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ORIGINAL RESEARCH

PROJECT DELAY RISK ASSESSMENT

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Abstract

Maintenance activities on power plant projects, which are located in remote areas, are prone to risks related to project delay due to the high complexity of work and limited completion time. This research aimed to fill the existing research gap by developing a delay risk assessment of those projects using a probability impact matrix, which is then transformed into a fuzzy set theory. A case study has been undertaken to represent this research topic at three PLTMGs in Nusa Tenggara. The research steps were potential delay risks identification, critical risk assessment, and risk response development. The results show that the critical risks are lack of skilled and experienced manpower, delay in material and equipment delivery, poor communication and coordination between the contractor and the client, unavailability of materials in the local market, and incomplete material received. Several risk responses are provided in this research, such as strengthening the qualification of the job vacancy, having regular training or sharing sessions before the project execution, and having a stock of emergency spare parts in the central warehouse.

KEYWORDS:

Absorption, Concrete, Durability, Materials, Structure, Sorptivity

1 | INTRODUCTION

A gas engine power plant (PLTMG) is a power plant that requires a diesel engine to drive the alternators to generate electricity. These power plants are usually found in remote areas or used as backup power in large power plants because of the unique characteristics of the diesel engine itself, i.e., reliability in starting and operation, capability to start automatically, ability to use several types of fuel and wide range of power rating[1]. However, conventional diesel engine emission has long been known to be carcinogenic to humans because of containing particulate matter and nitrogen oxides (NOx)[2]. It also causes several environmental issues, e.g., air, water, soil pollution, and climate change[3]. Therefore, PLTMG uses a dual-fuel diesel engine instead of a conventional diesel engine as PLTD. Dual-fuel engine (mostly natural gas and diesel fuel) offers solutions to reduce the negative impact of diesel emission[4]. Considering the fuel crisis in the last few years due to limited reservoirs, it may also be the best deal in the current state.

The diesel engine is one of the common types of the reciprocating internal combustion engine, i.e., an engine that converts chemical energy within a fuel into mechanical energy by admitting air and fuel into the cylinder for an ignition process that causes an explosion and produces high-pressure gases to push the piston to BDC and force the gas expansion. Diesel engines run in a fixed sequence of events that may be realized in two types of cycles, namely two and four-stroke cycles. A stroke means piston movement between TDC and BDC or half of the crankshaft revolution. To maintain liveability, the engine needs to be maintained. Maintenance existing power plant is a set of activities to extend equipment's lifecycle by conducting prevention actions or repairs. Project Management Institute[5] stated that previously, maintenance was interpreted as a necessary evil, cost, insurance, disaster repairing function, and prima donnas, so there is a tendency to be avoided.

Depending on the author's perspective, a maintenance strategy is classified into several types. Generally, it is classified into two main groups depending on how it approaches, i.e., reactive and proactive maintenance. The maintenance program of an existing power plant consists of a series of activities constrained by time and cost, and therefore, it is considered a project. In reactive maintenance, action will be carried out only after the equipment run-to-failure by repairing or replacing some components to retain the equipment's original condition, while proactive maintenance is the opposite of reactive, carrying out maintenance before the failure occurs to avoid it. Proactive maintenance plays an important role in maintaining equipment availability. Creating proper maintenance plans is the main way to reduce the probability of any disturbance occurring during the maintenance executions, given the complexity of work increases relative to engine ages.

Like any construction project, maintenance activities on power plant projects, especially gas engine power plants (PLTMG), have faced some time, cost, and quality constraints. 70% of projects cannot meet the expected completion date and experience an average schedule for maintenance that is very tight. The delay will influence the whole operation process of PLTMG by ten to thirty percent over the desired duration[6]. The project often faces unforeseen circumstances or uncertainties that might affect the project's time, cost, and quality. The negative uncertainties are called risks, which may be occurred during the project planning and execution, and become project threats. Andri´candri´c et al.[7] defines risk as "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives ."Related to time, risk will cause project delay, resulting in the owner losing revenue, and the contractor will have overhead costs due to longer work periods and poor credibility. Disputes among project parties may also be unavoidable.

However, risk could be managed by identifying, assessing, and managing risk responses. Risk management aims to reduce the likelihood of critical risk and its consequences. Identification of causing factors of project delay and delay risk assessment have attracted the interest of many researchers, especially in construction projects. Hossen et al.[8] assessed and allocated risk associated with highway construction projects by using RII. Muliano et al.[9] identified delay risks in the Batang-Kendal road project, while the research of Zulaiha et al.[10] observed risks in the East Coast of Malaysia road project. Yazdani-Chamzini[11] conducted a risk assessment of belt and road infrastructure in various places. Nightingale[12] identified risks in TBM tunnel projects and proposed a methodology for risk assessment based on Bayesian Belief Network.

Studies related to risk identification and assessment for maintenance projects have been limited. As aforementioned, maintenance activities on power plant project, especially gas engine power plant (PLTMG), have also at risk of experiencing delays given that it has high complexity of work, are located in remote areas, which has limited completion time, the project maintenance delay will influence the operation process of PLTMG. Therefore, this research aims to fill the existing research gap by developing a delay risk assessment model for maintenance projects in the power plant to avoid delay in the next activities, that is, the operation of PLTMG. The main objectives of this research are identifying the potential delay risks for maintenance projects at three PLTMGs in Nusa Tenggara, assessing the identified risks to determine the critical risks, and developing the risk response. Previous studies related to maintenance projects on PLTMG were still limited. Therefore the fuzzy approach is used to model the expert judgment for risk assessment. It used linguistic variables and fuzzy expressions to be more applicable than rigid mathematical rules, as claimed by Ross[13]. This approach has many advantages, especially in quantifying or capturing the vagueness in the linguistic variables and dealing with small observations[11, 14, 15]. Fuzzy methods can be used for risk assessment. Batool and Abbas[16] stated that it can evaluate risks simultaneously to conclude their contribution to the whole operational risk indicator. However, a great defect may arise when two or more sources of vagueness appear simultaneously[17].

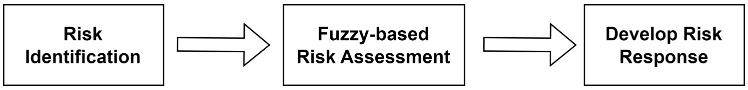


FIGURE 1 The risk analysis using a fuzzy approach.

TABLE 1 The conversion scale for risk severity.

Linguistic Variables	Description	Fuzzy Interval
Negligible	Involved negligible impact	(0.0, 0.0, 0.25)
Minor	Involved small impact	(0.0, 0.25, 0.50)
Moderate	Involved moderate impact	(0.25, 0.50, 0.75)
Major	Involved high impact	(0.50, 0.75, 1.0)
Catastrophic	Involved impact very highly	(0.75, 1.0, 1.0)

2 | PREVIOUS RESEARCHES

There have been serveral studies on risk assessment in highway construction projects which assessed risks in belt and road infrastructure projects in various places [7, 10, 18, 19]. Balta et al. [20] identified risks in TBM tunnel projects and proposed a methodology for risk assessment based on Bayesian Belief Network. They developed a decision-support tool to assess delay risk for risk mitigation strategies identification. There also have been studies on delay risks in power systems Hossen et al. [8], Wu et al. [15], Gallab et al. [17], Islam et al. [21], Yau and Yang [22], Pall et al. [23]. Moreover, Wang and Yuan [24] investigated the risk effects of schedule delays in infrastructure projects in general. This study focuses on maintenance activities on power plant projects, particularly in remote areas.

Wu et al. [15] conducted a risk assessment of offshore photovoltaic power generation projects in China. Sixteen identified risks within four main categories, i.e., micro-economic, technical, environmental, and management, were assessed based on a fuzzy framework involving hesitant fuzzy linguistic term sets, fuzzy triangular numbers, and fuzzy synthetic evaluation. Initially, the weight of the criteria was determined using the ANP method. Based on risk analysis, the highest risk level was owned by management, followed by micro-economic, while technical and environmental risks were in between medium and medium-high levels. This research presented risk response strategies for each risk factor.

Meanwhile, Wang and Yuan [24] proposed SD model development to investigate the interaction of the dynamic risk and how these risks might affect the overall project schedule. Potential risks were identified through a literature review from academic publications and reports dealing with project risk management. As a result, forty-seven identified risks were classified into six categories, i.e., clients, designers, contractors, sub-contractors, local authority, and external environment. RII evaluated data from the questionnaire survey.

Hossen et al. [8] also studies risk assessment using AHP and RII. Other methods used Bayesian belief network statistical analysis, which was applied to construction projects [9]. This study adopted a number of previous studies [24–26], which discovered several delay factors and their impacts associated with related maintenance projects, which are quite relevant.

3 | MATERIAL AND METHOD

The flowchart in Fig. 1 presents how this research was carried out. The research was divided into three main sections, i.e., risk identification, fuzzy-based risk assessment, and developing risk response.

Risk identification was started by listing relevant variables from the literature, which was then developed into a risk breakdown structure (RBS). The search for variables in the literature was wider than maintenance projects but extended to other projects, e.g., construction, to recognize more potential risks. These variables were selected based on their relevance to maintenance projects and synthesized based on the expert judgment through an interview. The population of this research was the project team at the site, while the sample also acted as respondents as the research applied purposive sampling. The respondents were the experts, consisting of the plant manager, maintenance manager, work planner, and maintenance engineer, who was asked to

TABLE 2 The conversion scale for risk likelihood.

Linguistic Variables	Description	Fuzzy Interval
Low	Unlikely to occur	(0.0, 0.25, 0.50)
Moderate	Likely to occur	(0.25, 0.50, 0.75)
High	Very likely to occur	(0.50, 0.75, 1.0)

TABLE 3 The conversion scale for risk level.

Linguistic Variables	Description	Fuzzy Interval
Very Low	Risk is tolerable without any mitigation	(0.0, 0.0, 0.25)
Low	Some partial mitigation may be needed	(0.0, 0.25, 0.50)
Moderate	Mitigation may be needed	(0.25, 0.50, 0.75)
High	Mitigation should be implemented to reduce the risk	(0.50, 0.75, 1.0)
Extreme	Mitigation to reduce risk must be implemented	(0.75, 1.0, 1.0)

TABLE 4 The risk matrix (3x5).

		Severity				
		Negligible	Minor	Moderate	Major	Catastrophic
Likelihood	Low	Very Low	Low	Moderate	High	Extreme
	Moderate	Low	Moderate	High	Extreme	Extreme
	High	Moderate	High	Extreme	Extreme	Extreme

give their opinion about relevant risk variables as well as to rate their opinion related to the risk severity (RS) and risk likelihood (RL) of risks using predetermined scales to obtain critical risks.

Critical risks were the top five high-value risks that required risk treatment. They were determined through fuzzy-based risk assessment and further used to develop the risk response. Risk severity was evaluated on a five-point scale, i.e., negligible, minor, moderate, major, and catastrophic. Risk likelihood was enough to be expressed on three-point scales, i.e., low, moderate, and high. Since the fuzzy approach was applied in this study, there were some steps related to fuzzy number conversion into fuzzy membership functions for risk severity and risk likelihood based on the conversion scale in Table 1 for risk severity and Table 2 for risk likelihood. The conversion scale of risk level should also be determined as the fuzzy output for the operation of fuzzy rules in the phase of the fuzzy inference system, along with the definition of risk severity and likelihood. Its conversion scale is given in Table 3 .

Data collected from the questionnaire survey were proceeded using a statistical approach and converted into fuzzy triangular numbers as defined in Table 1 and Table 2 . Furthermore, the fuzzy numbers of RS and RL were aggregated into fuzzy group numbers and proceeded in the fuzzy inference system by applying if-then rules. Matlab software was used to support the analysis. The fuzzy rules were developed based on the risk matrix referred to in the research of Ristic[27] and given in Table 4 .

Subsequently, risk response focused on the critical risks resulting from fuzzy-based risk assessment to minimize the probability of these risks' occurrence and reduce their consequences. Risk responses were summarized through focus group discussions among experts.

This research used a case study of three PLTMG in Nusa Tenggara, Indonesia, representing PLTMG operated in remote areas. They were built in 2017 and commercially operated in 2019 to support the electrical system in Nusa Tenggara and replace the role of diesel power plants that have been gradually discontinued due to environmental issues. These power plants are owned by an Indonesian state-owned enterprise with PT XYZ as an O&M contractor and located in a remote area that is earthquake-prone with a certain character of the local community, so risk-related to the relationship with the client as of the nature of the O&M agreement, environment, and human resources may arise during the project.

TABLE 5 The respondent's profile.

Category	Description	Respondent	
		Number	Percentage
Job Position	Plant Manager	3	22%
	Maintenance Manager	3	21%
	Work Planner	3	21%
	Maintenance Engineer	5	36%
Job Location	PLTMG A	4	28%
	PLTMG B	5	36%
	PLTMG C	5	36%
Work Experience	>15 years	5	36%
	10-15 years	6	43%
	<10 years	3	21%

4 | RESULTS AND DISCUSSION

To obtain relevant risk and assess the selected risk variables, the online survey was conducted on 14 respondents from three PLTMGs, including the plant manager, maintenance manager, and maintenance engineer, who are in charge of maintenance activities on PLTMG. Therefore, they have the capability and sufficient experience to answer the questions in the questionnaire. The survey had a 93% of response rate. The respondents comprised 22% plant managers, 21% maintenance managers, 21% work planners, and 36% maintenance engineers, of which 28% were working in PLTMG A, while 72% of the remaining people were working in PLTMG B and C, respectively. The respondent profile is described in Table 5 .

4.1 | Risk Identification

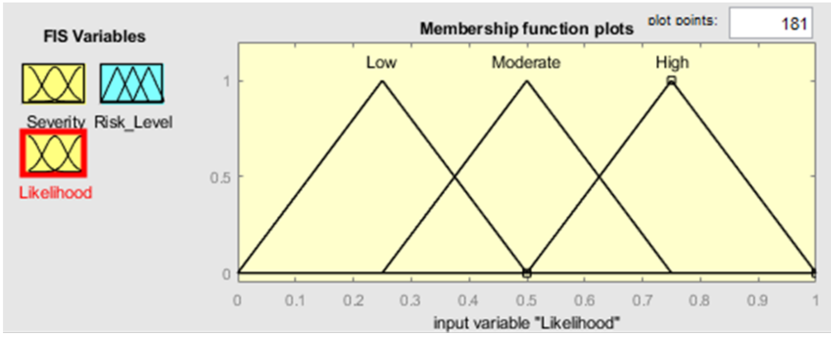
Thirty-seven risks were identified and classified into seven categories, namely manpower, material, equipment, technical, contractor, client, and workplace, based on the result of the review of the literature and work breakdown structure (WBS) of major inspection. The survey resulted in twenty-seven validated risk variables, as detailed in Table 6 . Several risks were simplified by merging them into a single risk.

According to Table 6 , maintenance risks are divided into six categories, namely manpower, material, equipment, client, workplace, and contractor. Risk-related manpower includes a lack of skilled and experienced manpower, manpower disputes and strikes, cultural gaps and language barriers, and excessive workload. Manpower plays an important role in project executions; unskilled and inexperienced manpower cannot do the job properly and/or use special tools or operate the equipment. The risk of excessive workload and less rest time during the project can worsen the manpower performance because of fatigue and increase the chance of disputes among them. Furthermore, every person has a certain culture/ perspective that affects how he manages and executes the project based on his/ her background and/ or habits in previous work. Having different culture from the organization may make him treat the project differently and influence the ongoing progress. Likewise, language barriers, the inability to communicate with each other due to differences in language, also may interfere with the progress because the information cannot be delivered properly.

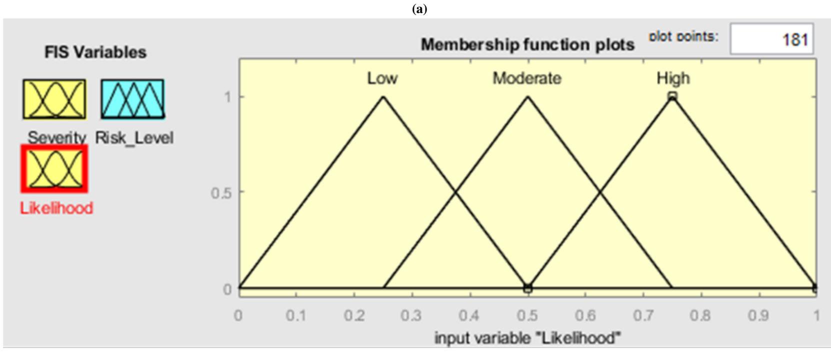
4.2 | Fuzzy-Based Risk Assessment

A fuzzy model was designed by defining the risk severity and likelihood as fuzzy inputs and the risk level as the fuzzy output and choosing Mamdani as a fuzzy inference system, as shown in the following Fig. 2 . The centroid method was employed as the defuzzification method.

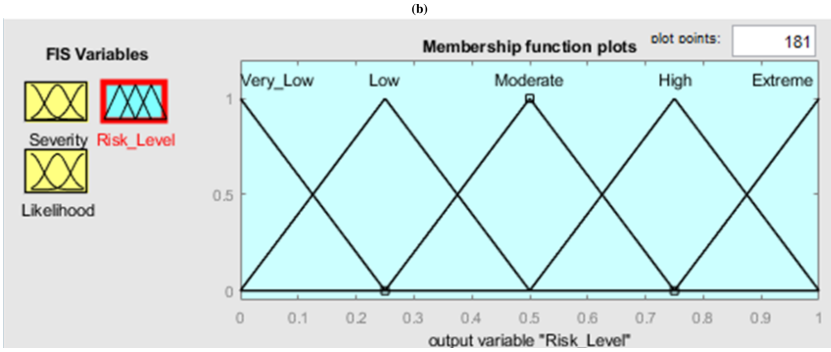
Fuzzy-based risk assessment was started by transforming the linguistic variables of risk severity and likelihood to the corresponding fuzzy membership function based on the conversion scale in Table 1 and Table 2 . Subsequently, the fuzzy numbers of each variable of risk parameters were plotted, as shown in Fig. 2 . For example, the fuzzy number of the moderate severity variable was plotted on 0.25, 0.50, and 0.75. Meanwhile, the high likelihood variable was plotted on 0.5, 0.75, and 1.00. It should also be implemented for the risk level as fuzzy output based on Table 3 . For instance, the extreme risk level should be plotted on 0.75, 1.0, and 1.0.



(a)



(b)



(c)

FIGURE 2 The Membership Function Plot of (a) Risk Severity, (b) Likelihood, and (c) Risk Level .

Once fuzzy inputs and output have been plotted to the membership function, fuzzy rules, also called if-then rules, should be defined in the phase of the fuzzy inference system. In this research, the rules with a total of fifteen rules were developed based on Fig. 3 .

The fuzzy inference engine generates a 3D surface of the fuzzy model in Fig. 4 based on the membership function of the fuzzy inputs and fuzzy rules. This surface illustrates the correlation between fuzzy inputs and output and provides several regions of fuzzy output depending on the value of fuzzy inputs. However, this plot cannot identify the risk level as clearly as the fuzzy rule viewer in Fig. 5 . The fuzzy rule viewer demonstrates a graphical user interface of fuzzy inputs and fuzzy outputs. Each row on this page represents the number of rules applied in this model. The plot in the fuzzy output column interprets fuzzy rules' application to the output variables. In contrast, the bottom column is the aggregate output obtained by combining the outputs of each rule. A red line in the bottom column points to the defuzzified value of the fuzzy output.

According to Fig. 5 , a severity of 0.8 and a likelihood of 0.62 would result in a risk level of 0.906.

According to Table 7 , it can be concluded that the top five high-value risks are R01 (lack of skilled and experienced manpower), R05 (delay in material delivery), R12 (poor communication and coordination between the contractor and the client),

TABLE 6 The risk breakdown structure.

Category	Description	References
Manpower	Lack of skilled and experienced manpower (R01)	Zulaiha et al.[10], Islam et al.[21], Wang and Yuan[24]
	Manpower disputes and strikes (R02)	El-Sayegh and Mansour[18], Lee et al.[28]
	Cultural gaps and language barrier (R03)	Hossen et al.[8], Adiam[25], Gebrehiwet and Luo[29]
	Excessive workload (R04)	Anggraini et al.[19], Yau and Yang[22]
Material	Delay in material delivery (R05)	Muliano et al.[9], Zulaiha et al.[10]
	Incomplete material received (R06)	Shangea et al.[26]
	Broken material (R07)	Adiam[25]
	Material missing in the warehouse (R08)	Shangea et al.[26]
	Unavailable material in the local market (R09)	Muliano et al.[9], Gebrehiwet and Luo[29]
Equipment	Delay in equipment delivery (R10)	Muliano et al.[9], Zulaiha et al.[10], Yau and Yang[22]
	Equipment breakdown (R11)	El-Karim et al.[30], Eskander[31], Assaf and Al-Hejji[32]
Client	Poor coordination and communication between contractor and client (R12)	Kuo and Lu[6], Yau and Yang[22], Wang and Yuan[24]
	Additional work by the client (R13)	Muliano et al.[9]
	Client's decision (R14)	Hossen et al.[8]
	Delay in payment by the client (R15)	Kuo and Lu[6]
Workplace	Force majeure (R16)	Alsharif and Karatas[33]
	Accident at workplace (R17)	Muliano et al.[9], Assaf and Al-Hejji[32]
	Unavailable working space (R18)	Shangea et al.[26]
	Unavailable utilities at the workplace (R19)	Kuo and Lu[6], Adiam[25], Shangea et al.[26]
	Unavailable compressed air (R20)	Shangea et al.[26]
	Limited accessibility to the workplace (R21)	El-Sayegh and Mansour[18], Eskander[31]
Contractor	Inefficient resource planning (R22)	Hossen et al.[8], Balta et al.[20]
	VISA for a specialist visit (R23)	Shangea et al.[26]
	Poor coordination and communication between the site representative and head office (R24)	Wang and Yuan[24], Shangea et al.[26], Gebrehiwet and Luo[29]
	Complex approval procedure (R25)	Nightingale[12], Islam et al.[21], Wang and Yuan[24]
	Rework due to errors during the executions (R26)	Kuo and Lu[6], Gebrehiwet and Luo[29], Eskander[31]
	Incorrect installation (R27)	Anggraini et al.[19]

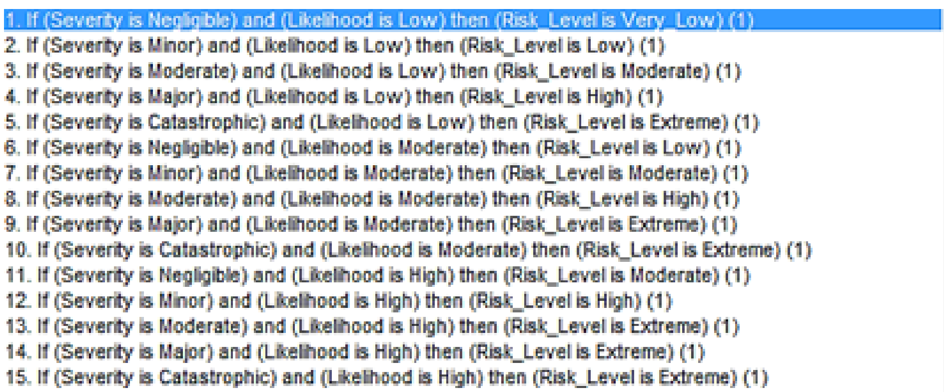

1. If (Severity is Negligible) and (Likelihood is Low) then (Risk_Level is Very_Low) (1)
2. If (Severity is Minor) and (Likelihood is Low) then (Risk_Level is Low) (1)
3. If (Severity is Moderate) and (Likelihood is Low) then (Risk_Level is Moderate) (1)
4. If (Severity is Major) and (Likelihood is Low) then (Risk_Level is High) (1)
5. If (Severity is Catastrophic) and (Likelihood is Low) then (Risk_Level is Extreme) (1)
6. If (Severity is Negligible) and (Likelihood is Moderate) then (Risk_Level is Low) (1)
7. If (Severity is Minor) and (Likelihood is Moderate) then (Risk_Level is Moderate) (1)
8. If (Severity is Moderate) and (Likelihood is Moderate) then (Risk_Level is High) (1)
9. If (Severity is Major) and (Likelihood is Moderate) then (Risk_Level is Extreme) (1)
10. If (Severity is Catastrophic) and (Likelihood is Moderate) then (Risk_Level is Extreme) (1)
11. If (Severity is Negligible) and (Likelihood is High) then (Risk_Level is Moderate) (1)
12. If (Severity is Minor) and (Likelihood is High) then (Risk_Level is High) (1)
13. If (Severity is Moderate) and (Likelihood is High) then (Risk_Level is Extreme) (1)
14. If (Severity is Major) and (Likelihood is High) then (Risk_Level is Extreme) (1)
15. If (Severity is Catastrophic) and (Likelihood is High) then (Risk_Level is Extreme) (1)

FIGURE 3 The fuzzy rules used in reference engine.

R09 (unavailability of materials in the local market), R06 (incomplete material received), and R10 (delay in equipment delivery). The risk of lack of skilled and experienced manpower and delay in material delivery had the same risk level value at 0.907, the highest among the others. More than 70% of respondents claimed that these two risks had major-catastrophic severity leading to the project delay if they occur. Only around 30% of respondents said these risks had a low likelihood of occurrence, which means these two risks are likely to occur at these power plants.

4.3 | Develop Risk Response

Risk responses for the critical risks mentioned in the previous sub-chapter were developed based on interviews with the same respondents and validated by the power plant operation. It is presented in Table 8 .

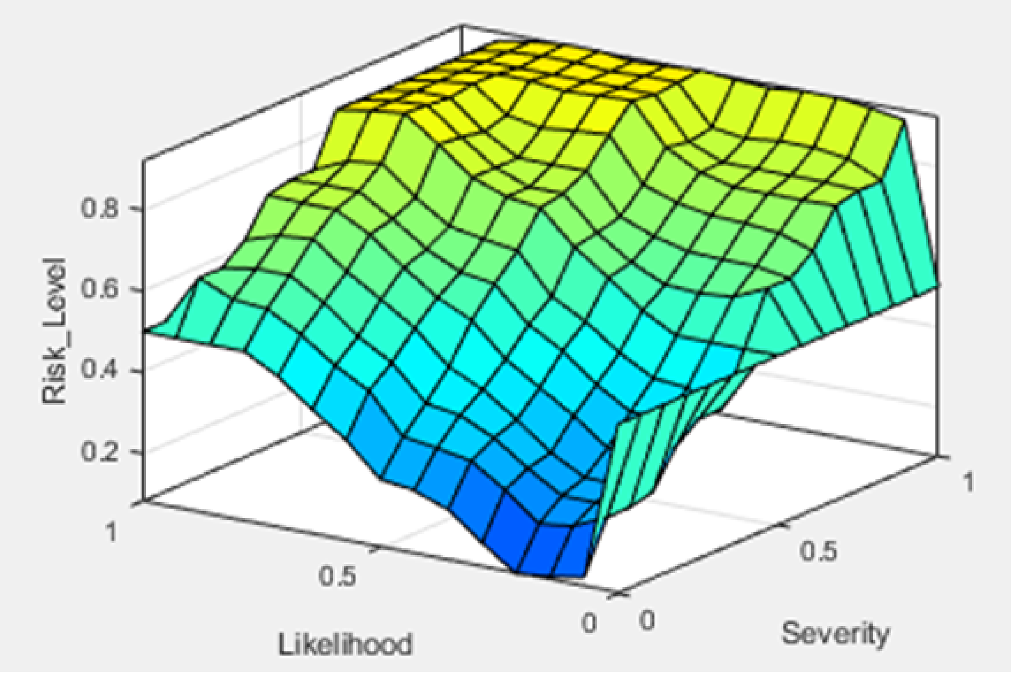


FIGURE 4 The 3D surface of fuzzy model.

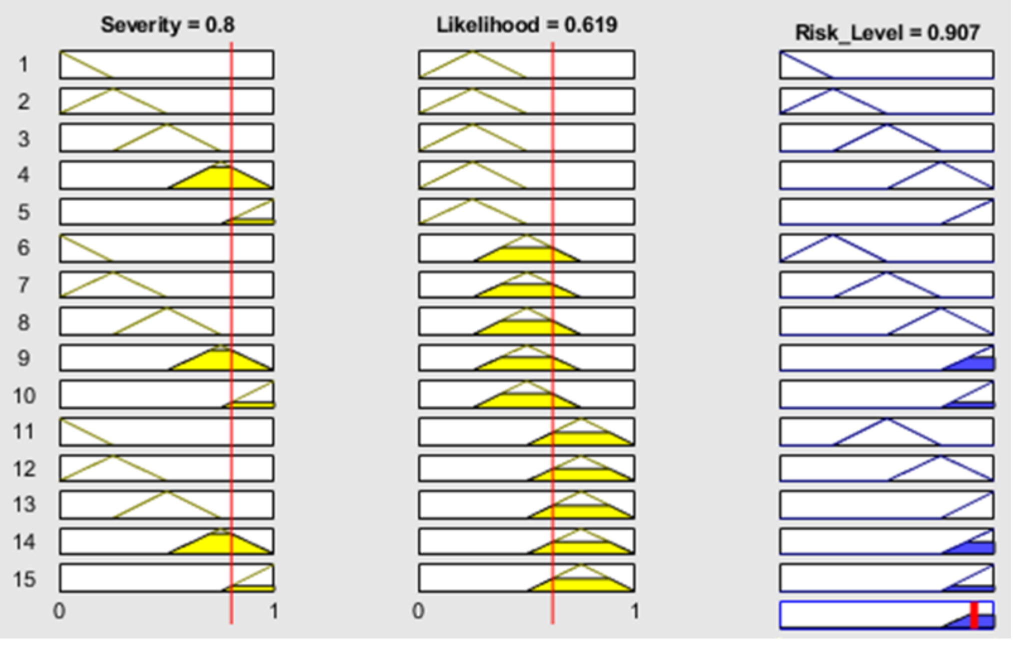


FIGURE 5 The graphical user interface of fuzzy inputs and fuzzy outputs.

5 | CONCLUSION

This study uses the fuzzy sets theory to assess risks and provide risk responses when performing maintenance activities in power plant projects. A fuzzy logic approach was adopted to handle the uncertainty conditions. The proposed model for quantifying delay risk in maintenance activities is considered a new approach compared to the conventional approach. The obtained results confirm the applicability of the suggested model. In power plant projects, delay risks are classified into manpower, material,

TABLE 7 The summary of the risk assessment result.

Risk	Severity	Likelihood	Level	Ranking	Category
R01	0.771	0.619	91%	1	Manpower
R05	0.800	0.619	91%	1	Material
R12	0.729	0.524	88%	2	Client
R09	0.729	0.571	87%	3	Material
R06	0.714	0.524	86%	4	Material
R10	0.700	0.500	84%	5	Equipment
R25	0.700	0.571	84%	6	Contractor
R14	0.686	0.524	83%	7	Client
R15	0.671	0.548	81%	8	Client
R18	0.657	0.548	80%	9	Workplace
R16	0.714	0.476	80%	10	Workplace
R03	0.643	0.548	79%	11	Manpower
R07	0.629	0.548	78%	12	Material
R08	0.614	0.548	78%	13	Material
R21	0.614	0.524	78%	13	Workplace
R27	0.614	0.476	74%	14	Contractor
R02	0.671	0.452	73%	15	Manpower
R04	0.614	0.452	71%	16	Manpower
R24	0.614	0.452	71%	16	Contractor
R11	0.671	0.429	71%	17	Equipment
R26	0.586	0.452	70%	18	Contractor
R20	0.657	0.429	70%	19	Workplace
R22	0.643	0.429	70%	20	Contractor
R19	0.629	0.429	69%	21	Workplace
R17	0.643	0.357	66%	22	Workplace
R13	0.586	0.381	65%	23	Client
R23	0.571	0.381	64%	24	Contractor

TABLE 8 The summary of the risk response.

Critical Risk	Type of Response	Descfription
R01 (lack of skilled and experienced manpower)	Risk Mitigation	Strengthen the qualification for a job vacancy (25%) Have regular in-house training (25%) Arrange sharing session before the project executions (20%) Assign a superintendent to support the executions and teach the manpower directly (20%) Exchange the team member (10%)
R05 (delay in material delivery) and R10 (delay in equipment delivery)	Risk Mitigation	Prepare a plan for maintenance planning six months or a year before the date of the executions (70%) Select a credible shipment agency (20%) Ensure compliance with the local regulation (10%)
R12 (poor communication and coordination between contractor and client)	Risk Mitigation	Inform the client in the meeting of energy allocation about the maintenance plan for next year (75%) Follow up in a weekly meeting (15%) Inform the client by sending an official letter (10%)
R09 (unavailability of materials in the local market)	Risk Mitigation	Prepare a plan for maintenance planning six months or a year before the date of the executions (60%) Have a stock of emergency spare parts in the central warehouse based on expert experience (40%)
R06 (incomplete material received)	Risk Mitigation	Finalize an order before delivery

equipment, client, workplace, and contractor. The risk responses for the critical risks can be in the form of strengthening the qualification of the job vacancy, having regular training or sharing sessions before the project execution, having a stock of emergency spare parts in the central warehouse, and so on.

The fuzzy logic approach is suitable for this case study's limited data and specific conditions. The data would be transformed into linguistic variables as input values and returns a result that can be wholly defined linguistic variable. To a larger extent, more case studies are needed to elaborate the analysis and to detect the emergence of new risks that may influence power plant projects.

CREDIT

Farida Rachmawati: Conceptualization, supervision, reviewing-editing. **Herdira Dita Ramadhani:** Conceptualization, methodology, data curating, investigation, software. **Aulia Shofi Nurhidayah:** writing – original draft preparation.

References

1. Chow JC. Diesel Engines: Environmental Impact and Control. Journal of the Air and Waste Management 2011;51:1258–1270. https://www.tandfonline.com/doi/abs/10.1080/10473289.2001.10464354.

2. Wireman T. Benchmarking Best Practices in Maintenance Management. New York, USA: Industrial Press; 2003. https://www.worldcat.org/title/64665804.

3. Stefana E, Marciano F, Alberti M. Qualitative risk assessment of a Dual Fuel (LNG-Diesel) system for heavy-duty trucks. Journal of Loss Prevention in the Process Industries 2016 1;39:39–58.

4. Bari S, Marian R. Evolution of Risk of Diesel Engine Emissions on Health During Last 4 Decades and Comparison With Other Engine Cycles: An Innovative Survey. In: ASME 2015 International Mechanical Engineering Congress and Exposition Houston, Texas, USA: American Society of Mechanical Engineers Digital Collection; 2016. p. 1–10. /IMECE/proceedings-abstract/IMECE2015/57557/263896.

5. Project Management Institute. A Guide to the Project Management Body of Knowledge (PMBOK Guide). Newtown Square, Pennsylvania, USA; 2017.

6. Kuo YC, Lu ST. Using fuzzy multiple criteria decision making approach to enhance risk assessment for metropolitan construction projects. International Journal of Project Management 2013 5;31:602–614.

7. Andri´candri´c JM, Wang J, Patrick, Zou XW, Zhang J, Zhong R. Fuzzy Logic–Based Method for Risk Assessment of Belt and Road Infrastructure Projects. Journal of Construction Engineering and Management 2019 9;145:1–12. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29CO.1943-7862.0001721.

8. Hossen MM, Kang S, Kim J. Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project. Nuclear Engineering and Technology 2015 4;47:362–379.

9. Muliano BE, Fahmi I, Asnawi YH. Delay Risk Assessment in Crusher System Construction at PT Freeport Indonesia Underground Mine. Jurnal Aplikasi Bisnis dan Manajemen (JABM) 2021 9;7:602–602. https://journal.ipb.ac.id/index.php/jabm/article/view/34924.

10. Zulaiha RP, Idris A, Irwan R. AHP-based analysis of the risk assessment delay case study of public road construction project: An empirical study. Journal of Engineering Science and Technology 2019;14:875–891.

11. Yazdani-Chamzini A. Proposing a new methodology based on fuzzy logic for tunnelling risk assessment. Vilnius Gediminas Technical University 2014;20:82–94. https://www.tandfonline.com/doi/abs/10.3846/13923730.2013.843583.

12. Nightingale CR. Telecommunication power systems. In: Telecommunications Engineer's Reference Book Butterworth-Heinemann; 1993.p. 24–1.

13. Ross TJ. Fuzzy Logic with Engineering Applications. 3rd ed. Chichester,West Sussex, England: John Wiley & Sons; 2010. https://www.worldcat.org/title/750835732.

14. Wang SQ, Dulaimi MF, Aguria MY. Risk management framework for construction projects in developing countries. http://dxdoiorg/101080/0144619032000124689 2010 3;22:237–252. https://www.tandfonline.com/doi/abs/10.1080/0144619032000124689.

15. Wu Y, Li L, Song Z, Lin X. Risk assessment on offshore photovoltaic power generation projects in China based on a fuzzy analysis framework. Journal of Cleaner Production 2019 4;215:46–62.

16. Batool A, Abbas F. Reasons for delay in selected hydro-power projects in Khyber Pakhtunkhwa (KPK), Pakistan. Renewable and Sustainable Energy Reviews 2017 6;73:196–204.

17. Gallab M, Bouloiz H, Alaoui YL, Tkiouat M. Risk Assessment of Maintenance activities using Fuzzy Logic. Procedia Computer Science 2019 1;148:226–235.

18. El-Sayegh SM, Mansour MH. Risk Assessment and Allocation in Highway Construction Projects in the UAE. Journal of Management in Engineering 2015 2;31:04015004. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29ME.1943-5479.0000365.

19. Anggraini D, Utomo J, Hatmoko D, Handajani M. Quantifying Delay Risk Potential of Road Projects during Construction Phase: A Case Study. MATEC Web of Conferences 2019;280:05009. https://www.matec-conferences.org/articles/matecconf/abs/2019/29/matecconf_icsbe2019_05009/matecconf_icsbe2019_05009.html.

20. Balta GCK, Dikmen I, Birgonul MT. Bayesian network based decision support for predicting and mitigating delay risk in TBM tunnel projects. Automation in Construction 2021 9;129:103819.

21. Islam MS, Nepal MP, Asce AM, Skitmore M. Modified Fuzzy Group Decision-Making Approach to Cost Overrun Risk Assessment of Power Plant Projects. Journal of Construction Engineering and Management 2018 11;145:04018126. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29CO.1943-7862.0001593.

22. Yau NJ, Yang JB. Factors Causing Design Schedule Delays in Turnkey Projects in Taiwan: An Empirical Study of Power Distribution Substation Projects. Project Management Journal 2012 6;43:50–61. https://journals.sagepub.com/doi/abs/10.1002/pmj.21265.

23. Pall GK, Bridge AJ, Skitmore M, Gray J. Comprehensive review of delays in power transmission projects. IET Generation, Transmission & Distribution 2016 11;10:3393–3404. https://onlinelibrary.wiley.com/doi/full/10.1049/iet-gtd.2016.0376.

24. Wang J, Yuan H. System Dynamics Approach for Investigating the Risk Effects on Schedule Delay in Infrastructure Projects. Journal of Management in Engineering 2016 7;33:04016029. https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29ME.1943-5479.0000472.

25. Adiam K. Delay analysis in energy utility maintenance project. In: Proceedings of the International Conference on Industrial Engineering and Operations Management Pilsen, Czech Republic: IEOM Society International; 2019. p. 343–354.

26. Shangea NW, Misra RN, K MS. Construction delay analysis of some Indian hydropower projects. IASH Journal - International Association for Small Hydro 2020;9:19–25. https://www.indianjournals.com/ijor.aspx?target=ijor:iash&volume=9&issue=2&article=003.

27. Ristic D. A tool for risk assessment. Safety Engineering 2013 12;3:121–127.

28. Lee J, Ni J, Singh J, Jiang B, Azamfar M, Feng J. Intelligent Maintenance Systems and Predictive Manufacturing. Journal of Manufacturing Science and Engineering, Transactions of the ASME 2020 11;142. https://asmedigitalcollection.asme.org/manufacturingscience/article/142/11/110805/1085488/Intelligent-Maintenance-Systems-and-Predictive.

29. Gebrehiwet T, Luo H. Risk Level Evaluation on Construction Project Lifecycle Using Fuzzy Comprehensive Evaluation and TOPSIS. Symmetry 2019, Vol 11, Page 12 2018 12;11:12. https://www.mdpi.com/2073-8994/11/1/12/htmhttps://www.mdpi.com/2073-8994/11/1/12.

30. El-Karim MSBAA, Nawawy OAME, Abdel-Alim AM. Identification and assessment of risk factors affecting construction projects. HBRC Journal 2017 8;13:202–216.

31. Eskander RFA. Risk assessment influencing factors for Arabian construction projects using analytic hierarchy process. Alexandria Engineering Journal 2018 12;57:4207–4218.

32. Assaf SA, Al-Hejji S. Causes of delay in large construction projects. International Journal of Project Management 2006 5;24:349–357.

33. Alsharif S, Karatas A. A Framework for Identifying Causal Factors of Delay in Nuclear Power Plant Projects. Procedia Engineering 2016 1;145:1486–1492.

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