratings and priority importance's. The aggregated grey priority importances are shown in Table 7. The grey linguistic scale, as presented by Sahu et al. (2012), is adopted in this study to provide decision information.

6.5. Fifth Step: Implication of the G-TOPSIS Technique.

Implication of the G-TOPSIS technique for defining the noteworthy MHE alternative.

Next, the G-TOPSIS approach, as discussed in Section 5, is used to identify the most significant MHE choice accompanying the group decision-making process. The presented G-TOPSIS approach is the amalgamation of the TOPSIS methodology and the theory of grey sets. The Grey aggregated appropriateness ratings, and associated G-TOPSIS values, implicating the distinguishing values of the normalized grey vector and the weighted normalized grey vector for different MHE alternatives are disclosed in Tables 8-12. The positive ideal alternative values and negative ideal alternative values are disclosed in Table 7, and the corresponding distances from the positive ideal alternatives and negative ideal alternatives are presented in Tables 13-14.

The appropriate selection of MHE by the concerned manufacturing or industrial firms can be effectively captured by

Table 6: Appropriateness linguistic ratings for Mono rails.

Indices	(Ω_i)	Ratings (α_i)	Appropriateness ratings in grey numbers				
			$\partial m\|1$	$\partial m\|2$	$\partial m\|3$	$\partial m\|4$	$\partial m\|5$
Handling cost	(Ω_1)	(α_1)	G	MG	G	MP	VG
Possession cost	(Ω_2)	(α_2)	P	VG	MG	F	G
Control mechanism	(Ω_3)	(α_3)	VG	F	P	VG	MG
Logistics	(Ω_4)	(α_4)	VP	G	MG	P	G
Nature of the movement	(Ω_5)	(α_5)	VG	MP	MP	G	F
Type of movement	(Ω_6)	(α_6)	VP	F	G	MG	MG
Travel arena	(Ω_7)	(α_7)	MG	P	VG	VG	MP
Quantity of Inventory	(Ω_8)	(α_8)	G	F	VP	G	VG
Inventory characteristics	(Ω_9)	(α_9)	VG	F	MG	MP	G
Type of Inventory	(Ω_{10})	(α_{10})	F	VG	G	MG	F

Source: Authors.

Table 7: Grey aggregated priority weights and ideal possible values of MHE indices.

(Ω_i)	(β_i)	Allied route	Grey aggregated priority weight $(\hat{\beta}_i)$	Positive ideal alternative	Negative ideal alternative
(Ω_1)	(β_1)	Min	(0.4600,0.6400)	(0.2718,0.6400)	(0.1495,0.2869)
(Ω_2)	(β_2)	Min	(0.6600,0.8400)	(0.5100,0.8400)	(0.2877,0.4327)
(Ω_3)	(β_3)	Min	(0.4600,0.5600)	(0.3220,0.5600)	(0.2542,0.3794)
(Ω_4)	(β_4)	Min	(0.5800,0.7200)	(0.4350,0.7200)	(0.2900,0.4469)
(Ω_5)	(β_5)	Max	(0.4600,0.6200)	(0.3632,0.6200)	(0.2058,0.4079)
(Ω_6)	(β_6)	Max	(0.5800,0.7400)	(0.4947,0.7400)	(0.2729,0.4788)
(Ω_7)	(β_7)	Max	(0.3600,0.5200)	(0.2492,0.5200)	(0.1292,0.2533)
(Ω_8)	(β_8)	Max	(0.6600,0.8000)	(0.5445,0.8000)	(0.3795,0.5800)
(Ω_9)	(β_9)	Max	(0.5400,0.6400)	(0.4263,0.6400)	(0.2700,0.4379)
(Ω_{10})	(β_{10})	Max	(0.3600,0.5600)	(0.2970,0.5600)	(0.2520,0.4900)

Source: Authors.

defining the relevant performance attributes and by conceptualising the present study. The results of the G-TOPSIS approach are disclosed in Table 15, which are subsequently used to define the ranking of the MHE alternatives. Selecting the appropriate MHE can help increase the profits of the concerned manufacturing firms.

Additionally, significant MHE can help reduce environmental pollution by considering ecological indices in the built MHE alternatives platform. Adopting commendable MHEs can reduce manufacturing lead times, enhance the efficiency of inventory flow, and improve facility utilisation and productivity (Kulak, 2005). Anand et al. (2011) presented a hypothetical case study to demonstrate the use of the ANP (Analytic Network Process) technique for evaluating the MHE problem in FMS design. Anand et al. (2011) found the conveyor to be a superior alternative for designing an FMS using ANP under the case situation they considered. The main aim of their work is to impart technical knowledge of the ANP technique to practitioners for formulating strategic decision-making policies in the MHE evaluation problem related to FMS design.

Table 8: Grey aggregated appropriateness ratings and associated G-TOPSIS values for Belt Conveyor systems.

(Ω_i)	(α_i)	Grey aggregated appropriateness rating $(\hat{\hat{\alpha}}_i)$	Normalized grey vector $\otimes G_{ij}^{*} \| TOPSIS$	Weighted normalized grey vector $\otimes G_{ij}^{*} \times \beta_i \| TOPSIS$
(Ω_1)	(α_1)	(3.600,4.600)	(0.5652,0.7222)	(0.2600,0.4622)
(Ω_2)	(α_2)	(6.000,7.800)	(0.4359,0.5667)	(0.2877,0.4760)
(Ω_3)	(α_3)	(6.200,7.600)	(0.5526,0.6774)	(0.2542,0.3794)
(Ω_4)	(α_4)	(3.800,4.800)	(0.7500,0.9474)	(0.4350,0.6821)
(Ω_5)	(α_5)	(6.000,7.600)	(0.7895,1.0000)	(0.3632,0.6200)
(Ω_6)	(α_6)	(3.200,4.400)	(0.4706,0.6471)	(0.2729,0.4788)
(Ω_7)	(α_7)	(5.000,7.800)	(0.6410,1.0000)	(0.2308,0.5200)
(Ω_8)	(α_8)	(4.600,5.800)	(0.5750,0.7250)	(0.3795,0.5800)
(Ω_9)	(α_9)	(3.800,5.200)	(0.5000,0.6842)	(0.2700,0.4379)
(Ω_{10})	(α_{10})	(5.800,7.200)	(0.7250,0.9000)	(0.2610,0.5040)

Source: Authors.

Table 9: Grey aggregated appropriateness ratings and associated G-TOPSIS values for Hoists & Cranes.

(Ω_i)	(α_i)	Grey aggregated appropriateness rating $(\hat{\hat{\alpha}}_i)$	Normalized grey vector $\otimes G_{ij}^{*} \| TOPSIS$	Weighted normalized grey vector $\otimes G_{ij}^{*} \times \beta_i \| TOPSIS$
(Ω_1)	(α_1)	(2.600,4.400)	(0.5909,1.0000)	(0.2718,0.6400)
(Ω_2)	(α_2)	(6.600,7.600)	(0.4474,0.5152)	(0.2953,0.4327)
(Ω_3)	(α_3)	(4.200,6.000)	(0.7000,1.0000)	(0.3220,0.5600)
(Ω_4)	(α_4)	(5.800,7.200)	(0.5000,0.6207)	(0.2900,0.4469)
(Ω_5)	(α_5)	(3.400,5.000)	(0.4474,0.6579)	(0.2058,0.4079)
(Ω_6)	(α_6)	(5.800,6.800)	(0.8529,1.0000)	(0.4947,0.7400)
(Ω_7)	(α_7)	(5.000,6.000)	(0.6410,0.7692)	(0.2308,0.4000)
(Ω_8)	(α_8)	(5.600,7.000)	(0.7000,0.8750)	(0.4620,0.7000)
(Ω_9)	(α_9)	(6.000,7.600)	(0.7895,1.0000)	(0.4263,0.6400)
(Ω_{10})	(α_{10})	(6.600,8.000)	(0.8250,1.0000)	(0.2970,0.5600)

Source: Authors.

7. Conclusions.

The presented work developed a competent approach and offered a DSF that can help decision-makers in industrial and manufacturing firms evaluate and benchmark worthy MHE alternatives. This study projected a DSF, which can be capably used in decision-making situations by the numerous industrial and manufacturing firms, only by considering distinct criteria such as ecological criteria, financial criteria, or ecological cum fiscal criteria connected into a single module, to opt for an admirable MHE alternative. In this work, the authors presented a decision platform that considers subjectivity and highlighted the procedural selection of a noteworthy MHE alternative amongst favoured choices. In this study, the authors align grey set theory with the renowned TOPSIS methodology to practically handle imperfect information in selecting an admirable MHE. The firm can utilise the presented framework to improve ecological performance by identifying eco-friendly MHE criteria and alternatives for installation on the DSF. The

Table 10: Grey aggregated appropriateness ratings and associated G-TOPSIS values for Automatic Guided Vehicles (AGV).

(Ω_i)	(α_i)	Grey aggregated appropriateness rating $(\hat{\hat{\alpha}}_i)$	Normalized grey vector $\otimes G_{ij}^{*} \| TOPSIS$	Weighted normalized grey vector $\otimes G_{ij}^{*} \times \beta_i \| TOPSIS$
(Ω_1)	(α_1)	(5.600,8.000)	(0.3250,0.4643)	(0.1495,0.2971)
(Ω_2)	(α_2)	(3.400,4.400)	(0.7727,1.0000)	(0.5100,0.8400)
(Ω_3)	(α_3)	(5.800,7.600)	(0.5526,0.7241)	(0.2542,0.4055)
(Ω_4)	(α_4)	(5.800,7.000)	(0.5143,0.6207)	(0.2983,0.4469)
(Ω_5)	(α_5)	(4.800,5.800)	(0.6316,0.7632)	(0.2905,0.4732)
(Ω_6)	(α_6)	(4.000,5.600)	(0.5882,0.8235)	(0.3412,0.6094)
(Ω_7)	(α_7)	(4.400,5.800)	(0.5641,0.7436)	(0.2031,0.3867)
(Ω_8)	(α_8)	(5.000,6.200)	(0.6250,0.7750)	(0.4125,0.6200)
(Ω_9)	(α_9)	(6.000,7.400)	(0.7895,0.9737)	(0.4263,0.6232)
(Ω_{10})	(α_{10})	(6.000,7.800)	(0.7500,0.9750)	(0.2700,0.5460)

Source: Authors.

Table 11: Grey aggregated appropriateness ratings and associated G-TOPSIS values for Mono rails.

(Ω_i)	(α_i)	Grey aggregated appropriateness rating $(\hat{\hat{\alpha}}_i)$	Normalized grey vector $\otimes G_{ij}^{*} \| TOPSIS$	Weighted normalized grey vector $\otimes G_{ij}^{*} \times \beta_i \| TOPSIS$
(Ω_1)	(α_1)	(4.400,6.400)	(0.4063,0.5909)	(0.1869,0.3782)
(Ω_2)	(α_2)	(5.800,7.200)	(0.4722,0.5862)	(0.3117,0.4924)
(Ω_3)	(α_3)	(5.200,6.200)	(0.6774,0.8077)	(0.3116,0.4523)
(Ω_4)	(α_4)	(4.200,5.600)	(0.6429,0.8571)	(0.3729,0.6171)
(Ω_5)	(α_5)	(4.600,6.800)	(0.6053,0.8947)	(0.2784,0.5547)
(Ω_6)	(α_6)	(5.200,6.800)	(0.7647,1.0000)	(0.4435,0.7400)
(Ω_7)	(α_7)	(2.800,3.800)	(0.3590,0.4872)	(0.1292,0.2533)
(Ω_8)	(α_8)	(6.600,8.000)	(0.8250,1.0000)	(0.5445,0.8000)
(Ω_9)	(α_9)	(4.800,6.600)	(0.6316,0.8684)	(0.3411,0.5558)
(Ω_{10})	(α_{10})	(6.000,7.000)	(0.7500,0.8750)	(0.2700,0.4900)

Source: Authors.

authors provided a platform that effectively captures the lingo of experts and offers a chain of subjective indices for MHE evaluation.

The presented study can be adopted by novel academicians, scholars and practitioners for developing an additional DSF by utilizing other distinguished MCDM techniques, i.e., VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje), -GRA (Grey Relational Analysis), MOORA (Multi-Objective Optimisation by Ratio Analysis), and SAW (Simple Additive Weighting) to adorn robust decision results. Due to its reliance on grey set theory, the presented work demonstrates the ability to address the risks associated with decision-makers' subjective perceptions. The crucial outputs of the presented work are:

a) The study developed an intended DSF that can support decision-makers or directors of distinguished industrial and manufacturing firms in adopting an MHE alternative, to be operational under their required grounds.
b) The subjective opinions of decision makers, which are vague, inconsistent, and incomplete, can be aggregated using the projected Grey-TOPSIS approach.
c) The projected DSF can assist managers in other segments, such as cement, steel, automobiles, and oil refineries,

Table 12: Distances from positive ideal alternative.

(Ω_i)	(α_i)	*Grey aggregated appropriateness rating* $(\widehat{\alpha}_i)$	*Normalized grey vector* $\otimes G_{ij}^{*}\big\vert TOPSIS$	*Weighted normalized grey vector* $\otimes G_{ij}^{*} \times \beta_i \big\vert TOPSIS$
(Ω_1)	(α_1)	*(5.800,7.600)*	*(0.3421,0.4483)*	*(0.1574,0.2869)*
(Ω_2)	(α_2)	*(5.000,6.600)*	*(0.5152,0.6800)*	*(0.3400,0.5712)*
(Ω_3)	(α_3)	*(5.600,6.800)*	*(0.6176,0.7500)*	*(0.2841,0.4200)*
(Ω_4)	(α_4)	*(3.600,5.600)*	*(0.6429,1.0000)*	*(0.3729,0.7200)*
(Ω_5)	(α_5)	*(5.000,6.400)*	*(0.6579,0.8421)*	*(0.3026,0.5221)*
(Ω_6)	(α_6)	*(4.000,5.400)*	*(0.5882,0.7941)*	*(0.3412,0.5876)*
(Ω_7)	(α_7)	*(5.400,6.600)*	*(0.6923,0.8462)*	*(0.2492,0.4400)*
(Ω_8)	(α_8)	*(5.000,6.800)*	*(0.6250,0.8500)*	*(0.4125,0.6800)*
(Ω_9)	(α_9)	*(5.400,6.800)*	*(0.7105,0.8947)*	*(0.3837,0.5726)*
(Ω_{10})	(α_{10})	*(5.600,7.000)*	*(0.7000,0.8750)*	*(0.2520,0.4900)*

Source: Authors.

Table 13: Distances from negative ideal alternative.

Alternatives	(Ω_1)	(Ω_2)	(Ω_3)	(Ω_4)	(Ω_5)	(Ω_6)	(Ω_7)	(Ω_8)	(Ω_9)	(Ω_{10})
Industrial trucks (ζ_1)	*0.1260*	*0.3016*	*0.1364*	*0.0268*	*0.0000*	*0.2423*	*0.0131*	*0.1945*	*0.1807*	*0.0471*
Belt Conveyor Systems (ζ_2)	*0.0000*	*0.4347*	*0.0000*	*0.2917*	*0.2395*	*0.0000*	*0.1207*	*0.1158*	*0.0000*	*0.0000*
Hoists & Crane (ζ_3)	*0.3536*	*0.0000*	*0.1617*	*0.2897*	*0.1556*	*0.1698*	*0.1373*	*0.2028*	*0.0168*	*0.0237*
Automatic guided vehicles (ζ_4)	*0.2686*	*0.3748*	*0.1079*	*0.1119*	*0.0886*	*0.0362*	*0.2798*	*0.0000*	*0.1036*	*0.0726*
Mono rail (ζ_5)	*0.3623*	*0.2945*	*0.1425*	*0.0439*	*0.1068*	*0.1871*	*0.0800*	*0.1520*	*0.0738*	*0.0769*

Source: Authors.

in benchmarking the selection dilemmas associated with MHE alternatives.

d) The presented DSF can be supplementary utilised to benchmark an admirable MHE, which is surrounded by chains of subjective or objective cum subjective indices.

e) The study can help firms maintain their green image in line with government or administrative regulations.

8. Future Scope.

Academicians, scholars, and practitioners can further extend the built MHE evaluation platform to develop a more compact hierarchical MHE structure comprising additional MHE-related indices and their interrelated sub-indices. Additionally, a zone of other MCDM techniques, i.e., VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje), ANP (Analytical Hierarchy Process), GRA (Grey Relational Analysis), and MOORA (Multi - Objective Optimisation by Ratio Analysis), needs to be incorporated into the built structure to achieve a more compact decision result. Moreover, the fuzzy logic concept must also be incorporated into the built structure. Additionally, there is a need to develop a hierarchical structure for MHE, with second, third, fourth, and so on levels, and to distinguish the implications of fuzzy logic. MCDM techniques also need to be incorporated into these hierarchical structures for MHE, second, third, fourth, and so on.

Table 14: G-TOPSIS decision-making matrix.

Alternatives	(Ω_1)	(Ω_2)	(Ω_3)	(Ω_4)	(Ω_5)	(Ω_6)	(Ω_7)	(Ω_8)	(Ω_9)	(Ω_{10})
Industrial trucks (ζ_1)	*0.1919*	*0.0433*	*0.0000*	*0.2566*	*0.2395*	*0.0000*	*0.2762*	*0.0000*	*0.0000*	*0.0154*
Belt Conveyor Systems (ζ_2)	*0.3635*	*0.0054*	*0.1869*	*0.0000*	*0.0000*	*0.3046*	*0.1633*	*0.1334*	*0.2304*	*0.0769*
Hoists & Cranes (ζ_3)	*0.0102*	*0.4366*	*0.0262*	*0.0059*	*0.0886*	*0.1392*	*0.1432*	*0.0463*	*0.2157*	*0.0574*
Automatic guided vehicles (ζ_4)	*0.0950*	*0.0620*	*0.0835*	*0.1800*	*0.1556*	*0.2877*	*0.0000*	*0.2490*	*0.1282*	*0.0127*
Mono rail (ζ_5)	*0.0056*	*0.1433*	*0.0458*	*0.2793*	*0.1332*	*0.1190*	*0.2050*	*0.1027*	*0.1569*	*0.0000*

Source: Authors.

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