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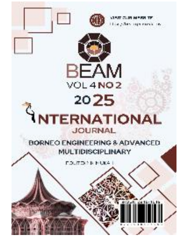

# Manufacturing Process Selection for Automotive Bumper Fascia Using an Integrated Analytical Hierarchy Process (AHP) – VIKOR Approach

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## Abstract

Selecting the most suitable manufacturing process for automotive bumper fascia is a complex decision-making problem due to the presence of multiple criteria and alternative options. This study presents a systematic evaluation to assess options by integrating the Analytic Hierarchy Process (AHP) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods. The objective is to determine the most appropriate manufacturing process for an automotive bumper fascia. Four potential manufacturing processes were evaluated, namely injection moulding, reaction injection moulding, compression moulding, and vacuum forming. The evaluation was based on six main selection criteria. AHP was used to determine the criteria weights, while VIKOR was applied to rank the alternatives. The integrated approach revealed that compression moulding (MP 3) is the most suitable manufacturing process for automotive bumper fascia. This combined decision-making framework effectively supports the selection of the optimal manufacturing process and can also be applied to other complex industrial decisions involving multiple factors.

*Keywords: - Analytical hierarchy process (AHP), VIKOR, manufacturing process selection, automotive bumper fascia*



## 1. Introduction

Considering Concurrent Engineering (CE) principles during product development is essential for improving design efficiency, reducing time-to-market, and enhancing overall product quality. A cornerstone of CE is early decision-making, which focuses on making informed, proactive choices during the initial phases of design and manufacturing. Early intervention facilitates the identification and resolution of potential design or production issues before they evolve into costly modifications or delays (Zhong et al., 2017).

The automotive industry, a pivotal segment of global manufacturing, involves the complex integration of vehicle design, development, production, and distribution across various types of vehicles, including passenger cars, commercial trucks, buses, and motorcycles. Among the key safety components in vehicle design are bumper systems, which serve as the primary defense mechanism in low-speed collisions as shown in Fig. 1.

This system not only absorbs impact energy but also mitigates structural damage and enhances occupant safety (Khan et al., 2023). Given their dual role in safety and aesthetics, bumper fascia must be produced using manufacturing processes that deliver optimal mechanical performance, surface quality, cost-effectiveness, and environmental sustainability. Therefore, selecting the most appropriate manufacturing process at an early stage is both a strategic and technically complex task, as it impacts critical decisions related to tooling, material selection, production scalability, and overall product lifecycle performance (Arslan et al., 2023).

To address this complex challenge, this study implements an integrated multi-criteria decision-making

(MCDM) framework combining the Analytical Hierarchy Process (AHP) and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods. AHP is utilized to structure the decision problem hierarchically and assign relative weights to the evaluation criteria based on expert input (Saaty & Vargas, 2012). VIKOR is employed to rank alternative manufacturing processes by analyzing their performance against the weighted criteria, thereby facilitating a balanced trade-off analysis among competing objectives such as cost, lead time, structural integrity, and environmental compliance (Yazdani et al., 2022). By integrating AHP and VIKOR, the selection model offers a systematic and evidence-based framework for identifying the most suitable process, guided by six primary selection criteria and twelve sub-criteria derived from both academic literature and industrial best practices.

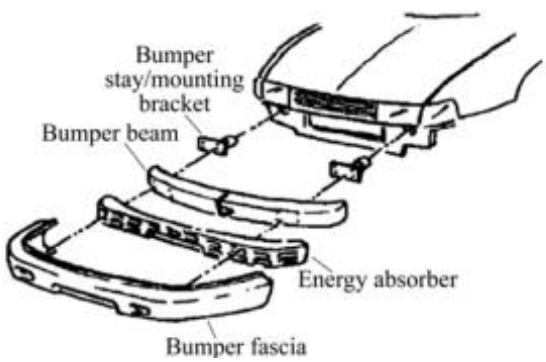


Fig. 1: Bumper systems (Rush, 1990)

In conclusion, the integration of AHP-VIKOR at the early design phase not only improves decision accuracy but also ensures transparency, consistency, and traceability, which are critical to the success of concurrent engineering (Tareq et al., 2024).

## 2. Literature Review

Considering the best manufacturing process at the early stage of product design has been widely recognized as one of the most critical phases in new product development as it determines the direction of the downstream design activities. MPS is a vital step in product development process, directly influencing cost, quality, sustainability, and time-to-market. In the face of increasing complexity and competing objectives, Multi-Criteria Decision-Making (MCDM) methods such as the Analytic Hierarchy Process (AHP) and VIKOR have become popular for structuring and solving MPS problems.

AHP was developed by Saaty (1980), facilitates decision-making by decomposing complex problems into hierarchical structures and conducting pairwise comparisons among criteria. It has been widely used in the manufacturing decision problems for its ability to incorporate both subjective judgments and quantitative data. For instance, Luqman et al. (2018) implemented AHP to determine the most suitable process to be employed in manufacturing of composite bicycle crank arm at the early stage of the product development process. VIKOR (Opricovic & Tzeng, 2004) addressed decision problems involving conflicting criteria by identifying compromise solutions close to the ideal. VIKOR is particularly suitable when decision-makers seek a balance between group utility and individual regret. VIKOR is employed to evaluate sustainable manufacturing processes and highlighted its advantage in handling trade-offs among environmental, economic, and technical factors. The method's ranking mechanism is valuable when decision-makers must choose among alternatives that excel in different aspects.

Recent studies have shown the advantages of integrated AHP-VIKOR approaches. AHP is often used to determine the relative weights of decision criteria, while VIKOR ranks the alternatives based on those weights. This integration combines the structural clarity of AHP with the compromise-focused ranking of VIKOR. Integrated AHP-VIKOR model is used for selecting optimal machining processes in the presence of uncertainty. Jayant & Singh (2015) used AHP and VIKOR for tackling multi criteria problems with conflicting and noncommensurable (different units) criteria. Zhu et al. (2015) employed integrating AHP and VIKOR to evaluate design concepts under subjective environment. Ortiz and López (2016) presented the application of AHP-VIKOR technique to support market selection process. Raju et al. (2024) used integrated AHP and VIKOR to evaluate seven different material options on sixteen criteria that comprise corrosion resistance, mechanical properties, cost, and a negative environmental impact.

Several researchers have extended AHP and VIKOR using fuzzy logic, intuitionistic sets, and machine learning integration. For example, a fuzzy AHP-VIKOR method is applied to select sustainable manufacturing technologies, demonstrating improved accuracy and stakeholder satisfaction. Babashamsi et al. (2016) addressed the prioritization of pavement maintenance alternatives by integrating the fuzzy analytic hierarchy process (AHP) with the VIKOR method. Despite their advantages, both AHP and VIKOR have limitations. AHP may suffer from inconsistency in judgment when the number of criteria is large (Saaty, 1980), while VIKOR relies heavily on the determination of best and worst values, which may be subjective (Opricovic & Tzeng, 2004).

Although there are many articles discussing the integrated application of AHP and VIKOR, there are still limited in terms of manufacturing process selection in automotive bumper fascia at the early stage of the design process that need to be explored.

## 3. Methodology

The research methodology presents the use of integrated AHP and VIKOR in determining the most appropriate manufacturing process for automotive bumper fascia as depicted in Fig. 2. It consists of two phases, Phase 1: Calculate the weight of each criterion via AHP. After forming a decision hierarchy, the weights of each criterion are calculated by AHP. A pair-wise comparison matrix (Table 1) of experts' evaluations is constructed to acquire criterion weights by using the scale in Table 2. Phase 2:

Evaluate manufacturing process options and determine the final rank by VIKOR as depicted in Table 3. There are four potential manufacturing processes were evaluated, namely injection moulding (MP1), reaction injection moulding (MP 2), compression moulding (MP 3) and vacuum forming (MP 4). The selection of the best manufacturing process depends upon a variety of factors and most of these factors are interrelated.

Table 1: AHP pairwise comparison

| Goal | GD | PC | CS | MT | EM | AV |
|---|---|---|---|---|---|---|
| Geometry of design (GD) | 1 | 3 | 3 | 5 | 5 | 1 |
| Production characteristics (PC) | 1/3 | 1 | 1/4 | 3 | 3 | 1/3 |
| Cost consideration (CS) | 1/3 | 4 | 1 | 3 | 3 | 1/3 |
| Material (MT) | 1/5 | 1/3 | 1/3 | 1 | 1 | 1/5 |
| Ease of maintenance (EM) | 1/5 | 1/3 | 1/3 | 1 | 1 | 1/5 |
| Availability of labour and equipment (AV) | 1 | 3 | 3 | 5 | 5 | 1 |

Table 2: AHP scale (Zhu et al., 2015)

| Numerical rating | Definition | Explanation |
|---|---|---|
| 1 | Equally preferred | Two activities contribute equally to the objective |
| 3 | Moderately preferred | Experience and judgment slightly favour one over another |
| 5 | Strongly preferred | Experience and judgment strongly favour one over another |
| 7 | Very strongly preferred | An activity is strongly favoured and its dominance is demonstrated in practice |
| 9 | Absolutely preferred | Importance of one over another affirmed on the highest possible order |
| 2, 4, 6, and 8 | Intermediate values | Used to represent compromise between the priorities listed above |
| Reciprocals ($1/a_{ij}$) | A value attributed when activity i is compared to activity j becomes the reciprocal when j is compared to i | |

Table 3: Normalized Data of Final Selection (VIKOR)

| Weights (AHP) | 0.170 | 0.307 | 0.114 | 0.05 | 0.05 |
|---|---|---|---|---|---|
| | | | Benefits | | |
| Criteria/ options | CS | GD | PC | MT | EM |
| MP 1 | 4 | 5 | 4 | 4 | 6 |
| MP 2 | 4 | 5 | 3 | 5 | 8 |
| MP 3 | 2 | 5 | 2 | 3 | 8 |
| MP 4 | 1 | 1 | 1 | 3 | 8 |
| best | 4 | 5 | 4 | 5 | 8 |
| worst | 1 | 1 | 1 | 3 | 6 |

## 4. Results and Discussion

In the evaluation of manufacturing process selection for automotive bumper fascia, an integrated approach employing AHP and VIKOR was utilized to support comprehensive decision-making, as depicted in Fig. 2. After progressing through AHP stages the result of weights of each criterion is depicted in Table 4.

To verify the consistency of the experts' pairwise judgments in AHP, the consistency ratio (CR) was calculated. The resulting CR value was 0.0425, which is below the acceptable threshold of 0.1, indicating that the judgments are c onsistent and reliable. However, if CR exceeds 0.1, the judgment matrix is deemed inconsistent and should be revised and improved (Saaty and Vargas, 2012).

Table 5 shows the results of the VIKOR application, ranking compression moulding as the best alternative with a Qi (VIKOR index) value of 0.0000, satisfying the first condition. The second-best alternative is injection moulding with a Q value of 0.0611, followed by reaction injection moulding as the third and vacuum forming as the least preferred, with Q values of 0.3132 and 1.0000, respectively.

Table 5: Results of ranking using VIKOR

| Criteria | Qi (VIKOR index) | Manufacturing process | Rank based on Qi |
|---|---|---|---|
| MP1 | 0.1611 | Injection moulding | 2 |
| MP2 | 0.000 | Compression moulding | 1 |
| MP3 | 0.3132 | Reaction injection moulding | 3 |
| MP4 | 1.0 | Vacuum Forming | 4 |

The second condition, acceptable stability, was met as compression moulding achieved top ranks in both S (utility measure) and R (Regret measure). The difference in Q values between compression moulding and injection moulding exceeded the DQ value, indicating its superiority. Thus, the integrated AHP-VIKOR method identifies compression moulding as the optimal manufacturing process for automotive bumper fascia. This integrated approach considers multiple criteria and offers a balanced compromise solution for decision-making in manufacturing processes.

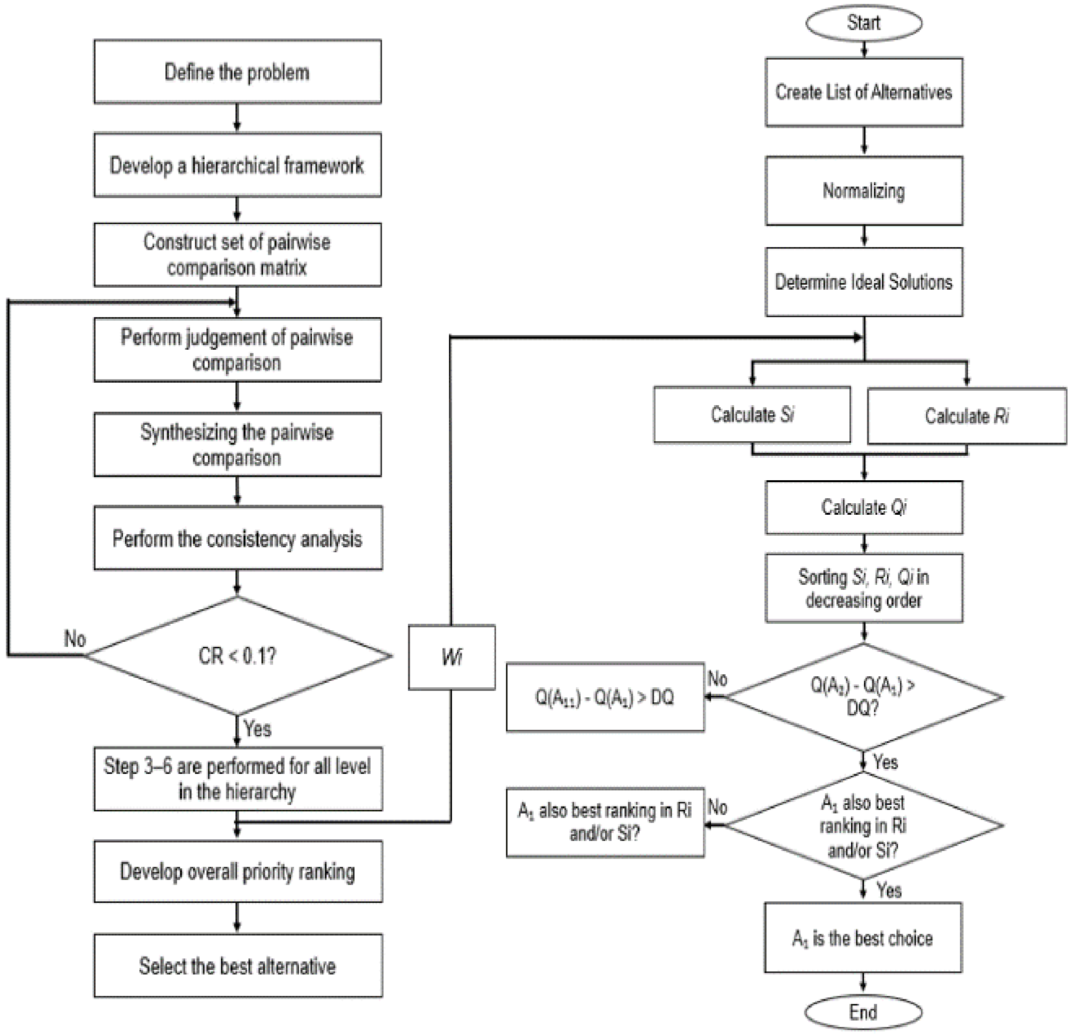


Fig. 2: Integrated AHP-VIKOR approach

## 5. Conclusion and Recommendations

In conclusion, selecting an appropriate manufacturing process for automotive bumper fascia is crucial for ensuring vehicle crashworthiness and occupant protection during collisions. This study highlights the importance of employing a systematic decision-making approach in manufacturing process selection. The integration of AHP and VIKOR provides a synergistic and effective method for evaluating and selecting the most suitable manufacturing process. The results showed that compression moulding (MP 3) is the best option, followed by injection moulding, reaction injection moulding, and vacuum forming.

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