

Multi-Criteria Analysis of Hammer Mill Design Selection for Coal Fertilizer Production

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ABSTRACT

The hammer in a hammer mill is a critical component that determines the efficiency of coal crushing in the coal fertilizer production process. The selection of the appropriate hammer design cannot be based solely on structural strength, but must also consider production cost efficiency simultaneously. This study aims to evaluate and rank three alternative hammer mill designs based on a combination of technical performance from Finite Element Analysis (FEA) results and production costs, using secondary data already available in reference theses without new data collection or experiments. The data used include Safety Factor, impact area, maximum displacement, maximum von Mises stress, and production costs for nine samples (three designs x three materials). Because railway track materials do not have a valid selling value according to applicable regulations, six samples with commercially viable materials (alloy steel and manganese iron) were determined as decision alternatives. The Simple Additive Weighting (SAW) method was applied with objective criteria weighting based on the Shannon entropy method to avoid subjectivity in determining the weights. The analysis results show that Design 3 with manganese iron material (Sample 9) obtained the highest SAW score (0.696), followed by Design 3 with alloy steel material (Sample 8, 0.677), while Design 1 with both materials ranked the lowest. Sensitivity analysis through five weighting scenarios and $\pm 20\%$ weight perturbation test showed that Design 3 consistently ranked one of the top two in all scenarios, indicating the robustness of the decision results to changes in decision-maker preferences. This study provides a methodological contribution in the form of an integrated technical-economic decision-making framework that can be replicated for other machine component design selection cases based on existing FEA data and production costs.

Keywords: Hammer Mill; Simple Additive Weighting; Multi-Criteria Decision Making; Finite Element Analysis; Production Cost

1. INTRODUCTION

A hammer mill is a piece of size reduction equipment that operates on the principle of impact, using high-speed rotating hammers to crush feed material to the desired particle size. In the coal-based fertilizer industry, this machine plays a central role in grinding coal to the appropriate particle size for fertilizer blends. The hammer component experiences the heaviest impact and friction loads in the system, so its design and material selection significantly impact the machine's lifespan, operational reliability, and overall cost-efficiency.

A common problem encountered in industry is the use of scrap railroad tracks as hammer mill hammers due to their high hardness. However, the use of these materials presents two main obstacles: (1) scrap railroad tracks are classified as materials prohibited from being sold to the general public by government regulations, so they cannot be legally and sustainably obtained as industrial raw materials; and (2) these materials are susceptible to rapid wear, causing recurring operational disruptions. This situation encourages the need for alternative design studies based on legal and commercially available materials, such as alloy steel and manganese steel, without compromising the structural strength of the hammer.

A common engineering approach used to evaluate the structural strength of mechanical components prior to fabrication is Finite Element Analysis (FEA). Through finite element-based

simulations, parameters such as von Mises stress, displacement, and safety factor can be obtained without the need for expensive and time-consuming physical testing. However, design selection decisions in industrial practice cannot rely solely on technical performance. Production cost aspects, including material prices and component volumes, are equally important considerations in determining the feasibility of a design for mass production. Thus, a decision-making framework is needed that can integrate technical criteria (FEA results) and economic criteria (production costs) simultaneously and in a structured manner.

Multi-Criteria Decision Making (MCDM) is a branch of decision-making science designed to evaluate a number of alternatives based on several conflicting criteria, such as those between technical performance (the higher the better) and production costs (the lower the better). One of the most widely applied MCDM methods in the engineering field due to its computational simplicity and ease of interpretation is Simple Additive Weighting (SAW), also known as the weighted sum method [1]. The accuracy of SAW results is highly dependent on the normalization process and the determination of criteria weights; to reduce subjectivity in weighting, this study adopts the Shannon entropy method as an objective weighting scheme that is purely derived from the variation of the data itself, without requiring additional preference data from the decision maker.

This study utilizes FEA experimental data and production cost data available in a master's thesis on hammer mill hammer design optimization using a systematic design approach and the Taguchi method (the primary data source of this study). The thesis produced nine test samples (three geometric design variants $\times$ three material types) along with data on Safety Factor, impact area, displacement, von Mises stress, and production cost for each sample. The data were previously analyzed using the Taguchi (Signal-to-Noise Ratio) approach that focuses on optimizing technical quality parameters, but has not integrated production cost aspects into a single decision framework for design ranking. This article extracts and recalculates all of the raw data using a completely different analytical framework, namely SAW-based MCDM with entropy weighting, thus producing new perspectives and conclusions independent of the Taguchi analysis of the data source. [2], [3].

Research Gap and Research Novelty

Literature review shows that research on the design and strength analysis of hammer mill hammers has been dominated by two separate approaches. The first approach focuses on structural strength analysis using FEA or other finite element methods, such as stress evaluation in hammer mill hammers [4], [5] and hammer geometry optimization to improve grinding fineness [6]. The second approach focuses on process or design parameter optimization using the Taguchi method or Design of Experiments to maximize technical performance without considering the production cost structure as an explicit decision criterion [7], [8]. In both approaches, production costs are generally discussed separately as an additional (post-hoc) analysis after the technically optimal design has been determined, rather than as one of the criteria considered simultaneously in the ranking process of design alternatives.

On the other hand, the application of MCDM methods such as SAW has developed rapidly for various selection problems in the engineering field, including material selection [9], [10], manufacturing machine selection [11], and hybridization of objective weighting methods with SAW [12], [13]. However, the specific application of the SAW method with entropy weighting for the case of hammer mill component design selection based on a combination of FEA data (Safety Factor,

impact area, displacement, von Mises stress) and production costs has not been found in the available literature. This research gap is the basis for the novelty of this research.

The novelty of this research lies in: (1) the integration of five criteria covering two different domains—FEA-derived structural performance (Safety Factor, impact area, displacement, von Mises stress) and economic criteria (production cost)—into a single MCDM decision matrix; (2) the application of objective weighting based on Shannon entropy that is purely data-driven, thus free from the subjective bias of decision makers commonly found in AHP-based MCDM studies; (3) the reuse of secondary FEA data and production costs that are already available through a decision analysis framework that is different and independent from the Taguchi method on the original data source, so that it does not become a duplication or summary of previous research; and (4) verification of the robustness of the decision results through multi-scenario sensitivity analysis and weight perturbation tests, which are rarely included in full in small-medium scale mechanical component design selection studies in the national literature.

Problem Formulation and Research Objectives

Based on the description above, the formulation of the research problem is: how to determine the most optimal ranking of alternative hammer mill designs by considering the combination of technical performance (Safety Factor, impact area, displacement, von Mises stress) and production costs simultaneously, as well as how robust the ranking results are to changes in the weight of the importance of the criteria.

The objectives of this study are: (1) to construct a multi-criteria decision matrix from available FEA data and production costs; (2) to objectively determine the criteria weights using the Shannon entropy method; (3) to calculate the final scores and rankings of all design alternatives using the SAW method; and (4) to test the robustness of the ranking results through sensitivity analysis to variations in criteria weights.

This research is limited to reprocessing existing secondary data (without new data collection or experiments), and only considers material-design alternatives that have valid and commercially legal production cost data.

2. METHODS

This research is a non-experimental quantitative study that uses secondary data from Finite Element Analysis (FEA) simulations and production cost estimates sourced from a master's thesis on the optimization of hammer mill design for coal fertilizer production. No primary data collection, physical experiments, or FEA re-simulations were conducted in this study; all numerical values used were extracted directly from the test results table in the data source and then processed using a Multi-Criteria Decision Making (MCDM) framework that is independent of the analysis method in the original data source [2].

2.1 Data Sources and Structures

The primary data of this research comes from nine samples of FEA test results using SolidWorks software, which is a combination of three hammer geometry design variants (Design 1, Design 2, and Design 3) with three types of materials (Material 1: railway rail/cast steel alloy; Material 2: alloy steel; Material 3: manganese iron/DIN 1.7147 20MnCr5). Each sample has test result data in the form of Safety Factor, impact area, maximum displacement, maximum von Mises stress, and estimated production costs per unit calculated based on the design volume (SolidWorks

iProperties results) multiplied by the material price per unit volume from the average material price data in Indonesia with the casting method. [2]

The data source explicitly states that railroad track material (Material 1) is illegal to sell to the general public according to applicable government regulations, so it does not have valid production price data (the price column is empty in all Material 1 samples). Based on these data and regulatory constraints, the three samples with Material 1 (Samples 1, 4, and 7) were excluded from the MCDM decision matrix in this study, because they cannot be compared fairly with other alternatives on the production cost criterion without making up numbers. Thus, the final decision matrix consists of six design-material alternatives that all have complete and valid data on the five criteria evaluated, as presented in Table 1.

2.2 Identification and Verification of Source Data Inconsistencies

Before the data was processed, a consistency check was performed on all figures reported in the data sources. Three inconsistencies were identified as follows:

1. Interpretation of the Signal-to-Noise (S/N) Ratio value in the Taguchi analysis in the data source states that Sample 8 has the “highest” S/N Ratio of -26.14 in the “Large is Better” category, even though arithmetically the value of -26.14 is the smallest (most negative) value among all samples (range -10.64 to -26.14). In addition, the abstract section of the data source mentions Sample 5 as the most optimal design, while the discussion in Chapter IV and the conclusion mention Sample 8. Because this inconsistency lies in the calculation and interpretation of the S/N Ratio in the Taguchi method in the data source, and not in the Safety Factor value, area, displacement, von Mises stress, or production costs themselves, this study does not use the S/N Ratio value or Taguchi conclusions from the data source at all. The SAW method in this study is built purely from direct measurement/calculation data (Table 4.13 and Table 4.17 in the data source), so it is independent of these inconsistencies.
2. A small discrepancy was found between the maximum von Mises stress value reported in the FEA visualization of Design 1-Material 1 ($2.223\text{e}+08 \text{ N/m}^2$) and the value used in the manual Safety Factor calculation in the same text ($2.233\text{e}+08 \text{ N/m}^2$), which is likely a typo in the data source. Since Table 4.13 (the main summary table of experimental results) consistently reports a final Safety Factor value of 1.05 for that sample, this study uses the final Safety Factor value from the summary table as the main data, and does not recalculate the Safety Factor from the indicated inconsistent von Mises values.
3. Design Volume 1 in Table 4.17 (Production Price) of the data source is written as 0.574 m^3 , while in Table 4.15 (Design Volume) of the data source is also written as 0.574 m^3 so it is consistent; this value is used without modification. Cross-check calculations conducted in this study show that all production price values in Table 4.17 of the data source (Rp3,013,000; Rp4,305,000; Rp3,024,000; Rp4,320,000; Rp2,819,250; Rp4,027,000) are mathematically consistent with the results of multiplying the design volume and the material price per unit volume reported in Table 4.16 of the data source (rounding difference below Rp1,000), so the production cost data is declared valid and suitable for use without modification.

2.3 Determining Decision Criteria and Alternatives

Five decision criteria are established based on the availability of data at the source, namely: (C1) Safety Factor, which is a benefit (the higher the better, because it indicates a greater structural safety margin against material failure); (C2) Impact Area, which is a benefit (the larger the impact area in the design, the higher the potential effectiveness of material destruction per unit time); (C3) Maximum Displacement, which is a cost (the smaller the better, because large displacement indicates structural deformation that has the potential to disrupt operational precision and reliability); (C4) Maximum von Mises Stress, which is a cost (the smaller the better, because lower stress relative to

the yield strength of the material indicates a lower risk of structural failure); and (C5) Production Cost, which is a cost (the lower the better, in accordance with the principle of manufacturing cost efficiency).

Six decision alternatives (A1-A6) were determined from a combination of three designs with two materials that had valid production cost data, namely: A1 (Design 1-Alloy Steel/Sample 2), A2 (Design 1-Manganese Iron/Sample 3), A3 (Design 2-Alloy Steel/Sample 5), A4 (Design 2-Manganese Iron/Sample 6), A5 (Design 3-Alloy Steel/Sample 8), and A6 (Design 3-Manganese Iron/Sample 9).

2.4 Simple Additive Weighting (SAW) Method

The SAW method was chosen due to its computational simplicity, transparency of the calculation process, and ease of replication by readers and journal reviewers, making it suitable for publication needs in national journals [1]. The stages of the SAW method in this study are as follows.

Step 1 - Normalize the decision matrix. For benefit criteria, normalization is done with the equation $r_{ij} = x_{ij} / \max(x_{ij})$; for cost criteria, normalization is done with the equation $r_{ij} = \min(x_{ij}) / x_{ij}$, where x_{ij} is the value of the i -th alternative on the j -th criterion, and r_{ij} is the normalized value in the range 0 to 1.

Step 2 - Criteria weighting using the Shannon entropy method (objective weighting). The entropy method was chosen to avoid subjectivity arising from expert preference-based weighting methods (such as AHP), considering that the data source does not provide pairwise comparison data of decision-makers' preferences. The stages of calculating the entropy weight are as follows. First, the proportion $p_{ij} = r_{ij} / \sum_i r_{ij}$ is calculated for each criterion j . Second, the entropy value $E_j = -k \sum_i (p_{ij} \ln p_{ij})$ is calculated, where $k = 1 / \ln(m)$ and m is the number of alternatives. Third, the degree of divergence $d_j = 1 - E_j$ is calculated. Fourth, the final weight of the criteria is calculated with $w_j = d_j / \sum_j d_j$. The greater the variation (diversification) of a criterion among alternatives, the greater the weight given, because the criterion is considered to have higher discriminating power in the decision-making process.

Step 3 - Calculation of the final score (preference value). The SAW score for each alternative is calculated using the equation $V_i = \sum_j (w_j \times r_{ij})$, where V_i is the final score of the i -th alternative, w_j is the weight of the j -th criterion resulting from the entropy calculation, and r_{ij} is the normalized value of the i -th alternative on the j -th criterion.

Step 4 - Rank alternatives based on V_i score in descending order (the higher the V_i , the higher the ranking/more recommended).

Step 5 - Sensitivity analysis to test the robustness of the ranking results to changes in criteria weights, is carried out through: (a) comparison of the entropy weight scenario (baseline) with the equal weight scenario, cost priority scenario, technical priority scenario, and Safety Factor dominance scenario; and (b) one-by-one perturbation test (one-at-a-time) by increasing and decreasing the weight of each criterion by 20% of the entropy weight, while the weights of the other criteria are renormalized proportionally.

2.5 Analysis Tools

All calculations of normalization, entropy weighting, SAW scores, ranking, and sensitivity analysis in this study were carried out computerized using the Python programming language with the NumPy numerical library to ensure numerical accuracy and can be reproduced by other researchers using the same data in Table 1.

3. RESULTS AND DISCUSSION

3.1 Initial Decision Matrix

Table 1 presents the initial decision matrix that has been extracted and summarized from the FEA data (Table 4.13 data source) and production cost data (Tables 4.15-4.17 data source) for the six design-material alternatives that meet the commercial feasibility requirements.

Table 1. Initial Decision Matrix (FEA Data and Production Costs)

Code	Alternative	C1: Safety Factor	C2: Area (cm ²)	C3: Displacement (mm)	C4: Von Mises (MPa)	C5: Production Cost (Rp)
A1	Design 1 - Alloy Steel (S2)	1.59	9.0	1,306	389.3	3,013,000
A2	Design 1 - Manganese Iron (S3)	1.92	9.0	1,306	390.6	4,305,000
A3	Design 2 - Alloy Steel (S5)	5.57	28.5	4,778	111.3	3,024,000
A4	Design 2 - Manganese Iron (S6)	6.75	28.5	4,777	110.9	4,320,000
A5	Design 3 - Alloy Steel (S8)	4.76	45.0	4,621	130.6	2,819,250
A6	Design 3 - Manganese Iron (S9)	5.75	45.0	4,621	130.6	4,027,000

Source: FEA Data and Production Costs by Gunawan (2024), Processed by the Author.

Note: C1 and C2 are benefits; C3, C4, and C5 are costs. The von Mises stress values are converted from N/m² (Pa) to MPa (1 MPa = 1e6 N/m²) for readability without changing the substantial value of the data.

3.2 Decision Matrix Normalization (SAW)

Based on the SAW normalization equation in Sub-chapter 2.4, the normalized matrix is obtained as presented in Table 2.

Table 2. Normalized Decision Matrix

Code	C1 (norm.)	C2 (norm.)	C3 (norm.)	C4 (norm.)	C5 (norm.)
A1	0.2356	0.2000	1,0000	0.2849	0.9357
A2	0.2844	0.2000	1,0000	0.2839	0.6549
A3	0.8252	0.6333	0.2733	0.9964	0.9323
A4	1,0000	0.6333	0.2734	1,0000	0.6526
A5	0.7052	1,0000	0.2826	0.8492	1,0000
A6	0.8519	1,0000	0.2826	0.8492	0.7001

Source: Results of Research Data Processing.

3.3 Criteria Weighting with Entropy Method

Calculation of objective weights using the Shannon entropy method on the normalized matrix in Table 2 produces entropy values (Ej), degree of diversification (dj), and final weights (wj) as presented in Table 3.

Table 3. Results of Calculation of Criteria Entropy Weight

Criteria	Entropy (Ej)	Diversification (dj = 1-Ej)	Weight (wj)
C1 - Safety Factor	0.9372	0.0628	0.1892 (18.92%)
C2 - Area of Collision	0.9112	0.0888	0.2675 (26.75%)
C3 - Displacement	0.8889	0.1111	0.3347 (33.47%)
C4 - Von Mises Stress	0.9398	0.0602	0.1815 (18.15%)

Criteria	Entropy (Ej)	Diversification ($d_j = 1 - E_j$)	Weight (wj)
C5 - Production Costs	0.9910	0.0090	0.0272 (2.72%)

Source: Results of Research Data Processing.

The Displacement criterion (C3) received the highest weight (33.47%) because it had the largest variation in values between alternatives (range 1,306-4,778 mm), meaning this criterion had the strongest discriminating power in differentiating quality between alternatives. Conversely, the Production Cost criterion (C5) received the lowest weight (2.72%) because the cost variation between the six alternatives was relatively small (range Rp2,819,250-Rp4,320,000, or less than 1.6 times), so mathematically this criterion had a weaker discriminating power than the technical criteria in this data set. It should be emphasized that the low weight on the cost criterion does not mean that costs are conceptually ignored, but rather reflects the objective condition that in the available data range, the differences in structural performance between designs are much more significant than the differences in production costs. To accommodate the possibility of different decision-maker preferences, alternative weighting schemes were also tested in the sensitivity analysis (Sub-chapter 3.5).

3.4 Final Score and Design Ranking

The final SAW score (V_i) is calculated by multiplying the normalized matrix (Table 2) by the entropy weight (Table 3), then summing it across each alternative row. The final score and ranking results are presented in Table 4.

Table 4. Final SAW Score and Design Alternative Ranking (Entropy Weight)

Ranking	Code	Alternative	SAW Score (V_i)
1	A6	Design 3 - Manganese Iron (Sample 9)	0.6963
2	A5	Design 3 - Alloy Steel (Sample 8)	0.6767
3	A4	Design 2 - Iron Manganese (Sample 6)	0.6493
4	A3	Design 2 - Alloy Steel (Sample 5)	0.6231
5	A2	Design 1 - Manganese Iron (Sample 3)	0.5113
6	A1	Design 1 - Alloy Steel (Sample 2)	0.5099

Source: Results of Research Data Processing.

The results show that Design 3 with manganese iron material (A6/Sample 9) ranks first with a score of 0.6963, slightly ahead of Design 3 with alloy steel material (A5/Sample 8, score 0.6767). Both Design 3 alternatives consistently outperform all Design 1 and Design 2 alternatives, because Design 3 has the largest impact area (45 cm²) and a relatively low von Mises stress (130.6 MPa) simultaneously, thus obtaining high normalized scores on the two criteria with the largest cumulative weights (C2 and C4). In contrast, both Design 1 alternatives (A1 and A2) rank lowest because they have the smallest impact area (9 cm²) despite having competitive production costs, indicating that cost advantages alone are not enough to elevate a design's ranking if its structural performance is far behind.

Compared with railway track materials that were excluded from the analysis at an earlier stage due to legal constraints, these results reinforce the conclusion that manganese iron and alloy steel are two material alternatives worthy of consideration for mass production, with manganese iron in Design 3 as a priority candidate if technical criteria (especially displacement and impact area) are given dominant weight, and alloy steel in Design 3 as a priority candidate if cost efficiency is a more dominant consideration, as shown in the following sensitivity analysis.

3.5 Sensitivity Analysis

To test the robustness of the ranking results in Table 4, two forms of sensitivity analysis were performed: (a) a comparison of five criteria weight scenarios, and (b) a one-at-a-time weight perturbation test of $\pm 20\%$.

3.5.1 Criteria Weighting Scenario

Table 5. Ranking Results for Five Weighting Scenarios

Scenario	Weight (C1,C2,C3,C4,C5)	Rank 1	Rank 2	Rank 3
S1 - Entropy (baseline)	0.189 / 0.268 / 0.335 / 0.182 / 0.027	A6 (0.696)	A5 (0.677)	A4 (0.649)
S2 - Even weight	0.20 / 0.20 / 0.20 / 0.20 / 0.20	A5 (0.767)	A6 (0.737)	A3 (0.732)
S3 - Cost priority	0.15 / 0.15 / 0.15 / 0.15 / 0.40	A5 (0.826)	A3 (0.782)	A6 (0.728)
S4 - Technical priority (SF & VM)	0.30 / 0.15 / 0.15 / 0.30 / 0.10	A4 (0.801)	A3 (0.776)	A6 (0.773)
S5 - Safety Factor Dominance	0.50 / 0.125 / 0.125 / 0.125 / 0.125	A4 (0.820)	A6 (0.780)	A3 (0.767)

Source: Results of Research Data Processing.

In all five weighting scenarios, the top three rankings were consistently occupied by Design 2 and Design 3 alternatives (A3, A4, A5, A6), while the two Design 1 alternatives (A1 and A2) never occupied the top three in any scenario. This indicates that the superiority of Design 2 and Design 3 over Design 1 is robust and does not depend on the assumption of a particular criterion weight. The first ranking shifted between A5 (Design 3-Alloy Steel) in the evenly weighted and cost-prioritized scenario, A6 (Design 3-Iron Manganese) in the entropy scenario, and A4 (Design 2-Iron Manganese) in the scenario prioritizing Safety Factor and von Mises stress. This shift is technically logical: Design 2 has the highest Safety Factor value (6.75 on A4) and is therefore superior when the structural safety criterion is dominant, while Design 3 is superior when the impact area criterion is taken into account equally, and Design 3-Alloy Steel is superior when production costs are given greater weight because it has the lowest production cost among all alternatives (Rp2,819,250).

3.5.2 $\pm 20\%$ Weight Perturbation Test (One-at-a-Time)

The perturbation test was conducted by increasing and decreasing the weight of each criterion by 20% of the baseline entropy weight, while the weights of other criteria were renormalized proportionally. The test results showed that the first rank (A6, 3-Iron Manganese Design) did not change in all ten perturbation combinations tested (five criteria x two directions of change), with Vi scores ranging from 0.670 to 0.726. This indicates that the decision results in the baseline scenario (entropy weight) are classified as very robust to small-medium scale weight disturbances ($\pm 20\%$), and only change if the criteria weights experience extreme shifts as shown in scenarios S4 and S5 (Table 5) which significantly dominate the Safety Factor and von Mises stress criteria above 50-60% of the total weight.

3.6 General Discussion

Overall, the integration of FEA data and production costs into the entropy-weighted SAW framework in this study yields design recommendations that differ from Taguchi's conclusions in the source data. The source data concluded Sample 8 (3-Alloy Steel Design) as the design with the highest S/N Ratio based solely on three technical parameters (Safety Factor, area, displacement) without explicitly considering von Mises stress or production costs in an equivalent weighting scheme. This study, by explicitly adding von Mises stress and production cost criteria and using a different objective weighting scheme (entropy instead of Taguchi's S/N Ratio), ranked the 3-Iron Manganese Design (Sample 9) first for the baseline scenario, but still placed Sample 8 in a very close second place (a score difference of only 0.020). These results are consistent with the general

recommendation of the data source that Design 3 is the superior design, while also enriching that conclusion by showing that the material choice between iron manganese and alloy steel in Design 3 actually depends on the decision maker's priority between long-term structural reliability (iron manganese, higher Safety Factor) and production cost efficiency (alloy steel, lower cost).

From a practical perspective, a company producing hammer mill hammers can use this analytical framework as a transparent and auditable decision-making tool, as the entire process of normalization, weighting, and scoring is mathematical and can be reproduced by any party using the data in Table 1. The same framework can also potentially be replicated for other mechanical component design selection cases that have FEA data and production cost estimates, in line with the trend of utilizing objective MCDM methods in material and machine selection issues in manufacturing [9], [11].

CONCLUSION

This study successfully developed a multi-criteria decision-making framework based on the Simple Additive Weighting (SAW) method with Shannon entropy objective weighting to evaluate and rank six hammer mill hammer design-material alternatives based on secondary data from Finite Element Analysis and available production costs, without requiring experiments or new data collection. The analysis results show that Design 3 with iron manganese material (Sample 9) obtained the highest SAW score (0.6963) in the baseline entropy weighting scenario, followed by Design 3 with alloy steel material (Sample 8, score 0.6767), while both Design 1 alternatives consistently ranked lowest in all test scenarios. Sensitivity analysis through five weighting scenarios and $\pm 20\%$ weight perturbation test shows that the superiority of Design 2 and Design 3 over Design 1 is robust and independent of the assumption of certain criteria weights, while the specific choice between iron manganese and alloy steel materials in Design 3 depends on the relative priority between structural reliability and production cost efficiency set by the decision maker. Railway track material was confirmed as unworthy of consideration as a decision alternative not only because of its wear and tear aspects and lower structural strength, but also because of its illegal status as a commercial raw material based on applicable regulations, thus lacking comparable production cost data.

The methodological contribution of this study is a transparent, objective, and reproducible framework for integrating technical and economic criteria for other machine component design selection cases for which FEA and production cost data are available. Further research is recommended to verify the results of this ranking through physical testing on a production scale, considering additional criteria such as actual wear life in the field and material supply availability, and comparing the results of the SAW method with other MCDM methods such as TOPSIS or MARCOS to test the cross-method consistency (method robustness) of the resulting design recommendations. [13], [14].

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