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Analysis of Traffic Performance and Passenger Car Equivalent Value in Tangerang – Merak Toll Road Section

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Cover Page Footnote

This research extends our sincere appreciation and gratitude for the collaborative efforts between the Traffic Corps of the Indonesian National Police (Korps Lalu Lintas POLRI) and the Faculty of Engineering, University of Indonesia (Fakultas Teknik Universitas Indonesia), as delineated in Agreement No. B/22/IV/2016 and 197/PKS/FT/UI/2016 regarding the Organization of Education, Training, Research, and Expertise Support. This partnership has significantly advanced human resource development, knowledge dissemination, and expertise enhancement, particularly in traffic management and transportation. We deeply appreciate the dedication of all involved parties, whose commitment and collaborative spirit have fostered the success and mutual benefit derived from this agreement. May this acknowledgment serve as a testament to our fruitful collaboration, and we eagerly anticipate continued cooperation and further milestones in our shared pursuit of excellence.

ANALYSIS OF TRAVEL TIME DIFFERENCES DUE TO OVER-DIMENSION VEHICLES ON THE TANGERANG – MERAK TOLL ROAD

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ABSTRACT

The Tangerang-Merak toll road serves as a vital link for passenger and freight transportation between Java and Sumatra, the two most populous islands in Indonesia. With eleven toll gates and three major ports along its route, the road witnessed a vehicle volume of 150 million in 2021, comprising 84% class I vehicles and 16% freight vehicles. However, the increasing freight traffic has led to a rise in traffic violations, particularly overloading and overdimension, which accounted for 4.3% of freight vehicles in 2022. These violations, aimed at reducing logistics costs, negatively impact road safety and traffic flow. The study aims to analyze the adverse effects of overdimension conditions on travel time and traffic flow using the Volume Delay Function (VDF) method. Results reveal contrasting traffic performance, with efficient vehicle handling but significant congestion issues, exacerbated by heavy vehicles. Additionally, the Effective Moving Pattern (emp) calculation method enhances understanding of vehicle contributions to traffic dynamics, offering insights for traffic management improvements. This research underscores the need for policy interventions to address overdimension violations and enhance traffic management on the Tangerang-Merak toll road.

Keywords: *Tangerang-Merak Toll Road; Overdimension Vehicles; Traffic Management*

INTRODUCTION

The Tangerang – Merak toll road plays a crucial role in various sectors, especially land transportation for passengers and goods. It connects the islands of Java and Sumatra, the two most populous islands in Indonesia. There are three major ports serving as entry points to Sumatra: ASDP Port, BBJ Port, and Ciwandan Port, along with eleven toll gates including: Cikupa Toll Gate, Balajara Timur, Balaraja Barat, Cikande, Serang-Panimbang, Ciujung, Serang Timur, Serang Barat, Cilegon Timur, Cilegon Barat, and Merak. In 2021, the vehicle volume on the Tangerang – Merak toll road reached 150 million, with 16% being freight vehicles and 84% being class I vehicles. This toll road supports Indonesia's logistics sector with an annual increase in freight vehicle volume, accompanied by a rise in traffic violations, particularly overloading and overdimension, which accounted for 4.3% of freight vehicles in 2022. Overdimension violations, which reduce logistics costs by increasing load per trip, have negative impacts on the vehicles and other road users. The traffic density and overdimension violations affect travel time, calculated using the Volume Delay Function (VDF) method from the U.S. Bureau of Public Roads, which correlates vehicle volume with road capacity. The VDF method, useful in transportation policy decisions, utilizes parameters such as travel time, traffic volume, and road capacity, along with exponential coefficients. Roess, Prassas, and McShane (2004) stated that traffic analysis is influenced by variations in vehicle numbers, types, and speeds, equated using Passenger Car Equivalence (PCE). Based on this background, the researchers aim to describe the adverse impacts of overdimension conditions on travel time and traffic flow on the Tangerang – Merak toll road, hoping that the results can serve as a basis for policy addressing this issue. Therefore, the research questions to be discussed are calculate the PCE value on the Tangerang – Merak toll road, the results of vehicle travel time calculations, and the differences in travel time due to overdimension vehicles.

METHODS

The research methodology for "Analysis of Travel Time Differences Due to Over Dimension Vehicles on the Tangerang – Merak Toll Road" begins with the background, which explains the importance of this toll road in land transportation and the increasing volume of vehicles and overdimension violations that impact travel time and traffic flow. The research questions include how to calculate the Passenger Car Equivalence (PCE) value, the results of travel time calculations, and the differences in travel time due to overdimension vehicles. The research aims to describe the adverse impacts of overdimension conditions on travel time and traffic flow and provide a basis for policy addressing this issue. The theoretical foundation includes the Volume Delay Function (VDF) method from the U.S. Bureau of Public Roads, which correlates vehicle volume with road capacity, and the PCE concept to equate different types of vehicles. Relevant journal literature reviews traffic analysis and travel time calculation methods. Data collection involves primary data from direct observations and secondary data from official sources such as BPS and Astra Tol. Data is processed by calculating the PCE for overdimension vehicles and the delay travel time using VDF. The analysis compares travel time changes under normal conditions and with overdimension vehicles, providing insights into the significant impact of overdimension violations on traffic efficiency on the Tangerang – Merak Toll Road.

RESULTS AND DISCUSSION

To gather accurate traffic volume data on the Tangerang-Merak toll road section, a systematic and comprehensive recording process is conducted. Focused on specific points on the toll road, such as between kilometers 32,200 and 34,500, the recording team monitors continuously for 24 hours to capture the number of vehicles passing in both directions. This collected data provides an accurate overview of traffic volume in the area, supporting effective and efficient traffic planning and management. Subsequent data processing converts vehicle volume into passenger car units by multiplying equivalents based on the Indonesian Road Capacity Guidelines. Traffic performance analysis involves collecting hourly traffic volume data and converting these values using passenger car unit values for each vehicle type, resulting in a more accurate picture of traffic load. Comparing traffic load with road capacity is crucial to identify the need for capacity improvements to address congestion and ensure smooth traffic flow. Additionally, the Degree of Saturation (DJ) value is used to assess traffic performance and determine travel speeds, with DJ results categorized according to service level classifications based on the International Highway Capacity Manual (IHCM).

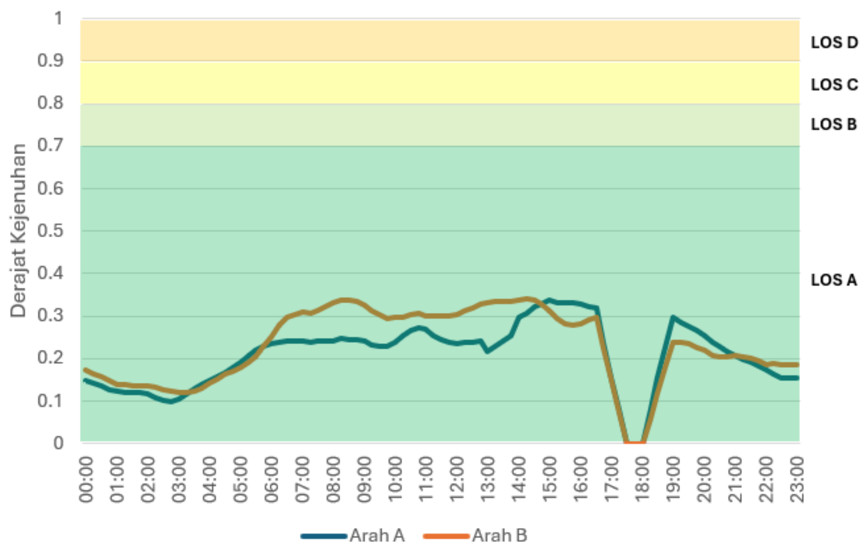

Figure 1 Traffic Performance based on V/C Ratio of the Tangerang-Merak Toll Road Section

Based on the Traffic Performance graph according to the V/C ratio of the Tangerang-Merak toll road section, it can be concluded that throughout the day, this toll road demonstrates optimal traffic performance. Both directions of traffic achieve a service level of A throughout the 24 hours, indicating excellent service conditions where vehicles can move smoothly without significant hindrance. This indicates that there are no traffic performance issues caused by vehicle flow volume on this toll road section. Thus, in terms of traffic performance, the Tangerang-Merak toll road section can be considered efficient and capable of handling vehicle volume well throughout the day.

Data processing of traffic speed on the Tangerang-Merak toll road section is conducted using travel time data from CCTV cameras installed along various road segments. The collected data records the travel time of vehicles through segments spanning 19 meters. To calculate speed, this travel time is processed by dividing the segment length (19 meters) by the recorded travel time, resulting in speed in meters per second (m/s). Subsequently, this speed is converted into kilometers per hour (km/h) by multiplying it by a factor of 3.6. Thus, the speed distribution for each vehicle passing through the toll road section is obtained. This speed data is then analyzed to observe speed distribution patterns, averages, medians, and variations in speed among vehicles. This analysis aids in understanding traffic conditions and identifying potential issues or congestion on the Tangerang-Merak toll road section. The next step involves determining the weighted speed for each direction. This process begins by summing the products of the speed of each type of vehicle and the volume of those vehicles. Then, this sum is divided by the total number of vehicles passing through that segment. From this value, the average speed for each direction within a one-hour time interval is obtained. This average speed data is then used to conduct traffic performance analysis, including evaluating traffic conditions, identifying potential bottlenecks or congestion, and making decisions regarding traffic management on the toll road section. The results of this analysis provide insights into the effectiveness of traffic management and assist in planning necessary improvements or adjustments to enhance traffic flow and safety. Lastly, traffic performance analysis based on speed is conducted using the 1985 HCM table to categorize the level of service (LOS) for each hour. This analysis is used to evaluate the condition of the Tangerang-Merak toll road section, enabling the identification of the level of service provided by the toll road section at various time intervals. By categorizing LOS, it is possible to determine the quality of traffic conditions on the road section, which can then be used as a basis for more effective traffic improvement and management.

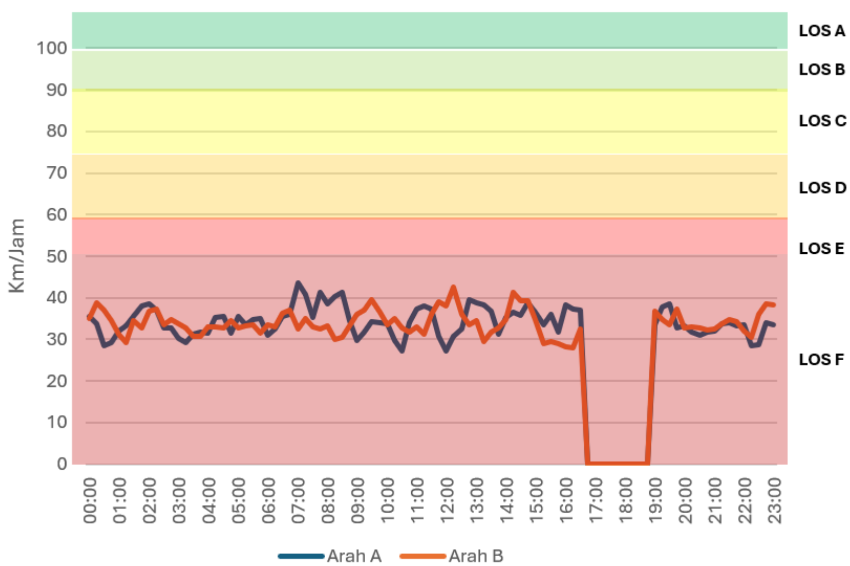

Figure 2 Traffic Performance based on Speed on the Tangerang-Merak Toll Road Section

Based on the traffic performance graph of the Tangerang-Merak toll road section, it can be concluded that throughout the day, this toll road exhibits problematic traffic performance. Both directions of traffic receive an F level of service throughout the 24 hours, indicating very poor service conditions. At the F level of service, vehicles move very slowly and often experience severe congestion. This results in many vehicles being forced to travel on the shoulders of the road, not only adding to the chaos but also increasing the risk of accidents and endangering the safety of drivers. Additionally, issues such as over dimension and overload (ODOL) on heavy vehicles further exacerbate the traffic conditions on this toll road section. Heavy vehicles exceeding the permitted dimensions and loads not only reduce traffic speed and efficiency but also damage the existing toll road infrastructure. The excess load from ODOL vehicles can cause damage to the road surface, accelerate wear and tear, and increase the frequency of road repairs that further disrupt traffic flow.

In the analysis of determining the emp values, eight types of vehicle groups were formed according to the classification of the 2023 Indonesian Highway Capacity Manual. This revision aims to provide more accurate and specific analysis, particularly addressing the issues of over dimension and overload (ODOL) frequently encountered in freight vehicles at the research site. Passenger cars and buses are identified separately to facilitate the analysis of their load and impact on traffic flow. Pickups/boxes, medium trucks, and large trucks are categorized more specifically to better understand the behavior and contribution of each vehicle type to ODOL issues. The results of this analysis are anticipated to assist in making more informed decisions regarding traffic management and the development of the Tangerang-Merak toll road. Through this analysis, useful insights are expected to be obtained for more efficient traffic management and better infrastructure planning in the future.

Table 1 Vehicle Volume Before Auxiliary Markings at the Study Intersection

Jenis Kendaraan		MP	Bus	Pickup	Truk	TruckB
MP	Pearson Correlation	1	.227**	.692**	.691**	-0.112
	Sig. (2-tailed)		0.003	0	0	0.148
	N	168	168	168	168	168
Bus	Pearson Correlation	.227**	1	.231**	.265**	0.105
	Sig. (2-tailed)	0.003		0.003	0.001	0.176
	N	168	168	168	168	168
Pickup	Pearson Correlation	.692**	.231**	1	.568**	-.183*
	Sig. (2-tailed)	0	0.003		0	0.018
	N	168	168	168	168	168
Truk	Pearson Correlation	.691**	.265**	.568**	1	-0.138
	Sig. (2-tailed)	0	0.001	0		0.075
	N	168	168	168	168	168
TruckB	Pearson Correlation	-0.112	0.105	-.183*	-0.138	1
	Sig. (2-tailed)	0.148	0.176	0.018	0.075	
	N	168	168	168	168	168

The correlation analysis results between vehicle types using the Pearson method in SPSS indicate a strong significance between passenger cars and buses and other vehicle types. This analysis assesses the correlation values among vehicles and measures their significance levels. The obtained significance values for passenger cars and buses concerning other vehicle types are below 10%, indicating a highly significant relationship between these vehicle types and others on the Tangerang-Merak toll road. The low significance values imply that changes in other vehicle flows have a substantial impact on passenger cars and buses. This influence could stem from various factors, including the frequency and usage patterns of these vehicles on the toll road. Moreover, the influence of other vehicles on passenger cars and buses can also be observed in terms of traffic management and toll road design. For instance, an increase in the number of trucks or heavy vehicles may lead to changes in the speed and efficiency of passenger cars and buses' journeys. Conversely, an increase in the number of passenger cars and buses may also affect the movement of other vehicles, creating complex traffic dynamics. Following this analysis, the next step in this study involves conducting an ANOVA test to determine the effectiveness of the traffic data analysis model. Through ANOVA testing, researchers can ascertain the most suitable and accurate observation time for obtaining representative results. This test is performed using a classification of five vehicle types: passenger cars, buses, pickups/boxes, medium trucks, and large trucks. Each vehicle group is analyzed separately to identify significant differences in recorded traffic flow within the specified time intervals. The ANOVA test results are then presented in a table format, providing a clear overview of the model's effectiveness in measuring traffic performance based on different vehicle types. The ANOVA table displays the F-statistic and p-value, used to determine the significance of differences between vehicle groups. If the p-value is lower than the set significance level, the difference between vehicle groups is considered significant. Additionally, the table presents the average vehicle flow values for each group, aiding in understanding existing traffic distribution and patterns. Through ANOVA analysis, researchers can pinpoint the most accurate and representative observation times for each vehicle type, crucial for traffic planning, management decisions, infrastructure development, and transportation policies on the Tangerang-Merak toll road. Thus, ANOVA not only evaluates the model used but also provides vital insights for improving and enhancing traffic performance.

Table 2 Speed vs Vehicle Flow

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	1.08E+62	5	2.16E+61	0.857	0.51
Residual	4.08E+63	162	2.52E+61		
Total	4.19E+63	167			

Based on the ANOVA test results using SPSS for the traffic flow of five classified vehicle types concerning weighted vehicle speed, it was found that the significance value exceeding 10% indicates minimal differences among vehicle groups. The obtained F-value of 8 from this test depicts that the differences among these vehicle groups are not significant. This suggests that the variations in weighted vehicle speed among the five vehicle types—passenger cars, buses, pickups/boxes, medium trucks, and large trucks—are not significantly different in the observed traffic flow context. This finding is crucial for understanding that weighted vehicle speeds tend to be uniform across various vehicle classifications in the analyzed traffic conditions. Subsequently, regression tests were conducted for the traffic flow of the five classified vehicle types concerning weighted vehicle speed using SPSS. This regression analysis aims to understand the relationship between the traffic flow volume from each classification—passenger cars, buses, pickups/boxes, medium trucks, and large trucks—and the average weighted vehicle speed. The analysis results demonstrate how variations in traffic flow from each vehicle type affect the overall speed on the observed toll road segment. Through this regression analysis, deeper insights into traffic dynamics and factors influencing vehicle speed are expected to be gained, facilitating more effective traffic planning and management strategies.

Table 3 Linear Regression Test: Speed against Traffic Flow

Unstandardized Coefficients			Standardized Coefficients	t	Sig.
B		Std. Error	Beta		
(Constant)	0.864	1.99		0.433	0.06
MP	0.00135	1.29	-0.131	-1.05	0.02
Bus	0.00162	1.68	-0.131	-1.599	0.01
Pickup	0.00526	7.75	0.078	0.703	0.04
Truk	0.00364	3.05	0.14	1.271	0.02
TruckB	0.00715	1.08	0.056	0.695	0.04

After conducting regression analysis for each classification of traffic flow against weighted speed, beta values were obtained for each classification. The analysis results indicated that the significance values for each classification were below 10%, indicating a strong influence of each traffic flow on the weighted speed. Thus, a regression equation describing the relationship between traffic flow and weighted speed can be formulated, which can be used to predict the weighted speed based on the traffic flow volume of each classification.

$$V = 0.864 + 0.00135Q_{MP} + 0.00162Q_{Bus} + 0.00526Q_{PB} + 0.00364Q_{TS} + 0.00715Q_{TB}$$

Description

V = Weighted Speed (Km/Hr)

Q_MP = Passenger Car Traffic Flow

Q_Bus = Bus Traffic Flow

Q_PB = Pickup/Box Traffic Flow

Q_TS = Medium Truck Traffic Flow

Q_TB = Large Truck Traffic Flow

In this study, Van Aerde and Yagar (1983) introduced the Effective Moving Pattern (emp) calculation method using speed data in their analysis. This method is based on establishing a relationship between speed (V) and traffic flow (Q) using multiple linear regression. This linear regression model depicts the mathematical relationship between speed and traffic flow. Determining the coefficients comparison of each vehicle type is crucial in generating the emp value. To calculate the emp value for each vehicle type, except for passenger cars, the ratio between the coefficients of each vehicle type divided by the coefficient of passenger cars (LV) is used as a parameter. Thus, this method provides a framework for measuring and comparing the relative contributions of various vehicle types to the effective movement patterns on the Tangerang-Merak toll road.

$$emp_{bus} = \frac{c_{bus}}{c_{mp}} = \frac{0.00162}{0.00135} = 1.2$$

$$emp_{pb} = \frac{c_{pb}}{c_{mp}} = \frac{0.00526}{0.00135} = 3.9$$

$$emp_{ts} = \frac{c_{ts}}{c_{mp}} = \frac{0.00364}{0.00135} = 2.7$$

$$emp_{tb} = \frac{c_{tb}}{c_{mp}} = \frac{0.00715}{0.00135} = 5.3$$

From the results of this study, new emp values were obtained for each vehicle type while retaining the passenger car emp value at 1 and the bus emp at 1.2. Adjustments were made to other vehicles to reflect their more accurate influence on traffic speed and flow. The emp value for pickup trucks, previously 1.2, was adjusted to 3.9, indicating a significant increase in the influence of these vehicles on speed and traffic flow. Similarly, the emp value for medium trucks, initially 1.2, was adjusted to 2.7, and for large trucks, initially 1.6, it became 5.3. These changes indicate that heavy vehicles have a greater impact on traffic flow patterns than previously estimated. Adjusting these emp values is important as it provides a more realistic picture of the relative contributions of various vehicle types to the efficiency and dynamics of traffic flow on the Tangerang-Merak toll road. With these new emp values, traffic planning can be done considering the more accurate impact of each vehicle type, which in turn can enhance traffic management and regulation. Toll road operators can use this information to develop more effective strategies, such as allocating special lanes for heavy vehicles or adjusting operating times to reduce congestion. Thus, this research not only updates the emp values used but also provides a stronger basis for decision-making oriented towards improving traffic performance and road safety.

In the obtained new emp results, it is necessary to reevaluate the traffic load. This evaluation is crucial to ensure that the new emp values reflect the actual conditions in the field. By comparing this latest data with the observed traffic flow conditions, it can be determined whether the adjustments made are in line with the dynamics and characteristics of the actual vehicles. This will help assess the accuracy and effectiveness of the emp model used, providing a stronger basis for future traffic planning and management. After converting traffic volume from vehicle units to Passenger Car Equivalent (PCE), the next step is to analyze traffic performance by understanding the traffic load from the total volume of all vehicle types on each segment every hour. This analysis involves collecting hourly traffic volume data and converting these values using the PCE value for each vehicle type, thereby providing a more accurate picture of the traffic load. Subsequently, this traffic load will be compared with the road capacity to determine the road performance level. This comparison is essential to identify whether the road capacity is sufficient or if there is a need to increase capacity to address traffic congestion and ensure smooth traffic flow. This traffic performance analysis will provide valuable insights for more effective and efficient road infrastructure planning and management.

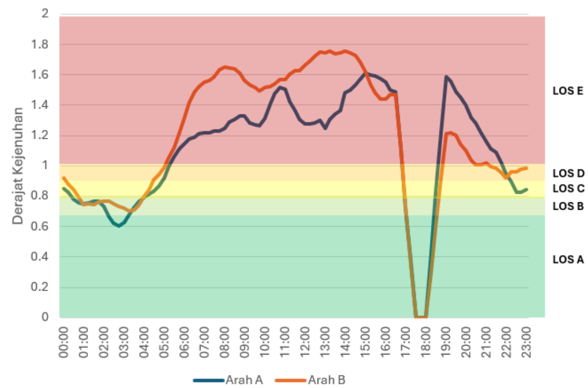

Figure 3 Traffic Performance based on V/C Ratio of the Tangerang-Merak Toll Road Section

Based on the Traffic Performance graph based on V/C ratio of the Tangerang-Merak toll road section, it is evident that there are significant differences in conditions due to the adjustment factor of emp. During peak hours, there is a decrease in traffic performance reaching the level of service F, indicating very poor service conditions. The main cause is the influence of freight traffic resulting in a decrease in vehicle speed leading to significant congestion. Changes in emp values directly affect traffic dynamics, especially during busy hours when traffic density increases drastically. This analysis provides crucial insights for toll road managers to evaluate the effectiveness of traffic management and design more efficient strategies to reduce congestion and improve service on the Tangerang-Merak toll road. With a better understanding of the factors influencing traffic performance, efforts for improvement and enhancement can be directed towards creating a smoother and safer driving experience for road users.

CONCLUSION

This study yields several significant conclusions. Firstly, based on the analysis of traffic performance graphs along the Tangerang-Merak toll road section, two contrasting situations affecting vehicular flow are evident. While the speed-based traffic performance indicates efficiency and the ability to handle vehicle volume well, there are serious congestion issues resulting in a significant decline in service levels. Factors such as heavy vehicles with over-dimension and overload (ODOL) exacerbate this condition. Secondly, the Effective Moving Pattern (emp) calculation method introduced by Van Aerde and Yagar (1983) provides a more accurate picture of the relative contributions of various types of vehicles to traffic efficiency and dynamics on the toll road segment. Adjusting emp values helps improve the model and provides a stronger basis for future traffic planning and management. Lastly, the reassessment of traffic loading emphasizes the need for ongoing adjustments to reflect actual field conditions, while the analysis of traffic performance graphs reveals significant differences during peak hours. Thus, this study offers valuable insights for toll road managers to evaluate and enhance traffic management to reduce congestion and improve service along the Tangerang-Merak toll road.

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