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TRAFFIC RISK ANALYSIS OF THE SEMARANG - DEMAK TOLL ROAD

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ABSTRACT
The high incidence of accidents on toll roads and the diverse risks faced by drivers underscores the importance of studying traffic issues on these roads. This analysis aims to identify significant risks, enabling effective risk management and mitigation. Additionally, it enhances road user safety, traffic flow, and the operational sustainability of toll roads. The risk analysis begins with identifying risks using the Risk Breakdown Structure (RBS) method, followed by assessments of frequency and impact, evaluation of risk criticality, ranking and categorization, and the management of highly critical risks. The findings of this study reveal 22 risks that impact traffic on toll roads, with the three highest risks being drowsy driving, rear-end collisions, and tire blowouts.

Keywords: risk; toll road; traffic

INTRODUCTION
Toll roads are public roads that form part of the road network system and function as national highways. Traffic on toll roads is managed by imposing certain fees according to the approved tariffs. (Karpushko et al., 2021). The authority to manage toll roads lies with the Government, and part of this governmental authority related to corporate entities' regulation, business operation, and oversight is executed by the BPJT (Republik Indonesia, 2005). In specific circumstances that prevent the development of the toll road network by Corporate Entities, the Government may take appropriate measures within its powers, such as undertaking the construction of toll roads partially or entirely, with operations managed by the private sector. In 2014, the Government of Indonesia constructed 718 km of toll roads, and by 2024, the total length of toll roads in Indonesia reached 5,200 km (Mandia et al., 2022). One of Indonesia's newly operational toll roads is the Semarang-Demak Toll Road Section 2. This road supports the Pantura Semarang-Demak National Road, which frequently experiences congestion. The 16.31 km toll road was officially inaugurated and began operations on February 28, 2023 (Yanwardana, 2023). Seven accidents were reported on this toll road within three months of operation (Maulana et al., 2023).

Toll roads are designed as expressways; however, they often encounter traffic issues, including various risks. Traffic risk originates from the components within it, namely vehicles, roads, and people. Traffic itself refers to the movement of vehicles and people in the roadway space (Republik Indonesia, 2009). There are still many casualties and fatalities due to traffic accidents, indicating that the achievement of "Vision Zero" is still a long way off (Kristianssen et al., 2018). Vision Zero is globally recognized as a road traffic safety policy with great potential (Kim et al., 2017). The traffic safety status is strongly related to traffic flow, speed, occupancy, and other traffic status evaluation indicators (Sun et al., 2020). Risk management is the decision-making process involving the implementation of actions aimed at increasing the likelihood of achieving the desired objectives, so that the organization can continue to function effectively (Domańska-Szaruga, 2020). The loss due to faced risks varies significantly depending on their causes and effects (Dalimunthe et al., 2021). According to the International Standard (2009), it is explained that the risk management process consists of 5 (five) stages, namely goal setting, risk identification, risk analysis, risk evaluation, and risk treatment (ISO, 2018). Risks related to traffic on toll roads include the risk of accidents, damaged traffic facilities, traffic congestion, and security and safety threats (Satriaputri & Cahyadi, 2016). The highest risk factor related to traffic accidents on toll roads is human factors caused by negligence (Haryanto & Lativa, 2020). The significant number of accidents and diverse risks drivers encounter on toll roads highlight the need for a more in-depth examination of traffic issues in these areas. Analyzing traffic risks on toll roads is crucial, particularly in risk management, ensuring the safety of road users, facilitating smooth traffic flow, and supporting the sustainability of toll road operations.

METHOD

This research was carried out on the Semarang-Demak Toll Road and aims to investigate the traffic risk factors associated with this route, categorizing it as exploratory research. Exploratory research is an initial type of research that is broad in nature. Exploratory research is very important because it provides a strong foundation for subsequent studies (Purkon et al., 2022). The factors influencing traffic on the Semarang-Demak Toll Road are examined through various reference sources and input from toll road management.

Data Collection Techniques

The data in this study include primary data in the form of questionnaire data related to traffic risk assessment and secondary data in the form of literature related to toll road risks. Data collection begins with collecting secondary data to obtain/identify initial risks, which are then used as a reference for compiling the questionnaire. he questionnaire consists of 22 variables divided into five indicators: road infrastructure, traffic flow, security, safety, and environmental and natural conditions. The variables are assessed using an ordinal scale with a value of 1-5. The frequency/probability assessment scale can be seen in Table 1 (Saputro, 2022) and the impact assessment scale can be seen in Table 2.

Table 1.
Frequency Scale /Probability

No	Level	Scale
1	Very Rarely	1
2	Rarely	2
3	Sometimes	3
4	Often	4
5	Very Often	5

Table 2.
Impact Scale

No	Level	Scale
1	Very Small	1
2	Small	2
3	Medium	3
4	Large	4
5	Very Large	5

The selection of respondents in this study employed a purposive sampling technique, which is a method of sampling based on specific criteria. The respondents in this study were representatives from the toll road authority.

Data Analysis Techniques

Risk Analysis identifies risks using the Risk Breakdown Structure (RBS) method. In RBS, risks are divided into four levels, starting from level 0 through activities known to be risky. Then, at level 1, they are divided into more detailed sub-risks, namely risks in management, external, and so on. Level 2 discusses, more specifically, the level 1 risk. Level 3 details the risks at level 2 into more detailed risks. The next step is to calculate the level of frequency and impact by converting the scales in Tables 1 and 2 to the values in Table 3 (Adham & Nugraha, 2022).

Table 3.
Probability and Impact Matrix

Impact / Probability	Very small (0.05)	Small (0.10)	Medium (0.20)	Big (0.40)	Very large (0.80)
Very often (0.10)	0.05	0.09	0.18	0.36	0.72
Often (0.30)	0.04	0.07	0.14	0.28	0.56
Sometimes (0.50)	0.03	0.05	0.10	0.20	0.40
Rare (0.70)	0.02	0.03	0.06	0.12	0.24
Very rare (0.90)	0.01	0.01	0.02	0.04	0.08

The frequency and impact values are then used to determine the risk importance level and rank and categorize risks.

Risk Importance Level = Frequency x Impact

Note:
Probability/Frequency refers to the rate at which a particular risk occurs.
The impact refers to the extent to which a risk influences a project.

RESULT AND DISCUSSION

RBS Analysis (*Risk Breakdown Structure*)

After conducting validity and reliability tests, the risks were deemed to have passed for further analysis. Here, 22 risks are divided into five categories, as detailed in Table 4. The Risk Breakdown Structure (RBS) analysis was carried out by identifying risks based on risk groups.

Table 4.
Traffic Risk Breakdown Structure for the Semarang-Demak Toll Road

Level 1	Level 2	Level 3	Level 4	
Risky Programs	Traffic Risks on Semarang-Demak Toll Road	Road Infrastructure	X1	Damaged road
			X2	Broken signs
			X3	Faded road markings
			X4	Street lights out
			X5	Broken barrier fences
		Traffic Flow	X6	Partial toll road closure
			X7	Congestion due to high vehicle volume
			X8	Stopped traffic due to exit access issues
		Safety	X9	Tire burst
			X10	Rear-end collision
			X11	Drowsy driving
			X12	Drivers not adhering to speed limits
		Security	X13	Robbery
			X14	Residents throwing stones at drivers
			X15	Extortion by illegal tow trucks
			X16	Misuse of land by residents
		Natural Conditions and Environment	X17	Land subsidence
			X18	Flooding
			X19	Strong winds
			X20	Earthquake
			X21	Landslide
			X22	Vision obstruction due to smoke

Frequency and Impact Analysis

Frequency analysis to obtain the average frequency value of each risk is done by converting the frequency assessment scale in Table 1 with the values in Table 3, namely a value of 0.9 for risks with very frequent frequencies, 0.7 for risks with frequent frequencies, 0.5 for risks with occasional frequencies, 0.3 for risks with rare frequencies, and 0.1 for risks with very rare frequencies. The results of the frequency level assessment of each risk can be seen in Table 5. Similar to the frequency level analysis, the impact level analysis is also conducted by converting the impact rating scale in Table 2 to the values presented in Table 3, namely 0.8 for risks with very large impacts, 0.4 for risks with large impacts, 0.2 for risks with moderate impacts, 0.1 for risks with small impacts, and 0.05 for risks with very small impacts. The results of the impact level assessment for each risk can be viewed in Table 6.

Table 5
Frequency Level Assessment

Variable	Very Often	Often	Sometimes	Rare	Very rare	Average Frequenct Value
	0,900	0,700	0,500	0,300	0,100	
X1	0	1	13	10	7	0,352
X2	0	0	7	11	13	0,261
X3	0	2	13	12	4	0,384
X4	0	2	7	17	5	0,339
X5	0	0	10	9	12	0,287
X6	0	6	8	10	7	0,384
X7	0	5	14	8	4	0,429
X8	0	3	15	12	1	0,429
X9	0	4	15	12	0	0,448
X10	0	0	8	21	2	0,339
X11	1	11	16	3	0	0,565
X12	0	3	6	14	8	0,326
X13	3	5	9	10	4	0,455
X14	0	3	11	11	6	0,371
X15	0	2	10	9	10	0,326
X16	0	2	1	11	17	0,223
X17	0	2	2	13	14	0,248
X18	2	2	9	15	3	0,403
X19	1	4	8	13	5	0,390
X20	3	5	9	10	4	0,455
X21	0	0	6	8	17	0,229
X22	2	3	7	13	6	0,384

Table 6.
Impact Level Assessment

Variable	Very Large	Large	Moderate	Small	Very Small	Average Impact Value
	0,800	0,400	0,200	0,100	0,050	
X1	1	9	9	7	5	0,231
X2	1	7	12	6	5	0,221
X3	0	10	9	5	7	0,215
X4	2	5	8	13	3	0,215
X5	1	6	10	5	9	0,198
X6	0	10	5	9	7	0,202
X7	2	10	10	7	2	0,271
X8	1	8	12	8	2	0,235
X9	0	8	17	5	1	0,231
X10	7	7	11	4	2	0,358
X11	1	8	11	8	3	0,231
X12	0	6	11	5	9	0,179
X13	0	7	11	7	6	0,194
X14	1	5	11	7	7	0,195

Variable	Very Large	Large	Moderate	Small	Very Small	Average Impact Value
	0,800	0,400	0,200	0,100	0,050	
X15	1	9	6	5	10	0,213
X16	6	8	5	5	7	0,318
X17	1	5	11	10	4	0,200
X18	0	8	10	9	4	0,203
X19	2	7	11	6	5	0,240
X20	3	5	4	10	9	0,215
X21	2	5	7	13	4	0,210
X22	3	7	7	11	3	0,253

Risk Importance Level Analysis

To determine the level of risk importance, multiply the average frequency value and the average impact value. The results of the risk importance assessment can be seen in Table 7 and Figure 1, which show each indicator.

Table 7.
Risk Importance Level

Variable	Frequency (a)	Impact (b)	Level of Interest (a x b)
X1	0,352	0,231	0,0811
X2	0,261	0,221	0,0577
X3	0,384	0,215	0,0823
X4	0,339	0,215	0,0727
X5	0,287	0,198	0,0570
X6	0,384	0,202	0,0774
X7	0,429	0,271	0,1163
X8	0,429	0,235	0,1010
X9	0,448	0,231	0,1034
X10	0,339	0,358	0,1213
X11	0,565	0,231	0,1302
X12	0,326	0,179	0,0583
X13	0,455	0,194	0,0880
X14	0,371	0,195	0,0724
X15	0,326	0,213	0,0694
X16	0,223	0,318	0,0707
X17	0,248	0,2	0,0497
X18	0,403	0,203	0,0819
X19	0,390	0,24	0,0938
X20	0,455	0,215	0,0976
X21	0,229	0,210	0,0480
X22	0,384	0,253	0,0972

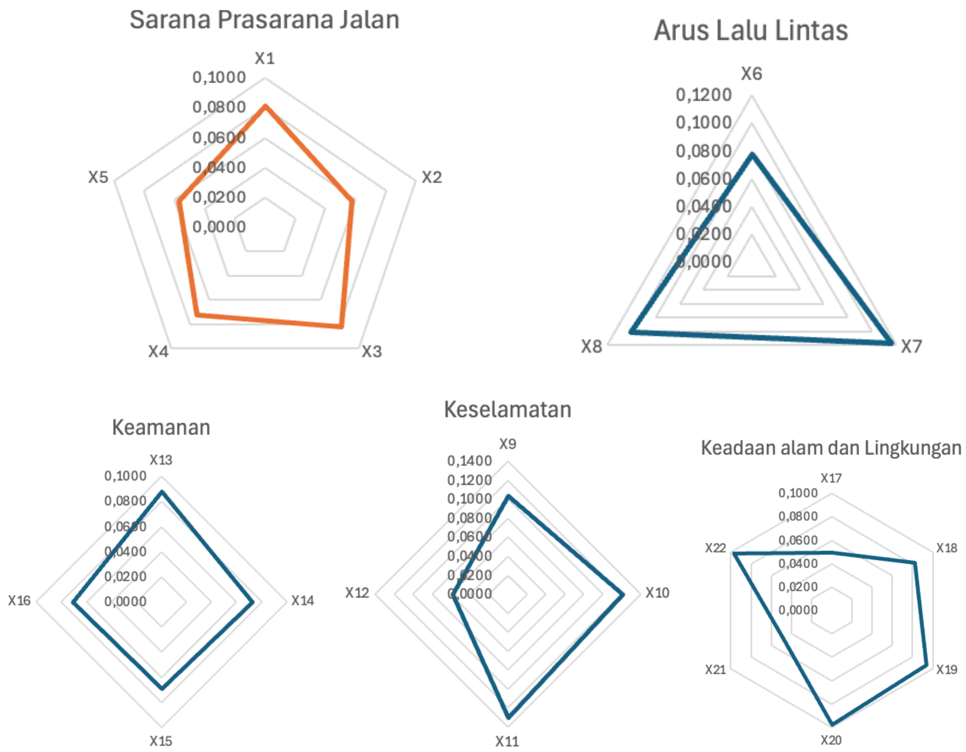

Figure 1.
Risk Importance Level Radar Chart (Per Indicator)

Risk Ranking and Categorization Analysis

Following the determination of risk importance levels, the process continued with establishing rankings and risk categories based on Table 3. Here, risk importance levels ranging from 0.01 to 0.05 fall into the low category, levels from 0.06 to 0.14 are classified as moderate, and levels from 0.15 to 0.72 are categorized as high. The results of the ranking and categorization of each risk are displayed in Table 8.

Table 8
Risk Ranking and Category

Variable	Risk	Level of Interest (a x b)	Ranking	Category
	Road Infrastructure			
X1	Damaged road	0,0811	12	moderate
X2	Broken signs	0,0577	19	Low
X3	Faded road markings	0,0823	10	Moderate
X4	Street lights out	0,0727	14	Moderate
X5	Broken barrier fencese	0,0570	20	Low
	Traffic Flow			
X6	Partial toll road closure	0,0774	13	Moderate
X7	Congestion due to high vehicle volume	0,1163	4	Moderate
X8	Traffic stopped due to exit issues	0,1010	5	Moderate
	Security			
X9	Tire burst	0,1034	3	Moderate
X10	Rear-end collision	0,1213	2	Moderate
X11	Drowsy driving	0,1302	1	Moderate
X12	Non-compliance with speed limits	0,0583	18	Low
	Safety			

Variable	Risk	Level of Interest (a x b)	Ranking	Category
X13	Robbery	0,0880	9	Moderate
X14	Stone throwing at drivers by residents	0,0724	15	Moderate
X15	Extortion by illegal tow trucks	0,0694	17	Moderate
X16	Land misuse by residents	0,0707	16	Moderate
	Natural and Environmental Conditions			
X17	Land subsidence	0,0497	21	Low
X18	Flooding	0,0819	11	Moderate
X19	Strong winds	0,0938	8	Moderate
X20	Earthquake	0,0976	6	Moderate
X21	Landslide	0,0480	22	Low
X22	Vision obstruction due to smoke	0,0972	7	Moderate

Based on the frequency level assessment that has been carried out, it is known that variable X11 (sleepy driver) has the highest average frequency value with a value of 0.565. The lowest average frequency value is in variable X16 (land abuse by residents), with a value of 0.223. Meanwhile, based on the impact level assessment that has been carried out, it is known that variable X10 (collision) has the highest average impact value, namely 0.358. The lowest average impact value is in variable X12 (Drivers do not obey speed limit rules) with a value of 0.179. Based on the analysis carried out, the risk with the highest risk importance value is a sleepy driver with a value of 0.1302, and the risk with the lowest value is a landslide with a value of 0.048. Of the 22 risks, 17 risks fall into the moderate category, and five categories fall into the low category. The three risks with the highest values are sleepy drivers, rear-end collisions, and tire bursts.

Sleepiness can significantly increase the risk of accidents on highways. When an individual feels sleepy or fatigued, their ability to focus and react to surrounding situations may be impaired. This is supported by research conducted by Rahmadiyani & widyanti (2023), which found that 79% of respondents in their study had experienced driving while sleepy at least once, and 32% had been involved in accidents while driving in a drowsy state. The toll road management plays a very important role in helping drivers reduce the risk of accidents caused by drowsy drivers. Fatigue and drowsiness are major factors that cause drivers to lose focus and control over their vehicles, which can lead to serious accidents. Therefore, toll road operators can take various strategic actions to support drivers and ensure their safety during their journey. Some of the actions that can be taken by toll road operators include providing rest areas and installing rumble strips. One of the most effective measures in reducing driver fatigue risks is providing adequate rest areas along the toll roads. These rest areas not only serve as places to rest but can also be equipped with comfortable and safe short sleep zones. Drivers who feel tired or drowsy can take a brief break to refresh themselves before continuing their journey. By providing proper sleeping facilities, drivers can rest for a short time and still feel refreshed and ready to continue their journey safely. In addition, toll operators can also provide facilities like coffee shops or light snacks to help drivers stay alert during their trip. Installing rumble strips is an effective solution to provide early warnings to drivers who may be drowsy or distracted. Rumble strips are placed on the edges or center of the road to alert drivers through vibrations in the vehicle. When a vehicle crosses the rumble strip, the driver will feel a vibration, which serves as a reminder to return to a safe lane or reduce speed. The installation of rumble strips is particularly effective on long and straight toll roads, where drivers are more likely to become drowsy. The location of rumble strips should be carefully selected, such as near rest areas or areas with high accident potential due to driver fatigue.

The second highest risk is a rear-end collision with a moderate category. However, in a study conducted by Amrullah (2024) it was found that traffic accidents due to rear-end collisions are the highest contributor to the death rate in traffic accidents that occur on toll roads. Rear-end collisions on toll roads can be caused by the interaction of several causal elements, including drivers, vehicles, highways, and the environment (Didin et al., 2023). To reduce the risk of rear-end collisions, various efforts can be made involving education, infrastructure, and technology. One of the main steps to reduce the risk of rear-end collisions is by educating drivers on the importance of maintaining a safe following distance between vehicles. Awareness campaigns regarding safe distances should be intensified across various media, including on highways and other busy roads. Drivers need to be made aware that having enough distance provides space for reactions in case of sudden braking. Emphasizing the importance of maintaining a safe following distance should be part of a broader road safety campaign. To support this awareness campaign, road authorities can install road markings that indicate safe distances between vehicles at specific points, especially on highways and congested roads. These markings could take the form of lines with specific intervals that make it easier for drivers to know how far they should be from the vehicle ahead. This will help drivers comply with safe distance rules without having to calculate it manually. Speed limits are an effective way to reduce the risk of rear-end collisions, as the higher the speed, the shorter the reaction time available to drivers in emergency situations. Appropriate speed limits based on road conditions and traffic flow can reduce rear-end accidents. In addition, road authorities can adjust speed limits at accident-prone areas, such as sharp curves or areas with poor visibility. Electronic boards or Variable Message Signs (VMS) can be installed to provide important information about traffic conditions that may affect safe following distances. For example, electronic boards can provide information about traffic congestion, accidents, or bad weather that can slow down traffic flow and impact the distance between vehicles. The installation of these electronic boards, both on highways and main roads, will allow drivers to adjust their speed and safe following distance based on real-time information.

A tire blowout is also a significant risk in the context of traffic accidents, especially on highways. A tire blowout can occur suddenly and often has the potential to cause serious accidents, particularly if the driver is unable to control their vehicle properly after the tire blows out. Therefore, highway managers play a crucial role in mitigating this risk and helping drivers reduce the potential negative impacts of such incidents. One of the steps that highway managers can take is to provide emergency lanes and wide, safe shoulders. This gives space for drivers experiencing technical problems, such as a tire blowout, to pull over safely to the side of the road without disrupting the flow of traffic. The existence of adequate emergency lanes also facilitates quicker access for emergency vehicles to reach the incident location. Additionally, highway managers can provide regular highway patrol services. These patrols ensure a quick response to emergency situations, including tire blowouts, which may occur unexpectedly. Patrol services can also assist with traffic diversion, providing directions to drivers who have stopped, and contacting assistance services if necessary. It is also important to provide 24-hour assistance services that are easily accessible to drivers who experience difficulties on the highway. These services can include emergency assistance such as tire changes, refueling, or even towing the vehicle to the nearest workshop. With a well-organized communication system between the driver and the assistance center, tension and anxiety can be reduced, and problem resolution can be expedited.

CONCLUSION

Based on the research conducted, information was obtained regarding the variables with the highest frequency, impact, and risk levels. The variable with the highest frequency value is driver drowsiness, with a value of 0.565. This indicates that drowsy drivers are one of the most frequently occurring factors in the context of accidents or incidents being studied. Meanwhile, the variable with the highest impact value is rear-end collision, with a value of 0.358. This suggests that, although driver drowsiness may occur frequently, the impact of rear-end collisions is greater in terms of the damage or consequences caused. Rear-end collisions often result in serious injuries or significant vehicle damage, contributing to the high impact value. For risk levels, the driver drowsiness variable again recorded the highest value, 0.1302. This indicates that, although the impact of rear-end collisions is higher, the risk of drowsy driving is more likely to result in an accident or high-risk event compared to other variables. Out of the 22 risks identified in this study, 17 risks fall under the moderate category. This shows that most of the risks, while not negligible, pose a lower level of danger compared to high-risk situations. Meanwhile, 5 other risks fall into the low category, meaning these incidents have a lower likelihood and impact in causing significant accidents or damage. The top three risks with the highest values are driver drowsiness, rear-end collisions, and tire blowouts, which provide a clearer picture of the factors that require particular attention in accident mitigation efforts. Drowsy driving and rear-end collisions, with high impact and risk levels, should be the main focus in awareness programs, safety policies, and infrastructure improvements, while tire blowouts, also a high-risk factor, require attention to vehicle maintenance and tire quality. Overall, these findings indicate that driver drowsiness and rear-end collisions are two key factors that should be closely monitored, and risk reduction strategies should focus on these factors to reduce the number of accidents and their impacts.

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