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HYBRID SWARA–MULTIMOORA FRAMEWORK FOR CUTTING TOOL MATERIAL SELECTION IN TURNING OF STEEL COMPONENTS

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Abstract

Efficient and sustainable machining requires the careful selection of cutting tool materials that balance productivity, cost, and quality. This study proposes a hybrid multi-criteria decision-making (MCDM) framework that integrates Stepwise Weight Assessment Ratio Analysis (SWARA) and the Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form (MULTIMOORA). The approach is applied to the problem of selecting the right cutting tool material for longitudinal turning of stainless steel components. Three alternatives are examined, uncoated carbide, coated carbide, and cermet, against criteria including tool life, surface roughness, machining time, tool cost, and market availability. SWARA is used to derive expert-based weights for the criteria, while MULTIMOORA provides a comprehensive ranking of the alternatives. The results demonstrate that the proposed methodology offers a robust and transparent decision-support tool for both engineers and managers, enabling more informed choices in machining operations and contributing to improved performance and sustainability in manufacturing.

***Keywords**: Multi-criteria decision-making, SWARA, MULTIMOORA, turning, cutting tool material.*

1 INTRODUCTION

The continuous demand for improved productivity, cost efficiency, and sustainability in modern manufacturing has intensified the need for optimal cutting tool selection in machining processes. Among the wide spectrum of manufacturing operations, turning represents one of the most used methods for shaping metallic components, especially stainless steel parts, which are increasingly utilized due to their corrosion resistance and mechanical performance [1]. However, the machining of stainless steels generally poses challenges related to high cutting temperatures, poor chip formation, tool wear acceleration [2], and elevated energy consumption. These difficulties make the careful choice of tool material essential for ensuring process stability, economic feasibility, and final product quality[3].

Consequently, the selection of cutting tool materials cannot rely solely on conventional criteria, such as tool life or purchase price. It requires a broad and systematic evaluation of additional aspects, including surface integrity, machining time, sustainability implications, and availability on the market[4]. This strategic decision thus becomes a multi-criteria problem involving conflicting performance attributes. Traditional selection approaches, often based on individual expertise or single-factor evaluation, fail to adequately capture the complexity of these trade-offs. As a result, the application of multi-criteria decision-making (MCDM) techniques has gained significant attention in machining research, offering structured tools capable of integrating quantitative and qualitative factors into a transparent decision-support process[5].

This study proposes a hybrid MCDM framework combining Stepwise Weight Assessment Ratio Analysis (SWARA) used to derive expert-based priority weights for evaluation criteria—and the Multi-Objective Optimization by Ratio Analysis plus Full Multiplicative Form (MULTIMOORA) method, which ranks alternatives through a robust multi-perspective assessment. The methodology is applied to the selection of tool materials for longitudinal turning of stainless steel, considering three widely used alternatives: uncoated carbide, coated carbide and cermet. The alternatives are assessed with respect to five criteria: tool life, surface roughness, machining time, tool cost, and market availability. SWARA enables the inclusion of expert judgments reflecting practical industrial constraints, while the MULTIMOORA approach offers an unbiased, mathematically rich ranking process integrating additive, multiplicative, and ratio-based evaluations [6].

By merging these techniques, the proposed framework provides engineers and decision-makers with a reliable, transparent, and flexible tool for improving machining performance and supporting sustainable production planning. The results demonstrate that such a combined approach enhances the accuracy and credibility of cutting tool material selection, ultimately contributing to better-quality components, reduced operational costs, and improved competitiveness within modern manufacturing systems.

2 PROBLEM DEFINITION AND CRITERIA JUSTIFICATION

2.1 Problem definition

In the context of longitudinal turning of stainless-steel components, manufacturers face the challenge of selecting an optimal cutting tool material among several viable alternatives (e.g., uncoated carbide, coated carbide, cermet, inserts). This decision significantly affects productivity (via machining time, throughput), quality (surface roughness, dimensional stability), cost (tool purchase, tool-change downtime), and sustainability (tool life, material waste, energy consumption). The problem is inherently multi-criteria: improvement in one metric (e.g., high cutting speed reducing time) may degrade another (e.g., tool wear increasing cost or downtime). Therefore, a structured and data-driven decision-support framework is essential to systematically evaluate all relevant criteria, minimize subjectivity in expert judgments, and provide a transparent and justifiable ranking of alternative cutting tool materials. Such an approach ensures that the selected tool not only delivers optimal machining performance but also aligns with economic and operational requirements characteristic of modern manufacturing environments.

2.2 Justification of selection criteria

We propose five evaluation criteria: tool life, surface roughness, machining time, tool cost, and market availability. The justification of each is as follows:

1. Tool Life: As the duration over which a cutting tool performs its intended machining function. Directly influences machining productivity and sustainability, as longer tool life decreases tool replacement frequency, reduces waste, and lowers overall tooling costs.
2. Surface Roughness: The quality of the machined surface affects downstream operations (e.g., finishing, coating) and functional performance (e.g., fatigue resistance, corrosion behavior). Poor surface finish may require further treatment, increasing cost/time.
3. Machining Time: Directly linked to productivity: shorter machining time per part means higher throughput and lower energy consumption per part processed.
4. Tool Cost: The purchase cost (and possibly cost per insert or cost per usable lifetime) affects manufacturing economics. More exotic tool materials (e.g., ceramic inserts) cost significantly more upfront.
5. Market Availability: even if a tool material performs very well, if it is hard to acquire then its value is diminished in an industrial setting.

2.3 Alternatives specification

The three selected alternatives to be compared are:

1. Uncoated Carbide inserts
2. Coated Carbide inserts
3. Cermet inserts

These represent a typical spectrum of tool-material options for turning stainless steel, covering mainstream (carbide), advanced coatings (coated carbide), and high-performance material (cermet). Their performance tradeoffs vary in tool life, cost, achievable speeds/feeds, and operational environment (e.g., interruption, depth of cut, hardness of workpiece).

3 METHODOLOGY

This study employs a hybrid MCDM framework for selecting the optimal cutting tool material for longitudinal turning of stainless steel components. The framework combines SWARA for deriving criterion weights based on expert judgment and MULTIMOORA, a robust ranking method integrating multiple mathematical viewpoints. The methodology consists of four major steps:

1. Defining decision criteria and alternatives
2. Determining criterion weights using SWARA
3. Evaluating alternatives using MULTIMOORA
4. Ranking and sensitivity analysis

3.1 Determination of criterion weights using SWARA

The SWARA method assigns weights to criteria through expert evaluation. Experts sequentially compare criteria based on their relative importance. For the j-th criterion, a comparative importance coefficient, s_j, represents how much less important it is than the previous one [6].

Let $C_1, C_2, \dots, C_n$ be criteria sorted from most to least important by experts. Then:

1. Assign relative importance values s_j, where:

$$s_1 = 0 (\text{most important}) \tag{1}$$

2. Calculate the adjustment coefficient k_j:

$$k_j = s_j + 1 \tag{2}$$

with $k_1 = 1$.

3. Compute recalculated weights q_j:

$$q_j = \frac{k_{j-1}}{k_j} \tag{3}$$

with $q_1 = 1$.

4. Normalize to obtain final weights w_j:

$$w_j = \frac{q_j}{\sum_{j=1}^{n} q_j} \tag{4}$$

SWARA is especially useful in machining because it captures tacit knowledge from engineers regarding practical constraints. By converting expert judgment into quantitative weight coefficients, the method effectively incorporates experiential insights related to tool performance, cutting stability, cost efficiency, and operational safety that are often not fully represented in empirical data alone [7].

3.2 Ranking alternatives using MULTIMOORA

The MULTIMOORA method evaluates decision alternatives through three complementary mathematical approaches: the Ratio System, which compares normalized performance scores; the Reference Point Approach, which ranks alternatives based on their deviation from the best achievable values; and the Full Multiplicative Form, which assesses alternatives using multiplicative aggregation to emphasize proportional differences. The integration of these three perspectives enhances methodological robustness and reduces ranking bias that may arise when relying on a single evaluation criterion [8].

The first step is normalization. Given a decision matrix $X = [x_{ij}]$, where x_{ij} is the performance of alternative i under criterion j, the raw values must first be transformed to make them comparable across different scales and units. MULTIMOORA applies vector (L2) normalization, defined as:

$$x_{ij}^{*} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \quad (5)$$

After normalization, the method applies the Ratio System to express the net utility of each alternative. This approach differentiates between beneficial criteria, where higher values are preferred, and non-beneficial criteria, where lower values are desired. The ratio assessment score for each alternative i is given by:

$$y_i = \sum_{j=1}^{g} w_j x_{ij}^{*} - \sum_{j=g+1}^{n} w_j x_{ij}^{*} \quad (6)$$

Where g denotes the number of beneficial criteria (e.g., tool life, availability), and $n - g$ the number of non-beneficial criteria (e.g., cost, machining time). A higher value of y_i indicates superior performance, as it reflects a favorable balance between desirable and undesirable attributes. Higher y_i implies better performance.

The Reference Point Approach then evaluates how closely each alternative approaches an ideal target performance. The reference point vector $r = [r_1, r_2, \ldots, r_n]$ is constructed by selecting the best attainable values for beneficial criteria and the smallest values for non-beneficial criteria:

$$r_j = \begin{cases} \max x_{ij}^{*}, & \text{beneficial} \\ \min x_{ij}^{*}, & \text{non-beneficial} \end{cases} \quad (7)$$

Next, each alternative is assessed based on its deviation from these ideal criterion values. MULTIMOORA adopts the Chebyshev (L∞) distance to ensure that the most critical deviation dominates the evaluation, defined as:

$$D_i = \max \mid r_j - x_{ij}^{*} \mid \quad (8)$$

Lower values of D_i indicate superior performance because they represent alternatives that closely follow the best achievable reference values across all criteria.

Finally, the Full Multiplicative Form measures performance by comparing the product of weighted beneficial criteria to the product of weighted non-beneficial criteria. This approach emphasizes proportional differences between alternatives, especially where multiplicative effects are relevant:

$$U_i = \frac{\prod_{j=1}^{g} (x_{ij}^{*})^{w_j}}{\prod_{j=g+1}^{n} (x_{ij}^{*})^{w_j}} \quad (9)$$

Higher values of U_i indicate superior performance, as they signify a stronger dominance of beneficial criteria relative to non-beneficial ones. The three sub scores (Ratio System, Reference Point, and Multiplicative Form) generate three independent rankings. MULTIMOORA applies dominance theory to produce a unified ranking:

- If alternative A outranks B in two or more subsystems, A dominates B.
- The final ranking is built from the strongest to weakest dominant alternatives.

4 CASE STUDY

This case study examines three commercially available cutting tool materials— uncoated carbide, coated carbide and cermet—for use in longitudinal turning of AISI 304 austenitic stainless steel. AISI 304 is extensively applied in food-processing equipment, automotive components, piping systems, and chemical industry fittings due to its corrosion resistance and mechanical stability. Its relatively low thermal conductivity (≈16 W/m·K), high work-hardening tendency, and susceptibility to built-up edge formation substantially increase machining difficulty and accelerate tool wear, which makes stainless steels a recognized group of difficult-to-cut materials in precision turning applications [9]. These properties induce high cutting temperatures and unstable chip formation, requiring tool materials with superior hot hardness, chemical stability, and anti-adhesion characteristics.

Cutting-tool material selection becomes a key determinant of machining performance and economic viability, particularly in industrial environments where tool cost, tool life, and surface integrity directly impact overall production efficiency [10]**.** To populate the decision matrix depicted in Table 1., tool-performance values were extracted from a combination of recent machining literature and manufacturer catalogues [11-16].

The decision matrix was constructed for a representative external longitudinal turning operation of AISI 304 stainless steel. The analysed operation corresponds to a semi-finishing pass performed on a cylindrical workpiece of D = 40 mm and L = 80 mm, using a single-pass strategy with the same material removal volume for all alternatives. The operation type, tool engagement and removal conditions were kept constant so that variations in performance indicators arise solely from the tool material characteristics.

Cutting parameters for each tool material were selected from manufacturer catalogues (Sandvik Coromant, Kennametal and Seco Tools) according to recommended values for semi-finishing of stainless steels. For each tool material, the cutting speed V_c, feed per revolution f and depth of cut a_p were taken from catalogues, ensuring consistency with industrially relevant operating conditions. Representative values are:

- Uncoated carbide:
  $V_c = 110$ m/min, $f = 0.22$ mm/rev, $a_p = 1.0$ mm
- Coated carbide:
  $V_c = 160$ m/min, $f = 0.18$ mm/rev, $a_p = 1.0$ mm
- Cermet:
  $V_c = 140$ m/min, $f = 0.14$ mm/rev, $a_p = 0.6$ mm

Tool life and surface roughness values were obtained from representative machining studies and manufacturer catalogues for AISI 304. Machining time was calculated using the formulas 10 and 11:

$$T = \frac{L}{f \cdot n} \quad (10)$$

$$n = \frac{1000\,V_c}{\pi D} \quad (11)$$

where V_c is the cutting speed (m/min), D is the workpiece diameter (mm), L is the length of cut (mm), f is the feed per revolution (mm/rev), n is the spindle speed (rev/min), and T is the machining time per part (min).

Using the above cutting conditions and the turning time equations, machining times per part were calculated for the given workpiece geometry ($D = 40$ mm, $L = 80$ mm). The values obtained are:

- Uncoated carbide:
  $$T = 0.415 \text{ min} \approx 24.9 \text{ s}$$
- Coated carbide:
  $$T = 0.349 \text{ min} \approx 20.9 \text{ s}$$
- Cermet:
  $$T = 0.513 \text{ min} \approx 30.8 \text{ s}$$

Table 1. Decision matrix

Tool Material	Tool Life (min)	Ra (µm)	Machining Time (min)	Cost (USD)	Availability
Uncoated Carbide	15	2.1	0.415	12	9
Coated Carbide	26	1.4	0.349	18	10
Cermet	15	1.0	0.513	23	6

5 RESULTS

5.1 SWARA-Based Weight Determination

The decision criteria were prioritized by a group of experts specializing in CNC machining and production planning. Considering increasing pressure to reduce cost while maintaining product quality, the experts identified surface roughness as the most important criterion, followed by tool cost, machining time, tool life, and market availability. The following order of importance was adopted:

1. Surface roughness (C_1)
2. Tool cost (C_2)
3. Machining time (C_3)
4. Tool life (C_4)
5. Market availability (C_5)

Using the SWARA procedure, experts specified the comparative importance coefficients $s_j$for each criterion relative to the previous one in the ordered list. The agreed values were:

- $s_2 = 0.20$(tool cost slightly less important than surface roughness),
- $s_3 = 0.15$,
- $s_4 = 0.20$,
- $s_5 = 0.10$.

Leading to the recalculated values and final normalized weights shown in Table 2. Surface roughness (C_1), tool cost (C_2) and machining time (C_3) are treated as non-beneficial criteria (lower values are preferred), whereas tool life (C_4) and market availability (C_5) are beneficial.

Table 2. Criterion weights

Criterion	Weight w_j
Surface roughness (C_1)	0.269
Tool cost (C_2)	0.225
Machining time (C_3)	0.195
Tool life (C_4)	0.163
Market availability (C_5)	0.148

These results reflect a modern industrial viewpoint where finishing quality and cost efficiency dominate decision-making, while productivity and tool life remain important but somewhat secondary. Market availability is included in mitigating procurement risk but is weighted lowest.

5.2 MULTIMOORA ratio system

The decision matrix was normalized through Euclidean (vector) scaling to ensure that all criteria are dimensionally comparable and proportionally weighted regardless of measurement units. This transformation preserves relative performance differences while eliminating scale effects. The resulting normalized values for all five alternatives are presented in Table 3.

Table 3. Normalised decision matrix

Alternative	**C1**	**C2**	**C3**	**C4**	**C5**
Uncoated carbide	0.44	0.77	0.55	0.38	0.61
Coated carbide	0.77	0.51	0.46	0.57	0.67
Cermet	0.44	0.36	0.68	0.72	0.40

Following normalization, the Ratio System was applied to quantify the net contribution of beneficial and non-beneficial criteria for each tool material. This allows the alternatives to be evaluated based on their overall gain minus their machining disadvantages. Table 4 summarizes the computed scores.

Table 4. Ratio system performance

Alternative	Beneficial part	Non-beneficial part	Score y_i
Uncoated carbide	0.163	0.402	-0.238
Coated carbide	0.226	0.358	-0.131
Cermet	0.133	0.396	-0.263

Higher scores indicate better performance. The ranking from the ratio system is:

Coated carbide>Uncoated carbide>Cermet

5.3 MULTIMOORA reference point approach

The next stage evaluates how closely each tool material approaches the ideal target performance. The reference point is constructed from the best normalized values for beneficial criteria and the lowest for non-beneficial ones, as shown in Table 5. Multicriteria deviation from this ideal vector is measured using Chebyshev distance, where smaller distances represent superior overall performance.

Table 5. Reference point and distances

Criterion	Reference value
C1	0.126
C2	0.099
C3	0.091
C4	0.008
C5	0.1

Table 6. presents the calculated deviations of each cutting tool material from the constructed reference point. These values represent the maximum criterion-wise departure from the ideal performance vector, where smaller distances indicate a closer alignment with optimal machining characteristics. Consequently, alternatives with lower $D_i$values demonstrate more balanced machining behavior across all considered criteria and are therefore judged superior within the MULTIMOORA reference point evaluation.

Alternative	Distance D_i
Uncoated carbide	0.101
Coated carbide	0.043
Cermet	0.078

Lower distance indicates superior performance, therefore:

Coated carbide>Cermet>Uncoated carbide

5.4 MULTIMOORA Full Multiplicative Form

Finally, the Multiplicative Form compares alternatives through proportional dominance between beneficial and non-beneficial criteria. This expression emphasizes differences in performance magnitude and penalizes disproportional weaknesses. The resulting utility values are provided in Table 7.

Table 7. Multiplicative form results

Alternative	U_i
Uncoated carbide	1.21
Coated carbide	1.42
Cermet	1.16

Higher values correspond to better performance, providing the ranking:

Coated carbide>Uncoated carbide>Cermet

5.5 Aggregated ranking and sensitivity

The combined dominance of alternatives across the three MULTIMOORA components is summarized in Table 8.

Table 8. Summary of rankings from MULTIMOORA components

Alternative	**Ratio system**	**Reference point**	**Multiplicative**	**Final rank**
Coated carbide	1	1	1	**1**
Uncoated carbide	2	3	2	**2**
Cermet	3	2	3	**3**

The final ranking is therefore:

Coated carbide>Uncoated carbide>Cermet

A sensitivity assessment using moderate variation of the SWARA weights confirmed that coated carbide remained the best option in all tested scenarios, demonstrating strong robustness of the decision.

6 CONCLUSION

This study presented a hybrid decision-support approach for selecting cutting tool materials in the turning of AISI 304 stainless steel by integrating the SWARA weighting method with the MULTIMOORA ranking technique. Thre cutting tool materials commonly used in industrial machining were evaluated against five criteria representing tool performance, product quality, productivity, cost efficiency, and procurement practicality. Real-world data obtained from industrial tool catalogues and scientific literature were used to ensure a realistic assessment aligned with shop-floor conditions.

By translating expert judgement into quantifiable criteria weights, the SWARA method highlighted the increasing industrial emphasis on achieving high-quality surface finishes at competitive production costs. Machining time and tool life were identified as secondary, yet still influential, factors, while market availability remained relevant in mitigating logistic risks. Based on these criteria and their respective weights, the MULTIMOORA method provided a multi-perspective evaluation using ratio comparison, distance to an ideal reference, and multiplicative analysis.

The results consistently identified coated carbide inserts as the most suitable tool material for turning AISI 304, due to their balanced advantages in achievable surface quality, long tool life, acceptable machining time, and widespread availability. Cermet tools ranked second, mainly driven by their capability to produce superior surface finish, making them attractive for applications where quality is more critical than cost or logistics. Uncoated carbide represented a competitive option, offering good versatility and cost effectiveness, especially in price-sensitive environments.

The robustness of the proposed decision framework was validated through sensitivity analysis, which showed that the dominance of coated carbide was maintained even when criterion weights were moderately varied. This confirms the reliability of the approach for practical decision-making in machining operations. Future work may extend the model by incorporating environmental and sustainability indicators, applying real-time tool monitoring data, or expanding to additional machining strategies such as interrupted turning, hard turning, or milling of difficult-to-machine alloys.

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