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Risk Analysis Based on Failure Mode And Effect Analysis (FMEA) in the ISO 9001:2015 Quality Management System On Toll Road Projects (Case Study: Toll Road Cikupa, STA 32+100 – 36+300)

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ABSTRACT

Toll roads play a crucial role in supporting national economic mobility and growth. Quality risks such as grain leakage, crocodile skin cracks, curls, grooves, removal of asphalt layers, and collapses frequently occur on the Tangerang-Merak Toll Road, specifically in the Balaraja-Cikupa section. This study aims to integrate the Failure Mode and Effect Analysis (FMEA) method with the ISO 9001:2015 standard to enhance risk management within the quality management system of toll road projects. It also evaluates the model's effectiveness in reducing potential failures, improving quality, and aiding decision-making. The study focuses on selected clauses from the ISO 9001:2015 quality management system, including planning and controlling operations, product and service requirements, control of externally provisioned processes, and involvement of production and service providers. The Risk Priority Number (RPN) is used to analyze potential failure modes, measured by severity, occurrence, and detection. At the study site, the highest RPN value was 294, linked to an asphalt mixture that was insufficiently liquid. The failure modes most strongly related to quality degradation were cracks and deformations undetected during initial inspections (X2-9), with a correlation of 0.922 and a significance value of 0.000. The combined effect of all free variables (X1, X2, X3, X4) on the decrease in work quality at the site (Y) accounted for 70.7%. This integration of FMEA and ISO 9001:2015 provides a valuable framework for improving risk management and quality assurance in toll road projects.

KEYWORDS detection, FMEA, jalan tol, occurrence, severity

INTRODUCTION

Toll roads in infrastructure and transportation play an important role in supporting national economic mobility and growth. As a strategic infrastructure, toll roads must facilitate traffic flow in developing regions, support the distribution of goods and services, and reduce the burden on the government budget through the contribution of toll road users (Efraty Kandiyoh et al., 2022). Toll road construction projects are inseparable from construction risks, especially related to quality, cost, and time (Rasyid & Prastyanto, 2020; Romania, 2017).

One of the main risks in toll road construction projects is quality risk. Problems such as damage to road pavement, which often arise before the planned life is reached, are a serious issue in toll road construction in Indonesia (Hamid et al., 2021). This kind of damage requires supervision and maintenance of existing roads to ensure that toll roads function according to the planned life (Mahyuddin et al., 2024). If not handled properly, damage to toll roads can affect vehicle travel time, increase the risk of accidents, and reduce overall traffic efficiency (Nugroho et al., 2024).

Damage to toll road projects can be caused by various factors, especially poor-quality control systems (Gusty et al., 2022). Common damage such as cracks in the road surface, subsidence, standing water, peeling asphalt layers, and road geometry inconsistencies require an effective risk approach, including quality control and the application of appropriate construction standards (Rumane, 2017; Simon, 2014; Siringorigo, 2024; Suwandono, 2016; Willar, 2016).

As one example, the 72.45 km Tangerang-Merak Toll Road, connecting West Tangerang to Merak at the western tip of Java Island, plays a vital role in the economy of Banten Province. However, damage such as grain release (raveling), alligator skin cracking (alligator cracking), curling (corrugation), grooves (rutting), removal (polished aggregate), and collapses are often found before the planned service life is achieved. The damage is often caused by weak quality control systems during the design and construction phases of pavement rehabilitation.

To reduce construction quality risks, quality risk analysis and performance evaluation of the quality management system (SMM) are required. One of the relevant methods for this purpose is Failure Mode and Effect Analysis (FMEA). FMEA is a commonly used tool in the industry to identify risks and problems at an early stage (Djaelani & Retnowati, 2022; Hensen, 2015; Malik, 2019; Rachman, 2016; Ramadhany & Supriono, 2017). The application of FMEA to construction risk analysis is supported by its ability to provide systematic risk identification, prioritize mitigation based on impact and probability, and produce data-driven preventive measures that are easy for implementers and policymakers to understand (Smith et al., 2020; Brown et al., 2018; Williams et al., 2020; Glendon et al., 2016).

Previous studies have explored various risk management approaches in construction projects, but limited research has specifically integrated FMEA with ISO 9001:2015 for toll road quality risk management. Rahman et al. (2018) applied FMEA in building construction projects but focused on general construction risks without specific integration with quality management systems. Similarly, Wijaya and Sutrisno (2019) used ISO 9001 implementation in infrastructure projects but did not incorporate systematic failure mode analysis. The novelty of this research lies in the comprehensive integration of FMEA methodology with ISO 9001:2015 clauses specifically for toll road quality risk assessment, providing a structured framework that addresses the gap between quality management standards and proactive risk identification in toll road construction projects (Aghivirwiati, 2022; Darma, 2021; Nasional, 2015).

In this study, a risk analysis will be carried out based on FMEA that is integrated with ISO 9001 for toll road projects, which will proactively identify risks, provide measurable mitigation priorities, and support data-driven decision-making to provide solutions to the challenges of implementing ISO 9001 in risk management. Problem formulation: How to integrate the FMEA method with ISO 9001 in improving risk management in toll road projects? How effective is this model in supporting proactive decision-making?

The objectives of this research include integrating the FMEA method with the ISO 9001 standard to improve risk management in the quality management system of toll road projects: evaluating the effectiveness of the model in reducing potential failures, improving quality, and supporting decision-making. This research is expected to provide recommendations for improving SMM in toll road projects and add to the academic literature on risk management and SMM in construction projects. It will also provide guidance for toll road managers in designing and implementing effective maintenance programs, with the goal of reducing the risk of damage and increasing the service life of toll roads.

RESEARCH METHOD

This research employed a quantitative approach using descriptive-analytical methods. It integrated the FMEA methodology with ISO 9001:2015 quality management system clauses to analyze quality risks in toll road construction projects. The study was conducted at the Tangerang-Merak Toll Road section Balaraja-Cikupa, covering 4.2 km (STA 32+100 to STA 36+300).

The research focused on quality risk factors in the toll road project. The population included all identified risks, with a sample of 21 potential failure modes categorized under four ISO 9001:2015 clauses. Data were collected from ten experienced professionals selected through purposive sampling. Primary data collection involved field surveys to identify pavement damage, structured questionnaires to assess risk parameters (severity, occurrence, detection), and direct observation of construction and quality control processes.

Secondary data were obtained from the National Road Pavement Center (BBPJN), PT. Marga Mandala Sakti (PT. MMS), and project documentation.

Analysis applied the FMEA method to calculate Risk Priority Numbers (RPN), along with statistical tests such as validity, reliability, correlation, and multiple linear regression. A fishbone diagram was also constructed to illustrate the key quality risk factors.

The stages carried out in the study are shown in Figure 1.

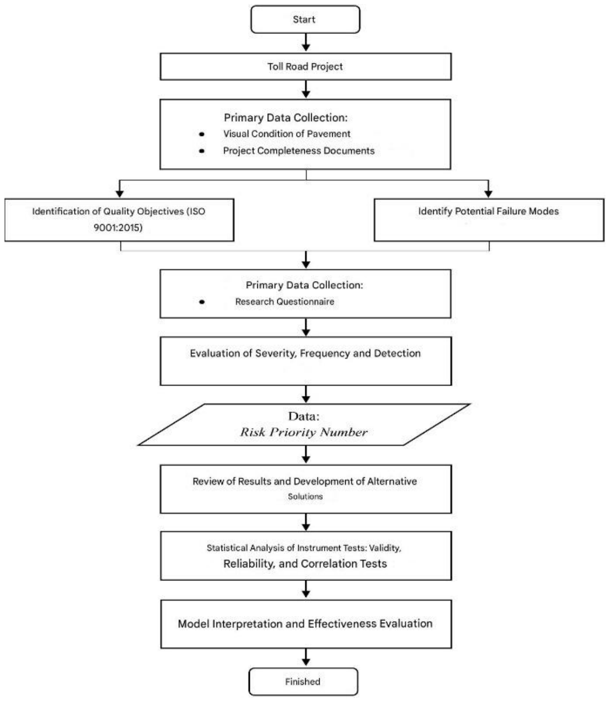


Figure 1. Research flow chart

The research began with a field study at the research site to collect data sources in problem identification. Furthermore, complementary data was collected related to the risks that existed at the research site. The quality risk data obtained was then analyzed using the FMEA method until the percentage of cumulative defect and RPN value were obtained. The preparation of RPN values gives priority to risk in the preparation of alternative repair solutions. Furthermore, statistical analysis was carried out for the research data instrument test, which consisted of validity test, reliability test, and correlation test. The model was interpreted using the determination coefficient test, the F test, and the multiple linear test and visualized using a fishbone diagram to illustrate the influence of quality risk factors on damage to the pavement layer that occurred.

RESULT AND DISCUSSION

Existing Pavement Structures

The pavement design of the Tangerang Merak toll road section Balaraja-Cikupa STA 32 + 100 – 36 + 300 (Figure 4.1) uses rigid pavement with a handling length of 4.2 km. Typical details of the transverse cut are presented in Figure 4.3.

The layers of the existing road pavement structure for the Tangerang-Merak toll road section from the existing design consist of:

1) Asphalted mixture layer as blacktopping with a thickness of 10 cm obtained by double AC-WC overlay at the relevant location.
2) Joint Plain Concrete Pavement (JPCP) or the surface layer of continuous concrete pavement without reinforcement with a thickness of 29 cm and has a concrete quality of FS 45 (K-500).
3) The bottom foundation layer consists of K-125 thin concrete with a thickness of 10 cm and a class A aggregate foundation layer with a thickness of 25 cm.
4) Subgrade the existing layer with a CBR design of 6%, a maximum dry density of 2,315 g/cm3 and an optimum moisture content of 6%.

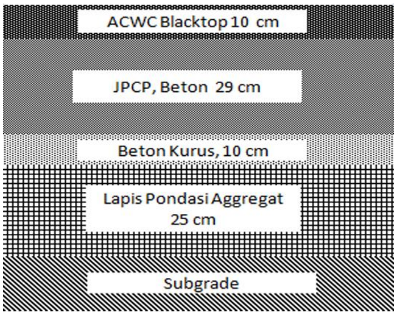


Figure 2. Existing Pavement Layer Data
(Source: Pavement design of the Tangerang-Merak Toll Road Balaraja-Cikupa STA 32+100 to 36+300)

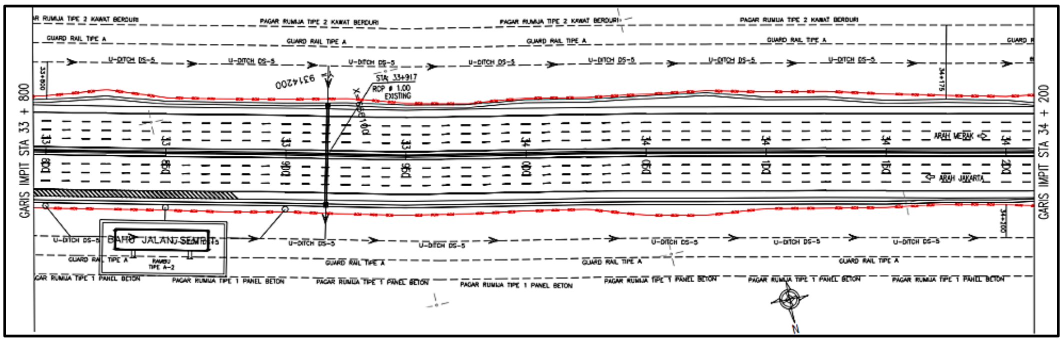
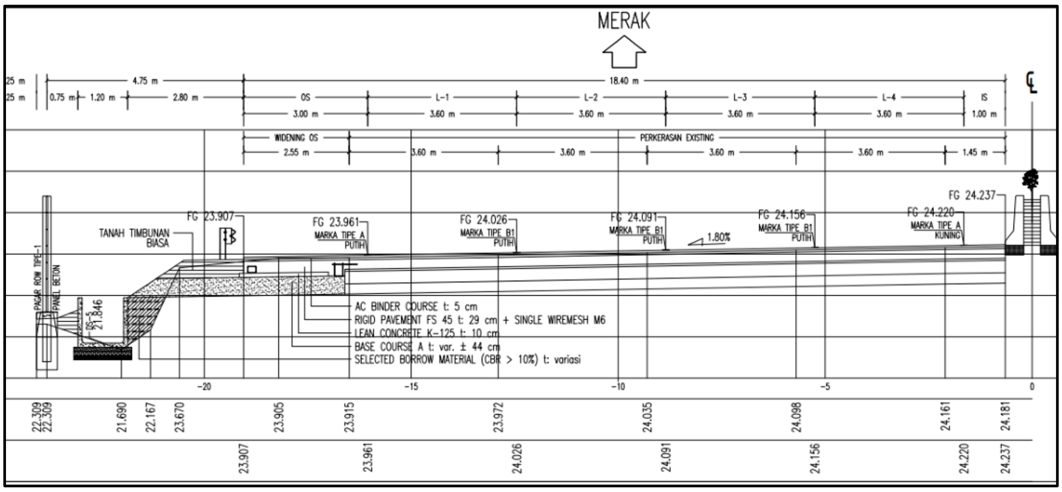
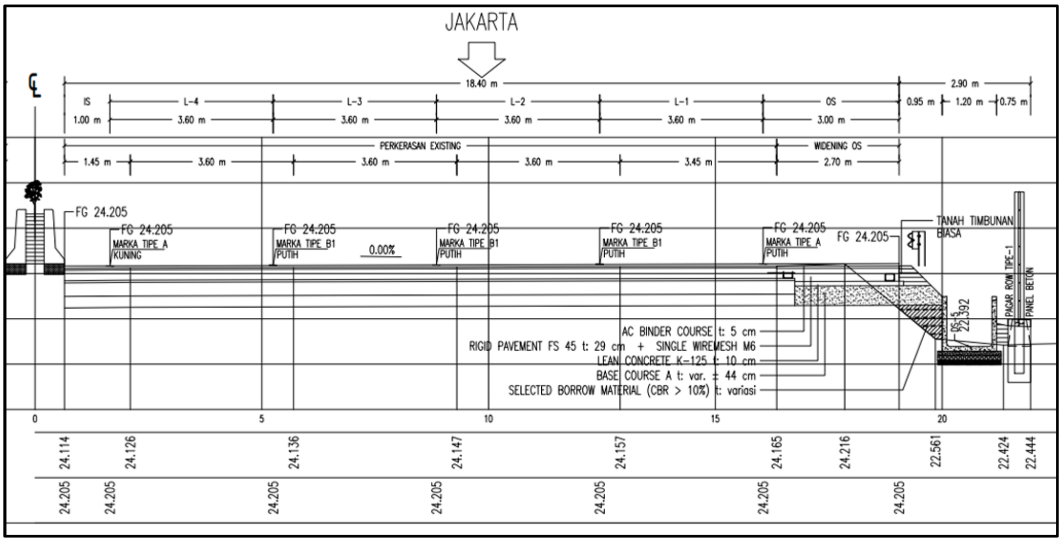


Figure 3. Layout of the Tangerang-Merak Toll Road Balaraja-Cikupa STA 32+100 – 36+300



(a)



(b)

Figure 4. Typical Cross Cut of the Tangerang-Merak Toll Road Balaraja-Cikupa STA Section 32 + 100 to 36 + 300

Identify Potential Failure Modes

Identification of quality risks is done with a field survey before creating a questionnaire feedback form. Based on the visual condition of the pavement, it can be known that the quality risks that occur at the study site include the formation of holes, jembul, grain release (ravelling), crack blocks, jembul patching, and sinking patching. These potential risks are classified based on the source of the risk that is the potential failure of the construction project.

The cause of road damage can come from various internal factors during the construction process, as well as external factors after construction takes place. The formation of potholes can be caused by rainwater and ineffective drainage system planning, non-standard material quality, passing vehicle loads, and unstable soil (Rachardi, 2018). Rainwater is one of the supporting factors that cause road damage. Ineffective drainage system planning causes a halt in the movement of rain towards the sewer and forms a puddle. The quality of the material that does not meet the standards and meets the condition of standing water, has the potential to cause a reduction in the bonding power between asphalt and broken stone which results in erosion and the emergence of small holes (Sembung et al., 2020). Post-construction transportation activities, such as excessive vehicle loads, can cause damage and reduce road service life by 3.1 years (Employee et al., 2021).

The cause of the occurrence of a swelling on rigid pavement when viewed from the construction process can be caused by excess moisture content in the subsoil, uneven soil compaction during geotechnical work, and supported by an ineffective drainage system (Employee et al., 2021). External factors such as temperature changes, poor material quality, and interconnectedness in the formation of jembul.

Transverse cracking or transerve cracking is cracks that are not connected to each other, which cross on rigid pavement systems (Maulana et al., 2022). This minor damage factor occurs because the concrete experiences rocking or vertical movement in the cracks due to traffic loads, excessive load from the concrete surface, poor material quality, and lack of curing or treatment of the concrete after the concrete reaches the final setting (Saputra et al., 2014).

Grain release or ravelling may be caused by ineffective drainage systems, poor material quality, climate, unstable soil conditions, thin pavement layer planning, and the process of carrying out pavement construction work that is not in accordance with the provisions listed in the specifications, which are interrelated and affect (Maulana et al., 2022). As for patching, both the patching of the jembul and the patching of the collapse are suspected to be caused by poor preparation of the road surface before patching (Fatikasari, 2021).

In general, damage or quality risk that occurs is classified into three categories, namely (1) damage due to initial work related to poor supervision weaknesses, design weaknesses, and poor material quality; (2) damage due to wear and time, such as surface wear, vehicle load, weather (cracking) and traffic abrasion, road marking, and joint fragility; (3) damage due to special causes, such as traffic accidents, potholes, and avalanches (Astuty & Purwanto, 2024).

The factors that cause quality risks on the Tangerang Merak Toll Road are then independent variables submitted to respondents in the questionnaire feedback form. Each factor causing quality risk is further referred to as a potential failure mode or failure modes is classified under clause 8 of ISO 9001:2015 into four causal items, as follows:

1) Planning and control of operations. The questions asked are related to the work schedule, quality control procedures during the construction process, material quality control and the thickness of the road work layer in accordance with technical specifications.
2) Requirements for products and services. The questions asked are related to checking the technical specifications of existing pavement structures.
3) Control of processes, products, and services. The questions asked include checking the supplier's audit documents in verifying the suitability of materials received in the field through project quality inspection documents.
4) Production and service providers in implementation.

Potential failures or failure modes that cause the emergence of quality risks at the study site can be grouped into planning and control operations (X1); requirements for products and services (X2); control of processes, products, and services (X3); and production and implementation service providers (X4). Failure modes or potential failures in planning and operation control items include unrealistic work schedules that cause project delays, the absence of clear quality control procedures in operational implementation, operational risks are not properly identified in the project plan, work schedule monitoring is not carried out regularly, so deviations are not detected. Failure modes on requirement items for products and services relate to failures in existing pavement structures that cause quality risks such as ineffective drainage systems, material non-conformity in pavement structures with established technical specifications, excess moisture content in the subsoil, uneven soil compaction, poor road surface preparation before patching, and cracks and deformations in pavement not detected in the initial inspection.

Failure modes in process control items, products, and services related to project quality inspection documents do not cover all critical aspects, materials supplied by external vendors do not conform to technical specifications, audit processes against external vendors are not carried out regularly, there is no good coordination between the project implementation team and external service providers.

Failure modes in production items or service providers (implementation) include failures in the production process in the field, technical errors, lack of field supervision of ongoing work, and absence of procedures to handle complaints or problems during the implementation process.

All of these potential failure modes are thought to have a direct impact on quality risk or damage to the study site (Table 1). The overall impact is interrelated and affecting. The potential failure mode is a variable in the questionnaire feedback form which aims to identify, determine the magnitude and frequency, and handle quality risks related to pavement structures on the Tangerang Merak Toll Road.

Table 1. Recapitulation of Potential Failures and Estimation of the Impact of Quality Risk Causes

No	Failure Modes	Impact
I. Operation Planning and Control		
X1-1	Unrealistic work schedules that cause project delays	Delays in project completion, which are related to delays in toll road operations, add to the cost of the project
X1-2	Absence of clear quality control procedures in operational implementation	Poor quality of work, leads to faster pavement damage, affects the durability of the expressway, and requires costly repairs
X1-3	Operational risks are not well identified in the project plan	Inability to anticipate and deal with problems that occur during construction, resulting in disruption and even damage in the pavement
X1-4	Monitoring of work schedules is not carried out periodically, so deviations are not detected	The mismatch between the planned progress and the reality, leads to delays and a deterioration in the quality of pavement construction
II. Requirements for Products and Services		
X2-1	Ineffective drainage system	The occurrence of puddles that can damage the pavement structure, accelerating wear and tear
X2-2	Material incompatibility of the pavement structure with the set technical specifications	Increased risk of cracking, deformation, or long-term structural failure
X2-3	Excess moisture content on the groundland	Disturbed subsoil stability, reduced carrying capacity, and potential damage to the pavement layer
X2-4	Uneven soil compaction	Differences in strength in the pavement structure, which can trigger cracks or deformation in certain parts of the toll road
X2-5	Composition of liquid asphalt mixture that is not optimal	An unoptimal asphalt mixture, which reduces the durability and durability of the pavement against vehicle loads and extreme weather
X2-6	Unstable subgrades	Instability of the expressway, with the risk of shifting or lowering leading to structural damage to the pavement
X2-7	Uneven asphalt installation process	Uneven road surface, reducing the life of the toll road
X2-8	Preparation of the road surface before patching is not good	Reduced adhesion of the new pavement layer to the old one, which leads to rapid damage and instability of the toll road
X2-9	Cracks and deformations in the pavement were not detected in the initial inspection	Damage to the toll road can occur faster than the life of the plan
III. Control of Processes, Products, and Services		
X3-1	Project quality inspection documents do not cover all critical aspects	Missed critical issues that can damage quality

No	Failure Modes	Impact
X3-2	Materials supplied by external vendors do not conform to technical specifications	Poor pavement quality, with a faster risk of damage or failure of the pavement structure
X3-3	The audit process for external vendors is not carried out regularly	Receipt of materials or services that do not meet standards, worsens construction quality, affects the life of toll roads
X3-4	Lack of good coordination between the project implementation team and external service providers	Errors in the implementation and storage of the technical plan, worsening the progress and quality of the project
IV. Production and Service Providers (Implementation)		
X4-1	Failures in the production process in the field, such as inappropriate material mixing	Pavement that does not meet specifications, with the potential for long-term damage that can accelerate the deterioration of the quality of the toll road
X4-2	Technical errors in the execution of the project, such as incompatibility with the thickness of the pavement layer	Poor durability of toll roads
X4-2	Lack of field supervision of ongoing work	Undetected technical errors or corrective actions that are not performed in a timely manner
X4-3	Absence of procedures for handling complaints or problems during project implementation	Delays in resolving issues that arise and lead to project delays and potential for greater damage

Source: Primary data processing, 2025

Quality Risk Factors Based on RPN

The results of severity, occurrence, and detection scores were obtained based on the assessment of the questionnaire from each respondent. The average severity of potential failures based on the responses of 10 respondents was 5.7 and had a median value of 6.0. This value indicates the potential for turbulence to be in moderate to high conditions, with the criteria of damage to the asphalt layer or road surface that results in safety risks that interfere with smooth traffic and require repairs in the near future.

The average frequency (occurrence) of potential failures based on the responses of 10 respondents was 5.9 with a median value of 6.0. This value represents the potential for failure to occur in a medium frequency. Potential failures can occur in 1 in 80 projects up to 1 in 500 similar projects.

The detection value actually shows an average of 7.6 with a median of 8.0 which indicates that the potential failure that occurs is less likely to be controlled to detect during the construction process so as to cause damage or quality risk as can be found on the site. The three severity, occurrence, and detection values showed that seven of the damage or quality risks that occurred were caused by potential failures or failure modes that often occurred in moderate frequencies with high severity, but small failures were controlled to be detectable during the construction period. The standard deviation for severity, occurrence, and detection data from thirty respondents in a row was 1.1; 0,8; and 0.1.

As for the average severity, occurrence and detection values of thirty respondents, the results of the calculation of the RPN value can be obtained. The following is an example of RPN calculation from potential failure modes in the production process in the field, such as inappropriate material mixing that is the cause of damage or quality risk to the road pavement structure on the Tangerang Merak Toll Road.

$$\begin{aligned} RPN &= severity \times occurrence \times detection \\ &= 6 \times 7 \times 7 \\ &= 294 \end{aligned}$$

Based on the risk priority value in Table 4.3, it can be known that the mode of potential failure in the damage to the pavement structure on the Tangerang Merak Toll Road is the composition of the liquid asphalt mixture that is not optimal and failures in the production process in the field, such as mixing materials that are not suitable. These two potential failures have an RPN value of 294 with an average of identical severity, occurrence, and detection values of 6, 7, and 6 respectively. This potential failure has a severity level of 6 or high with the criterion of damage to the asphalt layer or road surface which results in safety risks that interfere with the smooth flow of traffic and require repairs in the near future. The frequency of both failure modes in a construction project is in high frequency with low detection rate.

The potential for failure with a high degree of severity is uneven soil compaction and unstable subgrades, because it not only affects the pavement structure layer but also affects significant damage to the main structure which has the potential to endanger user safety and requires immediate repair with large cost swelling.

The RPN value is then used in making fishbone diagrams to determine the cause of potential failure modes of the Tangerang Merak Toll Road project. The five potential failures with the highest RPN values are suboptimal composition of the liquid asphalt mixture (X2-5), failures in the field production process (X4-1), cracks and deformations in the pavement not detected in the initial inspection (X2-9), lack of field supervision of the work in progress (X4-3), and technical errors in project implementation (X4-2).

Preparation of Alternative Solutions

The potential failure with the highest RPN value is the composition of the liquid asphalt mixture that is not optimal (X2-5) with a severity value of 6, occurrence 7, and detection 7. This suggests that this potential failure has a high degree of severity and needs to be corrected in the near future. This potential failure often occurs in high frequencies and is very low in the likelihood of detecting failure. A comprehensive strategy that can be carried out is to review the asphalt mixture formula so that it is in accordance with technical standards, such as the Marshall method. Based on the project quality inspection card document, testing schedules and material testing data related to asphalt are available, but based on the quality risks that arise such as grain release and patching, a review of the asphalt mixture formula used is required. To facilitate the detection of failure modes, laboratory checks related to moisture content tests on asphalt mixtures using standard methods such as ASTM D2041 are required to ensure the conformity of specifications. Corrective action that can be taken is a review of the asphalt mixture formula that will be used for overlay or layer replacement to prevent. In addition, it is necessary to conduct audits and evaluations of AMPs and material suppliers to ensure that the quality of the materials used meets the standard specifications.

Failure of the production process in the field (X4-1) has a severity value of 6, occurrence 7, and detection 7. This suggests that this potential failure has a high degree of severity and needs to be corrected in the near future. This potential failure often occurs in high frequencies and is very low in the likelihood of detecting failure. A comprehensive strategy that needs to be carried out is to implement a clear standard operating procedure (SOP) for each work item. In addition, production inspections in the field need to be carried out regularly. Detectable production failures need to be re-mixed or improved by adjusting the composition of the mixture, especially for local overlays or reconstruction of the affected segments.

Cracks and deformations on the pavement were not detected in the initial inspection with a value of RPN 252 with a severity value of 6, occurrence 7 and detection 6. This shows that this failure mode is more manageable than the composition of the liquid asphalt mixture is not optimal and production failure. A comprehensive strategy that needs to be carried out to prevent similar failure modes in other expressway construction projects is to use visual inspections and deflection tests at regular intervals. For cracks that are small in size, crack sealing or slurry sealing is required ((nono, 2013);(Ni et al., 2023)). Meanwhile, if significant deformation is found, repairs such as mill and overlay or full-depth repair are required (Manguande et al., 2020).

The lack of field supervision of the work in progress (X4-3) causes various other problems including failure modes of asphalt mixtures that do not meet specifications, failures in the production process, and the appearance of cracks and deformations in the pavement. The failure mode of lack of field supervision of the ongoing work is a crucial point for the overall improvement of the quality risks present in the project (Putra et al., 2021). A comprehensive strategy to address the potential failure mode of lack of field supervision of ongoing work includes the need for a daily supervision checklist system that covers all aspects of the work, ensuring strict supervision scheduling with daily reports to be submitted to project management. Random and periodic field audits need to be conducted to evaluate worker performance and ensure procedures are followed appropriately.

Potential failures of technical errors in project implementation (X4-2), such as inconsistencies in thickness and pavement layers, have a severity value of 6, occurrence 7, and detection 4. The potential for technical error failure to be detected is classified as moderate, or there is a control to detect failure. To carry out early detection of this potential failure, small-scale implementation trials can be carried out before application in all segments. The use of building information modeling (BIM) to predict and analyze possible errors before the project runs. Corrective actions that can be taken include implementing a corrective and preventive action (CAPA) system to improve problematic procedures. In addition, rework or rehabilitation is required according to the right technical recommendations. This strategy integrates prevention, early detection, and correction approaches to ensure that toll road projects run according to quality standards. By implementing technology, workforce training, and stricter supervision systems, the potential for failure in construction can be minimized, thereby increasing the resilience, safety, and lifespan of the toll road infrastructure plan.

Instrument Test Data Processing

The results of the recapitulation of questionnaire data processing were carried out on the testing of research instruments, namely validity tests, reliability tests, correlation tests and multiple linear regression tests with the help of the IBM SPSS 25 program.

Table 2. Validity Test Results

Variable		*Pearson Correlation*	Info
I. Operation Planning and Control			
X1-1	Unrealistic work schedules that cause project delays	0,813	VALID
X1-2	Absence of clear quality control procedures in operational implementation	0,967	VALID
X1-3	Operational risks are not well identified in the project plan	0,857	VALID
X1-4	Monitoring of work schedules is not carried out periodically, so deviations are not detected	0,743	VALID
II. Requirements for Products and Services			
X2-1	Ineffective drainage system	0,857	VALID
X2-2	Material incompatibility of the pavement structure with the set technical specifications	0,838	VALID
X2-3	Excess moisture content on the groundland	0,813	VALID
X2-4	Uneven soil compaction	0,924	VALID
X2-5	The composition of liquid asphalt mixtures is not optimal	0,851	VALID
X2-6	Unstable subgrades	0,888	VALID
X2-7	Uneven asphalt installation process	0,813	VALID
X2-8	Preparation of the road surface before patching is not good	0,813	VALID
X2-9	Cracks and deformations in the pavement were not detected in the initial inspection	0,89	VALID
III. Product and Service Process Control			

	Variable	*Pearson Correlation*	Info
X3-1	Project quality inspection documents do not cover all critical aspects	0,821	VALID
X3-2	Materials supplied by external vendors do not conform to technical specifications	0,821	VALID
X3-3	The audit process for external vendors is not carried out regularly	0,967	VALID
X3-4	Lack of good coordination between the project implementation team and external service providers	0,707	VALID
IV. Production and Service Providers (Implementation)			
X4-1	Failures in the production process in the field, such as inappropriate material mixing	0,773	VALID
X4-2	Technical errors in the execution of the project, such as incompatibility with the thickness of the pavement layer	0,869	VALID
X4-3	Lack of field supervision of ongoing work	0,821	VALID
X4-4	Absence of procedures for handling complaints or problems during project implementation	0,821	VALID
Y1-1	Decrease in Job Quality	0,860	VALID

Source: Primary data processing, 2025

Based on the validity test, as many as 21 X-free variables from a sample of 10 respondents had a calculated r-value greater than rTable = 0.632 overall and the data can be said to be valid data.

Table 3. Results of the X-Free Variable Reliability Test

Cronbach's Alpha	N of Items	Cronbach's Alpha Value	Information
0,860	4	0,600	RELIABLE
0,958	9	0,600	RELIABLE
0,931	4	0,600	RELIABLE
0,862	4	0,600	RELIABLE
0,976	21	0,600	RELIABLE

Source: Primary data processing, 2025

Based on the reliability test (Table 3), all variables X and variable Y have an alpha calculation of > 0.600. The measurement instrument is consistent and has acceptable reliability.

Correlation Test

Based on the results of the correlation test, the relationship between the X variable and the strongest quality degradation variable (Y) was obtained from the X2-9 variable, namely cracks and deformation on the pavement were not detected in the initial inspection. The relationship between the X2-9 variable and the Y quality degradation variable resulted in a value of 0.922 with a significance value of 0.000 which can be interpreted as a very strong relationship.

Table 4. Correlation Test

Correlation

		X2-9	Y
X2-9	*Pearson Correlation*		0,922**
	Sig. (2-tailed)		0,000
And	*Pearson Correlation*	0,922**	
	Sig. (2-tailed)	0,000	

***. Correlation is significant at the 0,01 level (2-tailed)*

Model Interpretation

Based on the normality distribution test of the data using the one-sample Kolmogorov-smirnov test, the questionnaire data has a normal distribution distribution (Figure 4.6). Therefore, the relationship test of the influence of variable X on variable Y can be tested by multiple linear regression test. These relationships can be used as a basis for analyzing a problem (Huda & Syifaul, 2019).

The hypothesis for the intervariable testing in this study is as follows:

H0 : There is no influence between quality management system variables on quality degradation on the Tangerang Merak Toll Road

H1 : There is an influence between the variables of the quality management system on the quality decline on the Tangerang Merak Toll Road

H0 is rejected if the value of F calculated in the linear regression test exceeds the F of the table for degrees of freedom (df) = 9, i.e. 3.18. Testing this hypothesis is by analyzing the value of the determination coefficient (R2) and the significance value of each variable. Based on the results of the multiple linear regression test conducted, it can be seen that there is an effect caused by the independent variables X1, X2, X3, and X4 simultaneously on the decrease in the quality of work at the study site (Y) by 70.7%. While the remaining 29.3% was explained by other causes outside the variables of this study.

Table 5. Normality Distribution Test Results

One-Sample Kolmogorov-Smirnov Test		
		Unstandardized Residual
N		10
Normal Parameters[a,b]	Mean	.0000000
	Std. Deviation	.44693169
Most Extreme Differences	Absolute	.212
	Positive	.212
	Negative	-.147
Test Statistic		.212
Asymp. Sig. (2-tailed)		.200[c,d]
a. Test distribution is Normal		
b. Calculated from data		
c. Lilliefors Significance Correction		
d. This is a lower bound of the true significance		

Table 6. Determination Coefficient Test Results

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	0,860a	0,739	0,707	0,47404

a) Predictors (Constant), X1, X2, X3, X4

Table 7. Statistical Test Results F

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Itself
1	Regession	5,102	1	5,102	22,705	0,001b
	Residual	1,798	8	0,225		
	Total	6,900	9			

a) Dependent variable: Y

b) Predictors (Constant), X1, X2, X3, X4

The test results showed that F was calculated with a value of 22.705 with a significance of 0.001 < 0.05 which can be interpreted that simultaneously the free variable X has an effect on the deterioration of the quality of the Tangerang-Merak Toll Road (Y). Then, the ratio of the calculated F-value of 22.705 is greater than the F-value of the table for degrees of freedom (df) = 9, which is 3.18. This indicates that H0 is rejected and H1 is accepted, or there is an influence between the variables of the quality management system on the quality decline on the Tangerang Merak Toll Road.

Table 8. Recapitulation of Multiple Linear Regression Test Results

Variable		**Significance Value**
I. Operation Planning and Control		
X1-1	Unrealistic work schedules that cause project delays	0,142
X1-2	Absence of clear quality control procedures in operational implementation	0,002
X1-3	Operational risks are not well identified in the project plan	0,06
X1-4	Monitoring of work schedules is not carried out periodically, so deviations are not detected	0,003
II. Requirements for Products and Services		
X2-1	Ineffective drainage system	0,06
X2-2	Material incompatibility of the pavement structure with the set technical specifications	0,003
X2-3	Excess moisture content on the groundland	0,142
X2-4	Uneven soil compaction	0,015
X2-5	The composition of liquid asphalt mixtures is not optimal	0,006
X2-6	Unstable subgrades	0,025
X2-7	Uneven asphalt installation process	0,091
X2-8	Preparation of the road surface before patching is not good	0,142
X2-9	Cracks and deformations in the pavement were not detected in the initial inspection	0,000
III. Product and Service Process Control		
X3-1	Project quality inspection documents do not cover all critical aspects	0,003

	Variable	Significance Value
X3-2	Materials supplied by external vendors do not conform to technical specifications	0,003
X3-3	The audit process for external vendors is not carried out regularly	0,002
X3-4	Lack of good coordination between the project implementation team and external service providers	0,008
IV. Production and Service Providers (Implementation)		
X4-1	Failures in the production process in the field, such as inappropriate material mixing	0,008
X4-2	Technical errors in the execution of the project, such as incompatibility with the thickness of the pavement layer	0,06
X4-3	Lack of field supervision of ongoing work	0,003
X4-4	Absence of procedures for handling complaints or problems during project implementation	0,003

Variables X1-2, X1-4, X2-2, X2-9, X3-1, X3-2, X3-3, X4-3, and X4-4 have a significance value of < 0.05 which means that it partially affects the quality degradation variable (Y) while the other variables have a significance value of > 0.05 which means that it has no partial effect on the quality degradation variable (Y). It can be known that the quality degradation or quality risk that occurs on the Tangerang Merak Toll Road is caused by the absence of clear quality control procedures in the implementation of operations (X1-2), monitoring of work schedules that are not carried out periodically, so that deviations are not detected (X1-4), material non-conformity in the pavement structure with the set technical specifications (X2-2), cracks in deformations on the pavement are not detected in the initial inspection (X2-9), project quality inspection documents do not cover all technical aspects (X3-1), materials supplied by external vendors do not conform to technical specifications (X3-2), audit processes against external vendors are not carried out regularly (X3-3), lack of field supervision of ongoing work (X4-3), and absence of procedures to address complaints or issues during project implementation (X4-4).

CONCLUSION

The study concluded that integrating the FMEA method with ISO 9001:2015 effectively improved quality risk management in toll road projects by identifying potential failures linked to key quality management clauses. The highest Risk Priority Number (RPN) of 294 was associated with issues in liquid asphalt mixture composition and material mixing, highlighting weak quality control during production, service delivery, and operational planning stages. This integration enabled more targeted preventive measures aligned with specific ISO clauses and supported proactive decision-making, with 70.7% of quality degradation explained by the four ISO 9001:2015 variables analyzed. Additionally, a strong correlation (0.922) was found between undetected cracks and deformations during initial inspections and quality risks, demonstrating FMEA's capability to focus management on critical preventive actions. Future research could explore the integration of this model with digital monitoring technologies to enhance real-time risk detection and mitigation in toll road construction projects.

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