

A Management Decision-Making Approach Using Integrated FMECA–AHP for Selecting the Best Conceptual Alternative

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Abstract

This study introduces a management-oriented decision-making framework that integrates Failure Mode, Effects and Criticality Analysis (FMECA) with the Analytical Hierarchy Process (AHP) to enhance the rigour and reliability of design evaluation processes. Although widely used in engineering applications, conventional decision approaches often lead to inefficiencies, prolonged evaluation cycles, and suboptimal performance outcomes due to their reliance on intuition or limited analytical structure. To demonstrate the practical utility of the proposed integrated framework, a case study was conducted to determine the most suitable conceptual design for a motorized rolling machine. The analysis identified Design 3 as the preferred option, achieving the highest overall score of 29.4% based on combined performance, cost, and risk-related criteria. The findings indicate that the FMECA–AHP integration improves transparency in the assessment process, minimizes subjective judgment biases, and supports a systematic comparison of competing design alternatives. Overall, the framework enhances organizational capability for structured, consistent, and evidence-based decision making in early-stage product development.

Keywords: Management Decision-Making, Failure Mode Effect and Critical Analysis (FMECA), Analytical Hierarchy Process (AHP), Design Selection and Design Process

Introduction

In competitive business environments, managers must make timely and effective decisions despite complex uncertainties and multiple conflicting criteria. Managers can use structured decision-making tools, such as multi-criteria decision-making (MCDM), to evaluate alternatives systematically and make rational, consistent, and timely decisions under uncertainty and competing objectives (Taherdoost and Madanchian 2023). Traditional decision-making approaches often rely on intuition or incomplete information, which may

lead to inconsistent outcomes. Structured decision tools such as the Analytical Hierarchy Process (AHP) and risk-based techniques such as Failure Mode, Effects and Criticality Analysis (FMECA) provide robust alternatives to support rational evaluation (Dabous et al. 2021). A wide range of management decision-making techniques such as Failure Mode and Effects Analysis (FMEA), Design for Manufacturability and Assembly (DFMA), Quality Function Deployment (QFD), and the Analytic Hierarchy Process (AHP). They are widely employed in industry, particularly during the early stages of product design, to support engineers and design teams in systematically addressing design-related problems (Ho and Maity 2024).

The quality control method such as FMEA that is practiced in industry can be integrated with another method if the enhancement of the product quality is needed. In order to produce a high quality of product, the designer needs to implement an effective quality related tools, for example FMEA and QFD which can be observed as a tool under the umbrella of concurrent engineering (Sapuan et al. 2006; Elbadawi et al. 2022). Hence, the objective of this paper is to illustrate the application of integration of FMECA and AHP so that can be used as one of management decision tools during development of a product especially in the early stage of the product development process. The integration between FMECA and other design methods have been proposed by researchers to improve the function of traditional FMECA. The integrations constructed depend to the area and capabilities of the method to be used.

Günaydın and Deste (2025) proposed a hybrid framework that integrates classical FMEA with multiple fuzzy MCDM techniques—fuzzy TOPSIS, fuzzy VIKOR, fuzzy GRA, and fuzzy MOORA—weighted through DEMATEL, to generate an averaged ranking that enables more sensitive failure analysis and mitigates the limitations of individual methods. Hameed et al. (2022) proposed a holistic methodology in which FMEA, QFD, TRIZ, LCA, and fuzzy TOPSIS were integrated to sustainably, economically, and innovatively redesign a pressure relief valve, with the final design chosen for prototyping. Di Nardo et al. (2022) proposed EN-B-ED Dynamic FMECA, integrating Entropy, BWM, EDAS, and System Dynamics, introducing cost as an objective factor to assess machine failure risks, applied in an Italian agri-food company. La Fata et al. (2022) introduced an interval-based ELECTRE TRI method to enhance FMECA by addressing uncertainty in expert evaluations and weighting risk parameters, providing a more robust management decision tool for classifying and prioritizing failure modes, validated through a propulsion-system case study.

To implement an integrated FMECA–AHP approach effectively, it is essential to critically examine the limitations of both traditional FMECA and existing hybrid FMECA–AHP frameworks. Conventional FMECA predominantly emphasizes technical risk factors—Severity, Occurrence, and Detectability—while often neglecting the economic implications of identified failure modes. This limitation can result in risk prioritization that does not accurately reflect the true operational impact, particularly when failure-related costs, including maintenance expenses, downtime, and resource allocation, are significant. Recent studies have indicated that many current FMECA applications continue to overlook broader economic considerations, potentially leading to incomplete or suboptimal decision outcomes (ElKasrawy et al., 2025).

The integration of AHP within the FMECA framework addresses these shortcomings by providing a structured multi-criteria decision-making mechanism capable of incorporating

cost and other relevant managerial parameters alongside technical factors. Through AHP, structured pairwise comparisons facilitate the assignment of weights that reflect organizational priorities, encompassing financial, safety, performance, and sustainability considerations (Chennoufi & Chakhrit, 2024). Although FMECA–AHP hybrids have been applied in various risk and reliability contexts, few studies have focused on their application in early-stage conceptual design, where economic, functional, and safety criteria must be concurrently evaluated. To address this gap, the integrated FMECA–AHP framework was applied in the present study to support the systematic selection of the optimal conceptual design for a motorized rolling machine, demonstrating its effectiveness as a comprehensive management decision-making tool.

The Integrated Framework of FMECA and AHP

The integrated FMECA–AHP framework was developed as presented in Figure 1. To illustrate its practical application in management decision perspective, a case study involving the selection of a motorized rolling machine design was conducted, as elaborated in next topic.

Determining The Best Design Concept Of Motorized Rolling Machine: A Case Study

A managerial case scenario was employed to demonstrate the applicability of the integrated framework in supporting concept selection within an organizational setting. Multiple conceptual alternatives were assessed using a set of criteria that included performance, cost, maintenance requirements, and potential risk factors. FMECA was utilised to identify critical failure risks and to assign severity, occurrence, and detection ratings. These outputs were subsequently incorporated into the AHP evaluation, enabling decision-makers to systematically consider both quantitative and qualitative criteria. There are five steps to perform the integrated process as discussed below:

Step 1: Perform FMECA Analysis

The FMECA analysis was performed to determine the risk level of each fault in terms of severity, occurrence, and detection of the failure. Each potential of failure was identified and measured by using the severity, occurrence and detection data as proposed by Hu et al. (2013). The detail of the analysis is shown in Table 1.

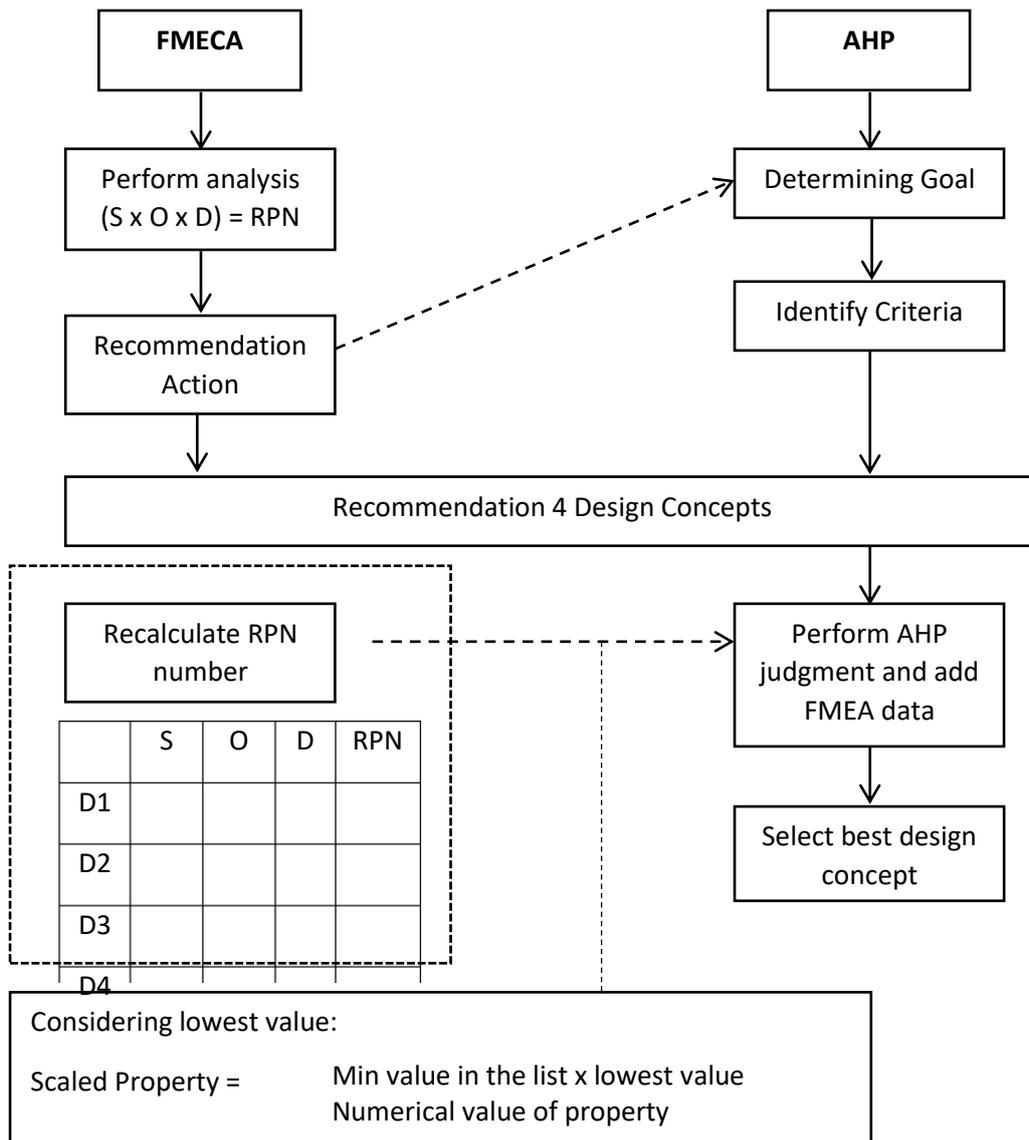


Fig. 1 The integrated FMECA and AHP framework

Step 2: Determining Recommendation Action and Recalculated RPN Number

The action to improve the current potential of failure was identified and four design concepts were proposed to solve the problem on a non-functional rolling machine as shown in Figure 2. After that, the risk priority number (RPN) was reduced by recalculating based on the recommended design concepts.

Step 3: Identify Product Design Specification (PDS)

The intention of the product design specification (PDS) must be set early in the process and represent the guide for the development. It was really essential to the success of the product since it is significant in describing the requirement of the product (Johari and Katimon 2023).

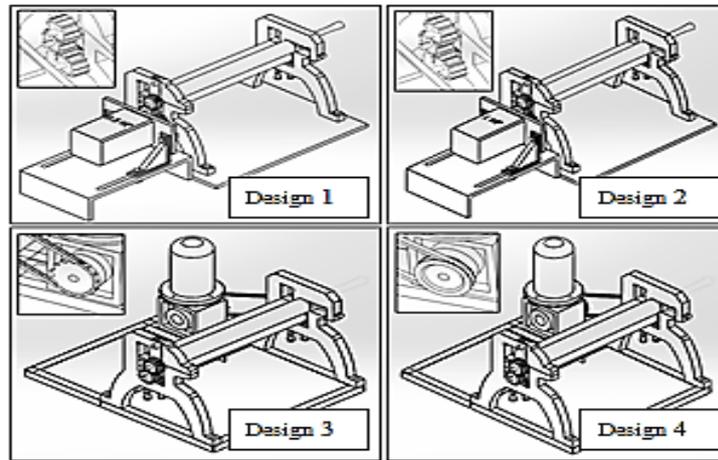


Fig. 2 Design concept of motorized rolling machine

Step 4: Performing AHP Analysis

After the recommended action and the criteria have been identified, the AHP judgment was performed by adding the FMECA data in the judgment. The AHP hierarchy structure was developed as in Figure

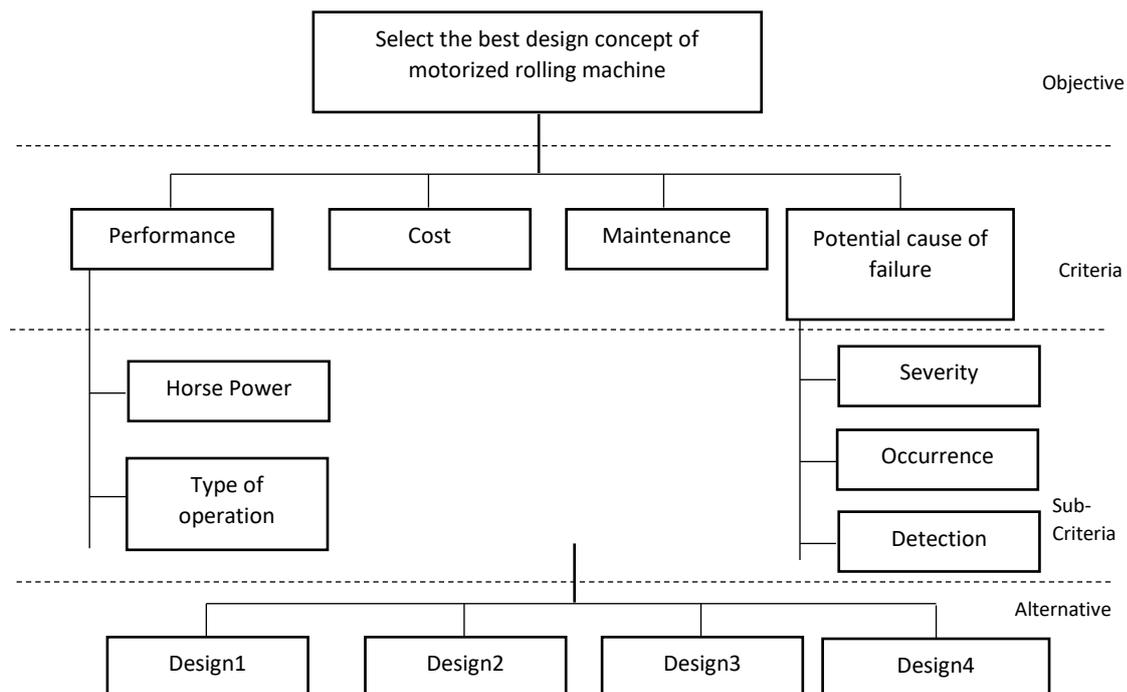


Fig. 3 The hierarchy structure to select the best design concept of motorized rolling machine

Design FMECA analysis for motorized rolling machine

ITEM (COMPONENT AND FUNCTION)	REQUIREMENT	POTENTIAL FAILURE MODE	POTENTIAL EFFECTS OF FAILURE	SEVERITY CLASSIFICATION	POTENTIAL CAUSE(S) OF FAILURE	CURRENT PROCESS			DETECTION	RPN	RECOMMENDED ACTION	SEVERITY OCCURRENCE DETECTION RPN				
						CURRENT CONTROLS PREVENTION	OCCURRENCE	CURRENT CONTROLS, DETECTION				SEVERITY	OCCURRENCE	DETECTION		
Motor	To move the roller	Motor jams	Rolling machine cannot be used to roll the sheet metal	8	Motor have no enough horsepower to perform the operation	None	10	None	3	240	Change to different motor with higher horsepower	Design 1 (0.5 HP)	3	2	2	12
												Design 2 (1HP)	1	1	2	2
Gear	Motor and roller connector	Backlash	Motion not smooth	5	Gear spec. was wrong	None	10	None	2	100	Change gear to the sprocket	Design 3	2	1	2	4
											Change gear to belting	Design 4	4	2	2	16

Table 2 Scale for pair-wise comparisons (Marques-Carvalho et al. 2025).

RELATIVE INTENSITY	DEFINITION	EXPLANATION
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favours one requirement over another
5	Essential or strong value	Experience strongly favours one requirement over another
7	Very strong value	A requirement is strongly favoured, and its dominance is demonstrated in practice
9	Extreme value	The evidence favouring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgements	When compromise is needed
Reciprocals	Inverse comparison	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i

The pairwise comparison was performed by comparing the relative importance of two criteria or alternative. The judgment was interpreted into a score via the use of relative nine-point scale as shown in Table 2 (Marques-Carvalho et al. 2025). A team of expertise in the rolling

machine operation and product development was responsible to do the judgement. Expert choice application was used to assist the AHP analysis. The application was developed by Forman et al. (2000) as a multi criteria decision support application based on the AHP methodology. Through this application, the priority of pairwise comparison was calculated automatically.

The summary of pairwise comparison judgment to get the priority vector for qualitative criteria was demonstrated as shown in Table 3.

Table 3
Pairwise comparison for main criteria

	P	C	M	PCF	PRIORITY
PERFORMANCE (P)	1	1/5	1/3	1/3	0.080
COST (C)	5	1	3	2	0.486
MAINTENANCE (M)	3	1/3	1	1	0.207
POTENTIAL CAUSE OF FAILURE (PCF)	3	1/2	1	1	0.227
NOTE: INCONSISTENCY RATIO = 0.01					

The advantage of the AHP is the consistency verification where performed to measure the degree of consistency among the pairwise comparisons by computing the consistency ratio (CR) (Azroy et al. 2015). Since the inconsistency of pairwise comparison judgment is less than or equal to 0.1, it shows the judgements made are consistent. After the priority vector for qualitative criteria was determined, the priority vector for quantitative data was calculated, there is comparison of alternative with respect to motor horsepower, cost, severity, occurrence and detection. The calculation to determine the priority vector for quantitative criteria was based on Braglia’s technique (Braglia 2000). The original value of data was used directly by applying the Braglia Technique. For example, the severity scored from the recommendation action, which is 3, 1, 2 and 4 was use directly to determine the priority.

Since the different desirable level condition between cost, severity (S), occurrence (O) and detection (D) with the other criteria, the scaled property evaluation was added to determine the priority vector. The priority vector for severity was calculated as shown in Table 4.

Table 4
Priority vector for alternative with respect to severity

Alternative	BRAGLIA TECHNIQUE			SCALED PROPERTY		
	Severity score			Scaled property		Priority
Design 1	3	3/10	=0.30	$(0.1 \times 0.1) / 0.30 = 0.03$	0.03/0.21	= 0.16
Design 2	1	1/10	=0.10	$(0.1 \times 0.1) / 0.10 = 0.10$	0.01/0.21	= 0.48
Design 3	2	2/10	=0.20	$(0.1 \times 0.1) / 0.20 = 0.05$	0.05/0.21	= 0.24
Design 4	4	4/10	=0.40	$(0.1 \times 0.1) / 0.40 = 0.03$	0.03/0.21	= 0.12
Total	10		1.00	0.21		1.00

The calculation to determine the quantitative criteria was repeated for determining the priority vector for occurrence, detection and cost. Overall priority vector was summarized in Table 5. All of the quantitative criteria were filled in the Expert choice direct assessment to

complete the AHP analysis. The AHP analysis was completed, and the result of the best concept design can be determined as shown in Figure 4.

Table 5
Overall priority vectors for AHP judgment

CRITERIA		PERFORMANCE		COST	MAINTENANCE	POTENTIAL CAUSE OF FAILURE		
		0.080		0.486	0.207	0.227		
Sub Criteria		Horse power	Type of operation			Severity	Occurrence	Detection
		0.50	0.50			0.40	0.40	0.20
Alternative	Design 1	0.20	0.375	0.221	0.125	0.160	0.170	0.250
	Design 2	0.40	0.375	0.177	0.125	0.480	0.330	0.250
	Design 3	0.20	0.125	0.294	0.375	0.240	0.330	0.250
	Design 4	0.20	0.125	0.308	0.375	0.120	0.170	0.250

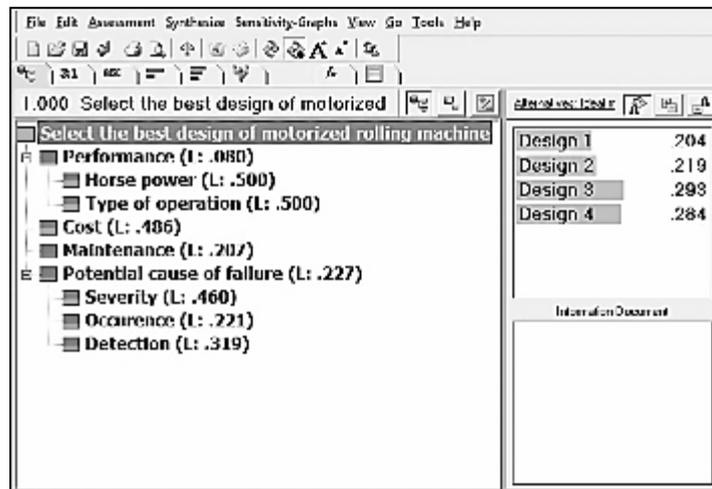


Fig. 4 Overall priorities for criteria, sub criteria and alternative by Expert choice

Step 5: Select the Best Design Concept

The best design concept for the motorized rolling machine is shown in Table 6. Based on the scores obtained, the best design is Design 3 (29.4%) followed by Design 4 (28.2%), Design 2 (22.3%) and Design 1 (20.1%).

Table 6
Result for the best design for motorized rolling machine

RANKING	ALTERNATIVE	SCORE	PERCENTAGE
1	Design 3	0.294	29.4%
2	Design 4	0.282	28.2%
3	Design 2	0.223	22.3%
4	Design 1	0.201	20.1%

Results

The integrated FMECA–AHP method produced a clear ranking of conceptual alternatives, enabling managers to select the option with the highest overall priority score. Through this integrated approach, Design 3 (29.4%) was identified as the best design concept after considering both the potential causes of failure and the product design specifications of the motorized rolling machine. Design 4 achieved the second-highest score at 0.282 (28.2%), while Design 1 recorded the lowest score at 0.201 (20.1%). The results further indicate that risk-informed decision frameworks enhance organizational decision quality by clarifying evaluation criteria, mitigating subjective judgment bias, and facilitating a structured and transparent comparison of alternatives.

Conclusion

This study demonstrates that integrating FMECA with AHP supports robust managerial decision-making. The framework enables organizations to systematically evaluate alternatives by incorporating performance, cost, and risk considerations. The integrated approach also introduces quality-related factors into the AHP evaluation by incorporating FMECA data, making it applicable during the early stages of the design process. The results show that Design 3 was selected as the best concept due to its highest overall score of 29.4%, while Design 1 recorded the lowest score at 0.201 (20.1%). Overall, the findings demonstrate that combining FMECA and AHP provides a systematic decision-support mechanism that enables decision-makers to identify and justify the most appropriate alternative during organizational decision-making and product development processes.

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