Selection of Sustainable Material Handling Equipment for Sugarcane Transportation Using Fuzzy SWARA-MOORA and MOLP

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**Abstract*.*** Material Handling Equipment (MHE) plays a vital role in improving operational efficiency in agro-industrial environment, particularly in the process of transporting sugar cane at sugar factories. The mismatch MHE specifications can lead to longer setup times, worker accidents, excessive energy consumption, and higher operational costs. This study aims to select the most efficient MHE considering sustainability by employing integrated MCDM and mathematical programming. The fuzzy SWARA (Step-wise Weight Assessment Ratio Analysis) method is used to determine the weights of criteria under uncertainty. Then fuzzy MOORA (Multi-Objective Optimization on the basis of Ratio Analysis) method is applied to rank the alternatives based on compromise solutions. Finally, MOLP (Multi Objective Linear Programming) is utilized to optimize the final selection by considering multiple objective simultaneously. This hybrid model support decision-makers in selecting MHE that meets operational requirements while aligning with long-term sustainability goals.

**Keywords :** Material Handling Equipment (MHE), multi-criteria decision-making, sustainability, Fuzzy SWARA, Fuzzy MOORA, Multi Objective Linear Programming.

# INTRODUCTION

The development of sustainable supply chain requires companies to improve operational efficiency by considering economy, environment, and social aspects. The use of heavy equipment such as manual overhead cranes in the sugarcane transfer process has a number of significant impacts, including high energy consumption and contributions to CO₂ emissions. In this context, selecting the right material handling equipment (MHE), such as crane, plays a pivotal role in supporting warehouse operations that cannot be overlooked [1]. In this context, the selection of appropriate Material Handling Equipment (MHE) is critical, as it directly impacts a company’s overall production costs and operational expenses [2].

However, many sugar factories still face challenges due to the use of conventional cranes in the sugarcane transfer process, which tend to be inefficient and pose risks to safety and operational sustainability. The attachment of hooks to loads is still done manually by workers, so the setup process takes longer because it requires positioning and adjusting the load to its ideal balance point before it can be lifted by the crane. The use of conventional MHE poses potential hazards that require attention to occupational safety and health protection. This inefficiency also has several significant impacts, such as consuming large amounts of energy and producing emissions that hinder efforts to achieve sustainability goals in the industry.

To address these challenges, a decision-making approach that can systematically accommodate various evaluation criteria is required [3], including technical, economic, and environmental aspects [4]. Previous studies have widely applied multi-criteria decision-making methods such as CODAS, EDAS, WASPAS, and VIKOR in the MHE selection process. [5] proposed a fuzzy group decision making for a material handling equipment selection problem by using VIKOR and Monte Carlo simulation. [6] proposed a methodology intended to facilitate decision-making in material handling equipment selection (MHES) contexts in which distribution center (DC) design or redesign by using stochastic multi criteria acceptability analysis. [7] solved material handling equipment selection problems using R. [8] solved material handling equipment selection problems using entropy integrated COPRAS and ARAS. The primary focus of these studies typically lies on technical and cost aspects, without considering sustainability factors or uncertainty in the evaluation. Some studies have integrated environmental criteria into equipment selection [9], only a limited number of studies have taken into account sustainability and combined fuzzy logic with mathematical optimization models to support more comprehensive and robust decision-making [2].

This study aims to address this gap by developing an integrated approach based on fuzzy SWARA, fuzzy MOORA, and MOLP to support the sustainable selection of MHE. In this study, the Fuzzy Step-wise Weight Assessment Ratio Analysis (FSWARA) method was used to determine the weight of criteria while considering uncertainty in the evaluation. Subsequently, the Fuzzy MOORA method was applied to rank MHE alternatives based on the principle of best compromise. Finally, MOLP is utilized to optimize the final selection by simultaneously addressing multiple objectives. This integrated approach not only responds to the operational requirements of warehouses but also promotes energy efficiency and minimizes environmental impact. This study is expected to provide a more adaptive and comprehensive framework for optimal material handling equipment selection in an industrial environment.

# METHODS

This study uses integrated multi-criteria decision-making techniques, namely fuzzy SWARA, fuzzy MOORA, and MOLP. The fuzzy SWARA method is used to calculate the weights of criteria and sub-criteria. The fuzzy MOORA method was used to determine the rankings. MOLP is used to determine the best MHE alternative. In addition, a more detailed explanation of the fuzzy SWARA, fuzzy MOORA, and MOLP methods is as follows.

## Fuzzy SWARA

Fuzzy SWARA is recommended for critical decision-making situations that require agreement among experts. Fuzzy SWARA is also considered simpler, easier to understand, and requires fewer pair comparisons than other methods such as AHP and ANP by are as follows [10].

**Step 1**. In the Fuzzy SWARA method, criteria are arranged in order of importance, from most important to least important, in accordance with the decision making objective. This process involves a panel of experts who evaluate and reach a consensus on the order of priority of these criteria. (1)

(1)

**Step 2**. Finding Comparative Values (Sj), using fuzzy to determine relative score criteria. This fuzzy comparison scale is used to assess evaluation criteria. Using the TFN Scale shown in. **TABLE 1**.

**TABLE 1** Linguistic variables and the respective triangular fuzzy number (TFN) [11]

|  |  |
| --- | --- |
| **Linguistic Variables** | ***Triangular Fuzzy Number*** |
| Equally Important (EI) | (1, 1, 1) |
| Relative Low Importance (RLI) | (0.67, 1, 1.5) |
| Low Importance (LI) | (0.4, 0.5, 0.67) |
| Very Low Importance (VLI) | (0.286, 0.33, 0.4) |
| Extremely Little Importance (ELI) | (0.22, 0.25, 0.286) |

Rank the most important criteria in order of importance to become the main ranking, then add up the ranks calculated using equation (2)

(2)

**Step 3**. Calculate the coefficient of comparative importance for each criterion using equation (3)

(3)

**Step 4**. Recalculation of weight using equations (4)

(4)

**Step 5**. Determine the relative weight of the criteria using equation (5).

(5)

## Fuzzy MOORA

The fuzzy MOORA method is used as a compromise method in multi-criteria decision making (MCDM) to rank and select alternatives that have conflicting or incomparable criteria [12].

**Step 1**. Determine the decision matrix of criteria and sub-criteria using scales expressed in **TABLE 2**.

**TABLE 2** Linguistic variables and scales for alternatives evaluation

|  |  |
| --- | --- |
| **Linguistic Variables** | **Corresponding TFNs** |
| Very Low (VL) | 1, 1, 3 |
| Low (L) | 1, 3, 5 |
| Medium (M) | 3, 5,7 |
| High (H) | 5, 7, 9 |
| Very High (VH) | 7, 9, 9 |

**Step 2**. Determine the fuzzy importance weights of evaluation criteria in equation (6)

(6)

**Step 3**. Calculate the normalization of fuzzy decision matrix using formula (7)

(7)

**Step 4**. Weighted normalized fuzzy decision matrix (8)

(8)

Where, = and is the fuzzy weight.

**Step 5**. Determine the ranking of beneficial (benefit) and non-beneficial (cost) for each criteria using formula (9) and (10)

for (9)

for (10)

Where, = and = .

**Step 6**. Calculating the overall performance value () using the vertex method in equation (11)

(11)

**Step 7**. The overall performance index is used to enable alternative rankings from best to worst. The alternative with the highest performance index is the most profitable option.

**Multi Objective Linear Programming**

The selection of the optimal material handling equipment (MHE) is carried out using MOLP method by considering multiple goals: maximizing equipment utility, minimizing total costs, reducing the number of defective products, and minimizing emissions.

1. Minimize total cost

*Min* Z1 = (15)

1. Minimize of the number of defective products

*Min* Z2  = (16)

1. Minimize Emission usage

Min Z3 = (17)

1. Maximize value purchasing

*Min* Z4 = (18)

Constraint:

1. MHE selection

(19)

1. MHE height capacity

(20)

1. Number of MHE i

(21)

**Indices:**

1, 2, …, n are the indices for the MHE

**Parameters:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | : | Moving frequency of MHE i |  | : | Distance in single transfer from MHE i |
|  | : | Allowable error MHE i |  | : | Purchase cost of MHE i |
|  | : | Demand |  | : | Maximum load capacity of MHE i |
|  | : | MHE emission factor (g/kWh) of MHE i |  | : | Fuel consumption (liters) of MHE i |
|  | : | MHE usage value of MHE i (derived from fuzzy MOORA) |  | : | Energy consumption (kW) of MHE i |
|  | : | MHE lifting height requirement |  | : | MHE lifting height of MHE i |
|  | : | Operator working hours |  | : | Moving cycle time |
|  | : | Efficiency (%) |  | : | Utility (%) |
| **Decision variables:** | | |  | : | Material handling cost per meter of MHE i |
| = The number of MHE *i* | | |

# RESULT AND DISCUSSION

## Case Study

This study explores the selection of material handling equipment (MHE) using cranes to support sugarcane transportation within a sugar factory in Indonesia. Cranes are intended to facilitate the movement of sugarcane, as a raw material, from the receiving dock to the production area. Four MHE alternatives are evaluated using a multi-criteria decision-making approach, based on three main criteria and seventeen sub-criteria, as outlined in **TABLE 3**.

**TABLE 3** Criteria and sub-criteria for MHE selection

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **Code** | **Sub-criteria** | **Code** | **Criteria** | **Code** | **Sub-criteria** | **Code** |
| Economic | C1 | Speed | SC1 | Social | C2 | Safety | SC11 |
| Power Requirement | SC2 | User Friendliness | SC12 |
| Load Capacity | SC3 | Operator Skill Requirement | SC13 |
| Lift Height | SC4 | On-Site Technical Assistance | SC14 |
| Compatibility to Aisle Width | SC5 | Timeliness Maintenance Training | SC15 |
| Compatibility to Doorway Height | SC6 | Environment | C3 | Energy & Fuel Consumption | SC16 |
| Compatibility to Storage System | SC7 | Energy & Fuel Emission Factor | SC17 |
| Task Application | SC8 |  |  |  |  |
| Spare Part Acquirement | SC9 |  |  |  |  |
| Reduction of Goods Damage | SC10 |  |  |  |  |

## Weights of Criteria and Sub-Criteria

The decision-makers evaluate the criteria and sub-criteria to determine their respective weights, as presented in **TABLES** **4** and **5**. These weights are derived using the Fuzzy Step-wise Weight Assessment Ratio Analysis (Fuzzy SWARA) method, based on the assessments provided by the decision-makers and subsequently converted into Triangular Fuzzy Numbers (TFNs). As shown in **TABLE 6**, the results indicate that speed (SC1), power requirement (SC2), and load capacity (SC3) are the most influential sub-criteria. This weighting serves as a foundation for guiding companies to prioritize operational efficiency and technical performance when selecting appropriate MHE.

**TABLE 4** Comparison Matrix between criteria

|  |  |  |  |
| --- | --- | --- | --- |
| Criteria | DM 1 | DM 2 | DM3 |
| C1 | (1, 1, 1) | (0.67, 1, 1.5) | (1, 1, 1) |
| C2 | (0.67, 1, 1.5) | (1, 1, 1) | (1, 1, 1) |
| C3 | (1, 1, 1) | (0.67, 1, 1.5) | (0.67, 1, 1.5) |

**TABLE 5** Sub criteria Matrix

|  |  |  |  |
| --- | --- | --- | --- |
| Sub-Criteria | DM 1 | DM 2 | DM 3 |
| SC1 | (1, 1, 1) | (0.67, 1, 1.5) | (1, 1, 1) |
| SC2 | (0.67, 1, 1.5) | (0.4, 0.5, 0.67) | (1, 1, 1) |
| SC3 | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| SC4 | (0.67, 1, 1.5) | (1, 1, 1) | (1, 1, 1) |
| SC5 | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| SC6 | (0.67, 1, 1.5) | (1, 1, 1) | (0.67, 1, 1.5) |
| SC7 | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| SC8 | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| SC9 | (1, 1, 1) | (0.67, 1, 1.5) | (1, 1, 1) |
| SC10 | (1, 1, 1) | (1, 1, 1) | (0.67, 1, 1.5) |
| SC11 | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| SC12 | (0.67, 1, 1.5) | (0.67, 1, 1.5) | (1, 1, 1) |
| SC13 | (0.67, 1, 1.5) | (0.67, 1, 1.5) | (1, 1, 1) |
| SC14 | (0.4, 0.5, 0.67) | (0.4, 0.5, 0.67) | (0.67, 1, 1.5) |
| SC15 | (0.67, 1, 1.5) | (0.67, 1, 1.5) | (1, 1, 1) |
| SC16 | (0.4, 0.5, 0.67) | (0.67, 1, 1.5) | (0.4, 0.5, 0.67) |
| SC17 | (0.29, 0.33, 0.4) | (0.67, 1, 1.5) | (0.67, 1, 1.5) |

**TABLE 6** Sub-Criteria Weights

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sub Criteria** | **SC1** | **SC2** | **SC3** | **SC4** | **SC5** | **SC6** | **SC7** | **SC8** | **SC9** |
| Global Weights | 0.236 | 0.036 | 0.043 | 0.025 | 0.028 | 0.014 | 0.007 | 0.004 | 0.002 |
| **Sub Criteria** | **SC10** | **SC11** | **SC12** | **SC13** | **SC14** | **SC15** | **SC16** | **SC17** |  |
| Global Weights | 0.0002 | 0.0005 | 0.0002 | 0.0001 | 0.00006 | 0.000008 | 0.000005 | 0.000002 |  |

## MHE Evaluation

The evaluation of MHE alternatives is carried out by a decision-maker using a comprehensive set of 17 sub-criteria, which are derived from three main criteria related to economic, social, and environmental aspects. Each sub-criterion reflects a specific performance indicator relevant to the effectiveness and efficiency of MHE in supporting sugarcane transportation within the factory. The decision-maker provides a qualitative judgment for each MHE alternative with respect to all sub-criteria, based on their expertise and practical experience. These judgments are then systematically compiled and presented in **TABLE 7**, serving as the basis for the subsequent application of the fuzzy MOORA to determine the most suitable alternative.

**TABLE 7** The decision maker’s judgment for MHE Selection

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sub-criteria** | **DM 1** | | | **DM 2** | | | **DM 3** | | |
| **A1** | **A2** | **A3** | **A1** | **A2** | **A3** | **A1** | **A2** | **A3** |
| SC1 | L | VH | H | L | H | H | L | H | H |
| SC2 | H | L | H | H | L | H | H | L | H |
| SC3 | M | M | M | M | M | M | M | M | M |
| SC4 | VL | VH | H | VL | VH | H | VL | VH | H |
| SC5 | M | H | M | M | M | M | H | VH | H |
| SC6 | M | H | M | H | H | H | H | VH | H |
| SC7 | M | M | M | H | H | H | M | M | M |
| SC8 | M | H | H | H | VH | VH | H | VH | VH |
| SC9 | M | M | H | M | M | H | M | M | H |
| SC10 | M | VH | H | H | VH | H | H | H | H |
| SC11 | L | VH | H | M | VH | H | M | VH | H |
| SC12 | L | VH | H | H | VH | H | H | VH | H |
| SC13 | M | M | L | M | VH | M | VH | VH | VH |
| SC14 | M | M | L | M | H | L | M | M | L |
| SC15 | M | M | M | M | M | M | M | M | M |
| SC16 | M | VL | M | M | VL | M | M | L | M |
| SC17 | M | M | M | M | M | M | M | M | M |

The performance value of each MHE alternative is calculated using the Fuzzy MOORA (Multi-Objective Optimization on the Basis of Ratio Analysis) method based on the evaluation results. The analysis reveals that Alternative 2 (A2) achieves the highest score (0.1193), making it the top priority. It is followed by Alternative 1 (A1) with a score of 0.1173, while Alternative 3 (A3), with a score of 0.1160, ranks lowest as it is the farthest from the ideal solution. These performance values are subsequently used as input for the Multi-Objective Linear Programming (MOLP) method to determine the optimal MHE alternative from both quantitative and qualitative perspectives.

## MHE Selection

After determining the criteria weights using Fuzzy SWARA and obtaining the priority order of alternatives through Fuzzy MOORA, the next step is to optimize the selection of the best alternative using the Multi-Objective Linear Programming (MOLP) method. This method integrates the qualitative results in the form of compromise values (S) from Fuzzy MOORA into the linear optimization model, enabling decision-making that considers both expert preferences and operational constraints of the company, such as the number of required tools and working conditions.

The MOLP calculation results indicate that the A2 alternative is the most optimal solution, with decision values *Y2* = 1 and *N2* = 1, while the other three alternatives are not selected (*Y*1 = *Y*3 = *Y*4 = 0). This confirms that A2 is the most suitable for supporting transporting of sugar cane, particularly in terms of performance, energy efficiency, and cost-effectiveness. Thus, the integration of Fuzzy MOORA and MOLP provides a more comprehensive and balanced approach in the selection of sustainable MHE.

## Implications of MHE Selection

The integration of Fuzzy SWARA, Fuzzy MOORA, and Multi-Objective Linear Programming (MOLP) in this study offers a robust framework for the sustainable selection of Material Handling Equipment (MHE), particularly within the context of sugarcane transportation in a sugar factory. The use of Fuzzy SWARA allowed decision-makers to systematically evaluate and assign weights to multiple criteria and sub-criteria, accounting for uncertainty and subjectivity in expert judgment. Subsequently, Fuzzy MOORA enabled the prioritization of alternatives through a compromise ranking that balances multiple performance indicators.

The incorporation of these qualitative results into the MOLP optimization model marks a critical advancement. By using the compromise scores (S values) from Fuzzy MOORA as input parameters, MOLP facilitates a final decision that integrates expert-derived preferences with real-world operational constraints such as equipment requirements, availability, and working conditions. This ensures that the selected alternative is not only the highest-ranked in theory but also feasible and practical in application.

From a practical standpoint, this study provides significant implications for industries seeking to enhance warehouse operations and logistics performance through the careful selection of equipment. The integrative decision-making model proposed here serves as a practical tool for companies, allowing them to improve operational effectiveness by selecting equipment that best fits performance and technical criteria, reduce environmental impact through the selection of energy-efficient and low-emission alternatives, ensure better alignment between equipment capabilities and actual working conditions, reducing the likelihood of underperformance or overinvestment, facilitate structured, transparent, and repeatable decision-making processes grounded in both expert input and quantitative analysis.

# CONCLUSIONS

The integration of Fuzzy SWARA, Fuzzy MOORA, and MOLP enhances the quality of strategic decisions regarding equipment selection by combining expert insight with quantitative rigor. It not only supports the selection of optimal MHE but also contributes to broader organizational goals related to sustainability, cost-efficiency, and operational excellence. Moreover, the flexibility of the model allows it to be adapted and applied in various industrial settings facing similar challenges in selecting sustainable logistics or material handling equipment. The model’s strength lies in its ability to support comprehensive and balanced decision-making, accommodating both subjective expert knowledge and objective optimization. This finding confirms that the selected alternative excels in key areas such as operational performance, energy efficiency, and cost-effectiveness. It aligns with the company’s goals for efficient resource utilization, lower energy consumption, and sustainability in manufacturing process. Future work could incorporate risk factors associated with MHE operations to enhance the selection of the most suitable alternative.

# References

[1] S. Hasan, A. Bouferguene, M. Al-Hussein, P. Gillis, and A. Telyas, "Productivity and CO2 emission analysis for tower crane utilization on high-rise building projects," *Automation in Construction,* vol. 31, pp. 255-264, 2013.

[2] M. Mathew and S. Sahu, "Comparison of new multi-criteria decision making methods for material handling equipment selection," *Management Science Letters,* vol. 8, no. 3, pp. 139-150, 2018.

[3] H. Zhang, Y. Peng, G. Tian, D. Wang, and P. Xie, "Green material selection for sustainability: A hybrid MCDM approach," *PloS one,* vol. 12, no. 5, p. e0177578, 2017.

[4] S. Dabic-Miletic, "Benefits and challenges of implementing autonomous technology for sustainable material handling in industrial processes," *J. Ind Intell,* vol. 2, no. 1, pp. 1-13, 2024.

[5] A. Hadi-Vencheh and A. Mohamadghasemi, "A new hybrid fuzzy multi-criteria decision making model for solving the material handling equipment selection problem," *International Journal of Computer Integrated Manufacturing,* vol. 28, no. 5, pp. 534-550, 2015.

[6] G. G. Torres-Hernandez, R. G. García-Cáceres, and J. W. Escobar-Velásquez, "Reference framework for material handling equipment selection in distribution centres," *International Journal of Logistics Systems and Management,* vol. 46, no. 3, pp. 356-379, 2023.

[7] S. Chatterjee and S. Chakraborty, "Application of the R method in solving material handling equipment selection problems," *Decision Making: Applications in Management and Engineering,* vol. 6, no. 2, pp. 74-94, 2023.

[8] S. S. Goswami and D. K. Behera, "Solving material handling equipment selection problems in an industry with the help of entropy integrated COPRAS and ARAS MCDM techniques," *Process Integration and Optimization for Sustainability,* vol. 5, no. 4, pp. 947-973, 2021.

[9] B. Bairagi, "A new framework for green selection of material handling equipment under fuzzy environment," *Decision Making: Applications in Management and Engineering,* vol. 6, no. 1, pp. 57-69, 2023.

[10] S. Vrtagić, E. Softić, M. Subotić, Ž. Stević, M. Dordevic, and M. Ponjavic, "Ranking road sections based on MCDM model: New improved fuzzy SWARA (IMF SWARA)," *Axioms,* vol. 10, no. 2, p. 92, 2021.

[11] D. H. Qendraj, E. Xhafaj, A. Xhafaj, and E. Halidini, "Ranking the most important attributes of using google classroom in online teaching for Albanian universities: A fuzzy AHP method with triangular fuzzy numbers and trapezoidal fuzzy numbers," *Adv. Sci. Technol. Eng. Syst. J,* vol. 6, pp. 297-308, 2021.

[12] G. Akkaya, B. Turanoğlu, and S. Öztaş, "An integrated fuzzy AHP and fuzzy MOORA approach to the problem of industrial engineering sector choosing," *Expert Systems with Applications,* vol. 42, no. 24, pp. 9565-9573, 2015.