Risk Analysis of Aircraft Maintenance, Repair and Overhaul (MRO) Project Delays Using a Fuzzy Logic Approach

*Mochamad Auliya Rasyid[1], A. A. B. Dinariyana[1]

[1] *Interdisciplinary School of Management Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*
**Corresponding author. Email: auliyarasyid@yahoo.co.id*

ABSTRACT

The aircraft MRO business is high-risk, particularly in terms of project delay for any reason such as workload limitation and acquisition of materials. This challenge is reflected in PT Garuda Maintenance Facility AeroAsia Tbk 2023 annual report performance where Service Level Agreement (SLA) realization was only 96.05% from the target of 100% and Customer Satisfaction Index (CSI) was 3.97, which is slightly off the target of 4.00. Subjective in nature, traditional risk analyses are. This study aims to objectively identify and quantify risk factors causing delay of MRO projects and formulate risk treatment plans. The methodology integrates expert interviews with fuzzy set theory for the quantification of qualitative data and is organized with the use of the ISO 31000 risk management standard. From analysis of 20 risk variables, it was determined that material-related problems are the most prevalent cause of delay. In particular, material delivery delay (R09) was the most critical with a risk score of 89.31%, followed by equipment damage and limitations (R02) and warehouse material shortages (R11). These results reflect the high-risk operating conditions for MRO projects where 75% of the risks were "High" in classification. The study concludes fuzzy logic application was successful in quantifying subjective expert views, being a more objective and nuanced basis on which to rank the risks than conventional methods. The ultimate risk ranking serves as an important tool for management with which to develop targeted risk treatment programs, highlighting improving supply chain control, improving equipment reliability, and streamlining workload manpower planning in the aim of achieving SLA and overall operational efficiency improvements.

Keywords: *Fuzzy Logic, MRO, Project Delays, Project Management, Risk Management*.

1. INTRODUCTION

The MRO company significantly contributes to the safety and operational continuity of airlines aviation industries. The global market for MRO is projected to grow rise up, with the Asian market projected to record a Compound Annual Growth Rate (CAGR) of 3.5% from 2025 to 2035 [1]. The projection of Indonesia national market for MRO is projected to grow from USD 1.2 billion in 2020 to USD 4.288 billion by 2045 [2].

Behind this growth potential, MRO projects are faces challenges by issues that cause delays in the form of shortage qualified manpower, supply chain problem, and financial limitations of customers [3]. The delay not only drive up operational costs but also degrade customer confidence and company reputation branding [4]. One of the determinant of this issue is in PT GMF AeroAsia Tbk 2023 annual report performance, whereby the SLA achievement was merely 96.05% with bellow a target of 100%. This deficiency led to a CSI of 3.97, just below the target of 4.00 [5].

The conventional risk analysis techniques may be dependent on subjective judgments and difficult to manage the qualitative of MRO project risk [6]. For this purpose, in this research, a fuzzy set theory approach is proposed because it is able to transform linguistic and subjectivity data into quantitative form, thereby increasing the level of precision in risk analysis. For filling this gap, in this research, a fuzzy logic method in the ISO 31000 framework is to assess project delay risk within the aircraft MRO sector a field where this technique has not been widely applied.

2. PREVIOUS RESEARCHES

Table 1. Risk Matrix

Risk Matrix		Consequence				
		Insignificant	Minor	Moderate	Major	Catastrophic
Likelihood	Certain	Medium	High	High	Crisis	Crisis
	Likely	Low	Medium	High	Crisis	Crisis
	Possible	Low	Medium	High	High	High
	Unlikely	Low	Low	Medium	Medium	High
	Rare	Low	Low	Low	Low	Medium

Fuzzy logic technique has widely been applied to risk management across various industries like an energy, construction, and shipp with a success rate in dealing with uncertainty and qualitative data. For example, Gallab et al. (2019) designed a Mamdani type fuzzy inference system for risk evaluation in maintenance activities that was reported to yield more accurate results than the conventional method [7]. Rachmawati et al. (2023) also successfully applied fuzzy set theory to classify delay risk of power plant project using qualitative variables [4]. In construction, fuzzy similarity [8] and integrating fuzzy logic with AHP were employed to build risk register and prioritize risk in a systematic method [9, 10]. A research in the ship industry also effectively incorporated Job Safety Analysis (JSA) into a Fuzzy Inference System to evaluate risks in ship maintenance operations [11].

There is limited research applying fuzzy logic to aircraft MRO project delay directly. There have been previous research in the MRO field that addressed delay risks based on the traditional ISO 31000 model show in Table 1 without fuzzy integration [3] or other research that identified logistical issues and supply chain agility as primary causes of MRO delays without considering advanced risk quantification methods [12, 13]. No prior research was found that directly integrates the ISO 31000 methodology with a fuzzy logic approach for assessing delay risks in aircraft MRO projects. Accordingly, this research is poised to fill this knowledge gap by developing a systematic risk assessment model that together an international risk management standard with a fuzzy logic model.

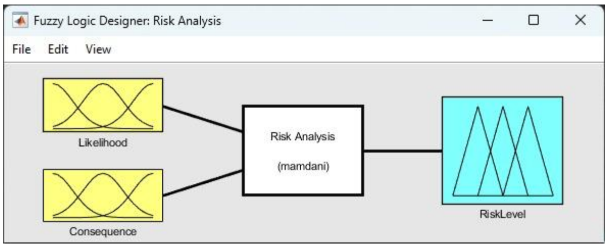


Figure 1 The Fuzzy Logic Modelling

3. METHODOLOGY

This research utilized a case study approach at PT Garuda Maintenance Facility AeroAsia Tbk, where delay risk on MRO project were the focused interest. This study using by the ISO 31000 risk management framework [14], which includes risk identification, analysis, assessment, and treatment, with a fuzzy logic model for an objective risk evaluation.

Table 2. MRO Project Delay Risk Variables

No	Code	Risk	Category	Refference
1	R01	Equipment delivery delay	Machine	Zulaiha et al. (2019)
2	R02	Equipment damage and limitations	Machine	El-Karim et al. (2017)
3	R03	Capacity limitations	Machine	Hossen et al. (2015)
4	R04	Infrastructure unavailable at the workplace	Machine	Putra & Taufik (2022)
5	R05	Lack of skilled and experienced employees	Manpower	Putra & Taufik (2022)
6	R06	Excessive workload	Manpower	Anggraini et al. (2019)
7	R07	Inefficient resource planning	Manpower	Hossen et al. (2015)
8	R08	Insufficient number of employees	Manpower	Gebrehiwet & Luo (2015)
9	R09	Material delivery delay	Material	Putra & Taufik (2022)
10	R10	Defective material received	Material	Shangea et al. (2020)
11	R11	Material shortage in the warehouse	Material	Pratiwi et al. (2021)
12	R12	Material unavailable in the local market	Material	Gebrehiwet & Luo (2015)
13	R13	Additional work from the Customer	Method	Muliano et al. (2021)
14	R14	Unilateral decision from the customer	Method	Hossen et al. (2015)
15	R15	Force majeure (weather, disaster, etc.)	Method	Gebrehiwet & Luo (2015)
16	R16	Planning errors	Method	Putra & Taufik (2022)
17	R17	Late payment by the Customer	Money	Pratiwi et al. (2021)
18	R18	Global Financial issues	Money	Gebrehiwet & Luo (2015)
19	R19	Customer's Financial capability	Money	Hossen et al. (2015)
20	R20	Lengthy payment process	Money	El-Karim et al. (2017)

Primary data were collected through questionnaires and interviews from 57 industry experts, including management, functional manager and project manager. The sample population was highly experienced, with 89.38% having over 10 years of experience in the MRO sector, show a credibility to the data collected. Secondary data were obtained from company internal reports, literature review, industry standards, and public report.

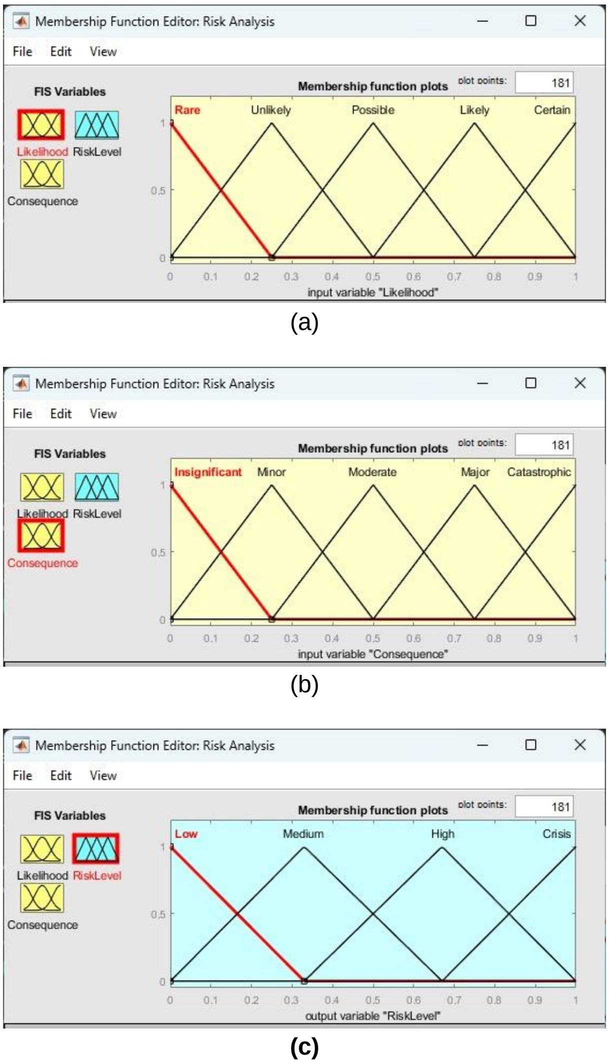


Figure 2 The Membership Function Plot of (a) Likelihood, (b) Consequence, and (c) Risk Level

The research process encompassed several steps:

Risk Identification: Twenty possible risk causes for the project delays were evaluated by literature review and expert judgement, and were categorized into machine, manpower, material, method, and money as shown in Table 2.

Fuzzy Logic Modeling: Figure 1 is a model was designed to assess risks based on an input likelihood and consequence. The three main steps of fuzzy logic (fuzzification, inference, and defuzzification) were using to process the input systematically [15] .

Fuzzification: Experienced linguistic judgments were converted into Triangular Fuzzy Numbers (TFNs) as shown in Figure 2.

Fuzzy Inference System: Set of 25 IF-THEN rules, as shown in Figure 3, based on the model Mamdani inference system, was used to process the fuzzy input with an output fuzzy level of risk.

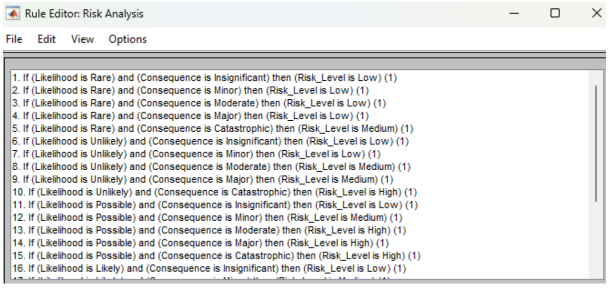


Figure 3 The Fuzzy Rule Membership

Defuzzification: The centroid method was used to convert the fuzzy risk level output into one crisp numerical value that can be using as result.

Development of Managerial Implications: The top ranked risk factor were evaluated as studied to conclude action managerial implications from the analysis. This last step converts the quantitative results before risk treatment for policy making strategic insights, resource optimization, and enhancing the overall Governance, Risk & Compliance (GRC) system so that the research is of practical utility for the organization.

4. RESULT AND DISCUSSION

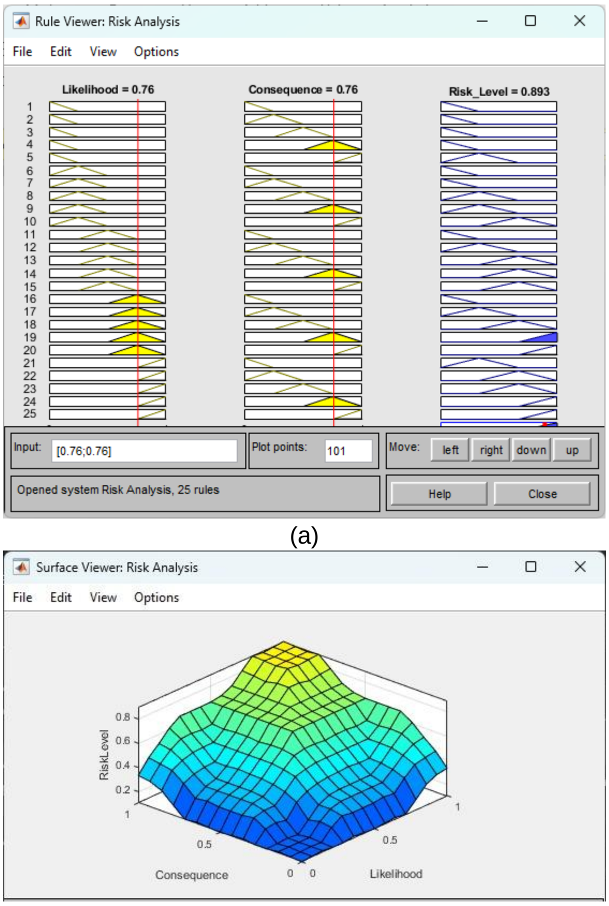
Table 3. Respondent Characteristics

Category	Description	Count	Percentage (%)
Work Experience	<10 Years	6	10.53%
	10-15 Years	36	63.16%
	>15 Years	15	26.32%
Position	Management	10	14.04%
	Project Manager	18	31.58%
	Functional Manager	31	54.39%

To obtain relevant data and identify the selected risk variables, an online questionnaire was conducted with 57 participants from PT GMF AeroAsia Tbk. They included management, functional manager and project managers. This diversified pool of participants has the skills and experience to provide valid responses. As indicated in Table 3. The most experienced age group (63.16%) is 10-15 years, and 89.38% of the respondents have been in the MRO industry for over 10 years, which ensures high familiarity with the operational risks

4.1. Risk Identification

Based on a literature review and expert validation, 20 risk factors were established and allotted to five categories: manpower, material, machine, method, and money. The categories form a systematic framework for comprehending the root causes of project delay. Material risks are identified as the paramount concern on the basis of the validated list.



(a)

(b)

Figure 4 Rule Viewer (a) and Surface Viewer Model Fuzzy (b)

These come under the heading of delays in the supply of material from suppliers, shortage of parts required in the warehouse, acceptance of defective material, and unavailability of some parts in the domestic market. The high reliance of the MRO business on a global supply chain of licensed aircraft parts renders it even more vulnerable to such logistical setbacks, in which an absent component can arrest the entire maintenance process and cause devastating delays. Likewise, manpower is an essential risk category that greatly contributes to project implementation.

The most important risks are a lack of staff, the absence of experienced and skilled technicians, and workload overload. Inexperienced manpower cannot possibly execute intricate assignments accurately or drive sophisticated machinery, resulting in rework and delays. Moreover, high workload without sufficient rest also leads to fatigue, reducing the level of performance as well as the potential for committing mistakes, directly impacting the Turn Around Time (TAT) of the project.

4.2. Fuzzy-Based Risk Assessment

A fuzzy model was used to numerically scale the expert judgment on the probability and effect of each identified risk. The model translates the linguistic inputs (e.g., "Likely," "Major") into numeric risk levels through fuzzification, inference, and defuzzification. This allows for more quantitative assessment of subjective risks. The final result is a ranked list of risks based on a derived Risk Level score, as outlined in Table 4.

The analysis incontrovertibly indicates that R09 - Delay in material delivery is the most critical threat with the highest Risk Level of 89.31% and ranked as "Very High". This finding reiterates that supply chain and logistics contribute to the most serious reasons for the delay of projects in the MRO industry, a result similar to previous studies. Moreover, a large majority of the identified risks (15 out of 20, i.e., 75%) are "High" risks.

This implies that MRO projects operate under a high-risk situation in many areas, e.g., machine availability (R02, R03), excessive workload (R06), and internal shortages of materials (R11). Money matters and techniques of project management related risks also as significant threats. Conversely, external and more uncontrollable influences like force majeure (R15) ranked lowest, suggesting that operational and internal risk factors are more of an immediate concern

4.3. Managerial Implications of Top Risk Factors

Detailed analysis of the top ranked risks reveals severe interdependencies and strategic vulnerabilities in the MRO working paradigm. The findings are not only operationally descriptive but also have significant managerial implications for strategic decisions.

4.3.1. Material Risks (R09 & R11) - Strategic Vulnerability in the Supply Chain

Vulnerability Dominance of material delivery delays (R09) and warehouse shortages (R11) directly indicates the company's current supply chain policy and internal inventory handling are less than optimal and internal inventory activities are inefficient. This two problem reflects both a dependence upon an uncertain external supply chain and an internal inventory management breakdown. To management, it heralds a call to adopt a change of direction from a transactional procurement strategy to a systematic and integrated supply chain policy including a thorough examination of material planning activities for eliminating inefficiencies.

Table 4. Ranking of MRO Project Delay Risks

Rank	Code	Risk	Category	Likelihood	Consequence	Risk Level
1	R09	Material delivery delay	Material	0.76	0.76	89.31%
2	R02	Equipment damage and limitations	Machine	0.71	0.68	75.24%
3	R11	Material shortage in the warehouse	Material	0.72	0.67	74.75%
4	R06	Excessive workload	Manpower	0.63	0.7	70.95%
5	R03	Capacity limitations	Machine	0.67	0.61	70.10%
6	R01	Equipment delivery delay	Machine	0.61	0.68	69.60%
7	R08	Insufficient number of employees	Manpower	0.61	0.7	69.60%
8	R17	Late payment by the Customer	Money	0.61	0.59	68.87%
9	R12	Material unavailable in the market	Material	0.57	0.68	67.86%
10	R20	Lengthy payment process	Money	0.69	0.56	67.71%
11	R13	Additional work from the Customer	Method	0.68	0.56	67.59%
12	R07	Inefficient resource planning	Manpower	0.54	0.64	67.09%
13	R14	Unilateral decision from the customer	Method	0.52	0.57	66.77%
14	R04	Infrastructure unavailable at the workplace	Machine	0.5	0.64	65.56%
15	R19	Customer's Financial capability	Money	0.47	0.61	61.21%
16	R16	Planning errors	Method	0.45	0.66	58.16%
17	R18	Global Financial issues	Money	0.5	0.44	57.73%
18	R10	Defective material received	Material	0.37	0.64	49.76%
19	R05	Lack of skilled and experienced employees	Manpower	0.3	0.68	41.40%
20	R15	Force majeure (weather, disaster, etc.)	Method	0.16	0.61	31.16%

4.3.2. Machine Risks (R02 & R03) - Asset Reliability as a Barrier to Growth:

The first ranking of equipment damage (R02) and capacity limitations (R03) implies that the reliability of the company's production assets is poor, and it acts as a bar to growth for the business. This indicates that the current asset management program is ineffective, resulting in not only surprise repair costs but also leading to production backlogs that will not enable the company to take on more projects. The management must realize that sales projections cannot be realized unless they spend a great deal on asset maintenance and long term capacity planning aligned to firm goals.

4.3.3. Manpower Risk (R06) - A Threat to Quality and Operational Sustainability

The emergence of excessive workload (R06) into the top-five hazards poses an acute risk to quality, safety, and operational viability. When professional staff members are forced to work beyond the limits of reason, the risk of human fallibility, fatigue, and demotivation is significantly increased. Management needs to take this into account as a business continuity risk of the core, requiring an urgent improvement of the personnel to work volume ratio and workforce planning system to prevent quality decline and ensure long term safety and sustainability.

5. CONCLUSION

This study was able to determine and assess the top risk factor causing delays on aircraft MRO projects using a fuzzy logic method with the incorporation of the ISO 31000 method. The study determined related material factor, i.e., material delivery delay (R09), to be the most critical risk, followed by equipment damage and limitation (R02) and internal material shortage (R11). These finding confirm that the MRO project scenario situation is inherently high risk, and a majority of the factors was under the category of "High".

Fuzzy logic proved successful in numerically quantifying subjective expert opinions, and there was a more objective and systematic basis for prioritizing risk compared to conventional methods. The resulting risk ranking will form an important management tool to formulate focused risk treatment plans based on enhancing supply chain management, equipment reliability improvement, and workload planning optimization to ensure SLA achievement and improved operation efficiency.

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