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THE EFFECT OF TOLL ROAD OPERATION ON NATIONAL ROAD PERFORMANCE IN CENTRAL JAVA PROVINCE

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One of the major infrastructure development programs of the Indonesian government is the construction of toll roads, such as the Trans-Central Java toll road. The construction of these toll roads subsequently affects various aspects of the country, including the capacity and performance of the national road network. However, the government needs to analyze the effect of the toll road network on the performance of the national road network both in the existing and the coming years. Therefore, this study aims to determine the effect of the Trans Java toll road network on the performance of national roads. The study area used was the Central Java Province with a specific focus on toll roads and national roads. The analysis was processed on the EMME/3 software to form a road network with Gravity Model. The findings showed that the largest movement between 2022 and 2048 is in internal zones. It was also discovered that the Volume-Capacity Ratio value of the road network in 2022 was stable while 512 roads were projected to be unstable in 2048. Moreover, the average travel speed on national road sections in 2022 with toll roads was found to be stable up to 2030 but the speeds started reducing from 2035 to 2048 where the value was recorded to be less than 40 km/hour.

Keywords: EMME/3, gravity model, performance of road network

1 INTRODUCTION

The government has initiated the Nawacita program to prioritize pathways for change to achieve a politically sovereign, economically independent, and culturally rich Indonesia. This is evident in the construction of toll roads such as the one in Trans Central Java, which subsequently affects the performance of the national road network. Sustainable infrastructure development can accelerate equitable development comprehensively. One of the manifestations of the program is the development of the Trans Java toll road infrastructure. Good road conditions provide many benefits to the community. The construction of toll roads will affect the performance of the national road network [1]–[4]. Road network traffic changes along with road network loading [5], [6]. A previous study reported that the traffic on road networks has changed due to the addition of new routes [7], [8]. This implies that the government needs to carefully address transportation problems in the country, taking into account both present and future movements.

Transportation problems are a vehicle with excess loads, significantly influencing road users' transportation and travel time costs. Improving national road performance continues to be carried out by building toll roads to connect and improve connectivity between regions. The connectivity between rural areas and suburban cities must be improved so roads can be well structured. The performance level of a road network can be assessed using three traffic parameters which include speed, traffic density, and Volume-Capacity Ratio (VCR) by comparing traffic volume and road capacity [9]–[11]. However, in reality, the performance of the national road network cannot be determined with certainty when the saturation point of traffic density occurs. In addition, the investment plan assessment has not been adequate for preventing traffic problems [9]–[11]. It is important to note that future traffic volume can be determined using the Origin-Destination Matrix forecasting with the gravity model equation. This method is designed to model the relationship between movement patterns and estimate future patterns through parameter values in the gravity model.

The existence of continuous developmental activities can increase the movement of people and goods, thereby, leading to some transportation problems when the process is not managed efficiently. This means there is a need for transportation planning with due consideration for movement needs[12]. Therefore, case studies were used to estimate the magnitude of the movement pattern in a destination using the gravity model, the Exponential-Negative resistance function, and the Least Squares method.

Therefore, this study aims to determine the influence of the Trans Java toll road network on national road performance. The government needs to analyze the effect of toll road networks on the performance of the national road network in both current and future years.[13]. In addition, one of the current government's main concerns is road performance, which is influenced by governance and is a critical issue [14]. This research is important to determine future traffic volume using a forecasting Destination Origin (OD) Matrix with a gravity model equation [15].

2 BASIC THEORY

2.1 Model Gravity

Transport modeling is the process of distributing the destination matrix on the road network to generate traffic flow in the planning year. This means Origin-Destination Matrix is the main component of the data needed in the process of planning and modeling the transportation system [16].

Several methods can be used to model the origin-destination matrix and these include the synthetic aspect involving the gravity model [17], [18]. Tamin (2000) defined the model as the development of an analogy to the law of gravity involving the gravity force of attraction being influenced by the masses of two objects and the distance between them. The concept of gravity in the context of transportation planning is that movement is influenced by trip generation and accessibility from the origin zone to the destination zone. Moreover, trip generation is equated with the mass of two objects while accessibility is represented by the distance between them. This led to the application of a balancing factor in the form of a limit on the rise and pull to produce the following equation:

$$T_{id} = O_i \cdot D_d \cdot A_i \cdot B_d \cdot f(C_{id}) \tag{1}$$

information:

T_{id} = Total movement from the origin zone to the destination zone

A_i, B_d = Balancing factor for each origin zine to the destination zone

O_i = Total moves generated from the origin zone

D_d = Total moves attracted toward the destination zone

$f(C_{id})$ = Barrier function

The accessibility value of the movement from the origin to the destination zones was determined based on the function of cost, time, and distance. There are several types of resistance functions in the gravity model which include[19]:

1. Rank Barrier Function
2. The Exponential-Negative Resistance Function
3. Tanner Barrier Function

2.2 Least Squares Method

There is an unknown β parameter value in the Gravity model equation and it can be determined using the Least Squares method which involves minimizing the difference between the modeling results and the observational data. The Least-Square estimation method is formulated in the following equation [2].

$$\frac{\partial S}{\partial \beta} = f = \sum_{i=1}^{N} \sum_{d=1}^{N} \left[\frac{2}{\hat{T}} \left(T_{id} - \hat{T}_{id} \right) . \frac{\partial T_{id}}{\partial \beta} \right] \tag{2}$$

This method is popular for the estimation of loading and usually considers measurement errors to provide a more accurate estimate.

2.3 Newton-Raphson calibration

The unknown β parameter in Equation [2] can also be determined through the Newton-Raphson Calibration which is usually completed through the elimination of the Gauss-Jordan Matrix using the following equation:

$$h = -\frac{f}{\frac{\partial f}{\partial \beta}} \tag{3}$$

The value of h can further be used in the following equation:

$$\beta_1 = \beta_0 + h \tag{4}$$

2.4 Traffic Forecasting

Traffic forecasting is an integral part of the road facility design process starting from the investment feasibility study to the development of working documentation. It is important to note that the transportation and distribution of cars in parts are usually determined by a series of interrelated factors. The complete and valid consideration of these factors in complex road networks is only possible through mathematical models and appropriate software applications[18]. Therefore, this study applied EMME/3 software and a gravity mathematical model to forecast traffic with due consideration for the growth factors to determine the amount of traffic attraction and generation in the coming year.

2.5 Growth Factor

Road planning techniques require several technical criteria to be considered in optimizing the planning results and anticipating emerging social or technical problems from roads. A necessary planning criterion is the value of traffic growth but it usually produces difficult accuracy in developing countries such as Indonesia [19].

2.6 Statistical Test Indicator

The level of similarity between the traffic flow modeling results and the actual traffic count can be determined using the Coefficient of Determination (R^2) value obtained through linear regression analysis. Table 1 shows the validity level of a model with the R^2 value.

$$R^2 = \frac{\Sigma_i(\hat{Y}_i - \bar{Y}_i)^2}{\Sigma_i(Y_i - \bar{Y}_i)^2} \quad (6)$$

Table 1. Coefficient Range Determination (R^2)

Mark R^2	Information
0,80 – 1,00	Very high
0,60 – 0,80	High
0,40 – 0,60	High Enough
0,20 – 0,40	Low
0,00 – 0,20	Very low

2.7 Volume-Capacity Ratio (VCR)

The performance level of the road network can be assessed using traffic parameters such as speed, traffic density, and Volume-Capacity Ratio (VCR). The VCR was defined as the ratio of the traffic volume to the road capacity and is normally applied as the main factor in determining the performance level of intersections and roads based on the Indonesian Highway Capacity Manual [20]. Its value is usually used to determine the road segment with a capacity problem.

The general formula for the volume-capacity ratio is as follows

$$VCR = \frac{V}{C} \quad (7)$$

Where:

VCR = Volume-Capacity Ratio

V = Traffic Volumes

C = Capacity (pcu/hour)

The Volume-Capacity Ratio indicates the condition of the road in serving the existing traffic volume. Meanwhile, future traffic volume can be estimated using traffic forecasting analysis and the results can be used to provide recommendations on the best ways to handle road sections [21]. Tamin (2000) was observed to have quoted the findings from the empirical studies conducted on traffic in Jakarta, showing that the Volume-Capacity Ratio at various conditions is listed in the following table.

Table 2. Volume-Capacity Ratio Values

Volume-Capacity Ratio (VCR)	Information
< 0,8	Stable condition
0,8 – 1,0	Unstable condition
>1,0	Critical condition

3 RESEARCH METHODS

3.1 Research sites

The study area used was the Central Java Province with a specific focus on toll roads and national roads. It is also important to note that the area was zoned based on districts/cities and this led to 35 internal zones used to represent each district/city as well as 9 external zones with access to national roads and roads in the province such as the areas in the provinces of West Java, East Java, Yogyakarta.

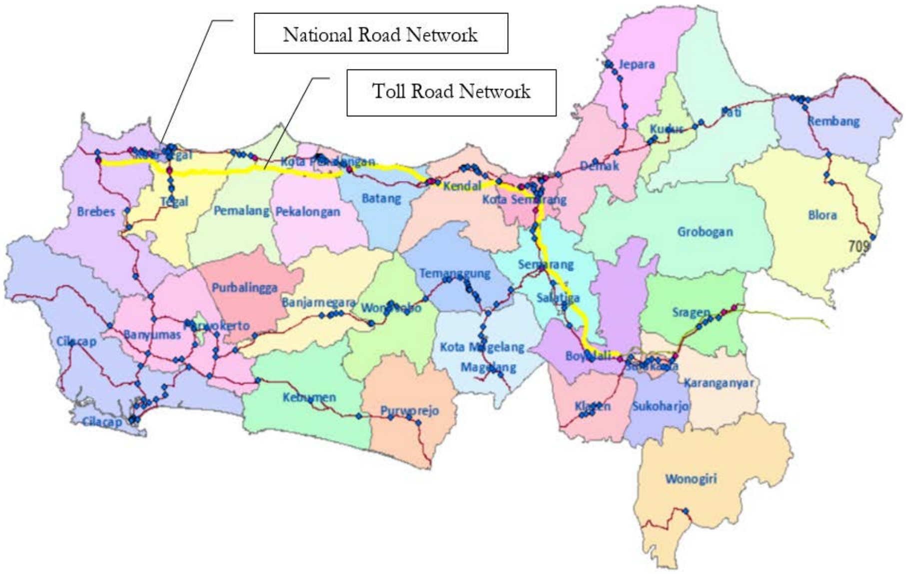

Figure 1. The study area in Central Java Province

3.2 Data analysis method

3.2.1 Database Processing

The data obtained were processed on the EMME/3 software to form a road network. The processing was initiated with the division of the zones based on city/regency and the center of the zone was the centroid. The data on the coordinates of the road sections were determined using ArcGIS with the road capacity, speed, travel time, and traffic volume applied as the input through the network editor. The other data used was the prior matrix which is an estimate of the OD Matrix formulated based on the assumption that each cell contains the number one with the movement in the zone of origin and the same destination was filled with zeros.

3.2.2 Origin–destination (OD) Matrix Estimation Results by EMME/3

The database obtained from the previous stage was entered into the EMME/3 software to be processed. The results were in the form of the 2022 OD Matrix and subsequently tested for validity.

3.2.3 Cost Matrix (Cid) in 2022

Another result obtained through the running process in addition to the movement Matrix was the Cost Matrix (Cid) but it only required one iteration process.

3.2.4 Beta Parameter Calibration (β)

The β parameter in the Exponential-Negative resistance function was calibrated using the Newton-Raphson method. The calculation was repeated in MATLAB up to the moment the fixed β value was recorded.

3.2.5 Origin–Destination (OD) Matrix Estimation of the Modelling Result in 2022

The β value from the calibration result was used in Equation [1] to produce the 2022 OD Matrix Gravity Model based on the generation-attraction limit.

3.2.6 Imposition of Traffic Flow on the Road Network

The OD Matrix was loaded onto the road network using the EMME/3 software based on the first Wardrop Equilibrium principle and this led to the production of the traffic flow on the road.

3.2.7 Validation Test

The traffic flow modeled and the one observed in the field were compared using the Coefficient of Determination (R^2) statistical test to determine the difference.

3.2.8 Origin–destination (OD) Matrix Estimation of 2048 Modelling Result

The O-D Matrix estimation for 2048 was obtained through a forecasting process using a growth factor (i%) value determined based on a multiplier for the estimated Oi and Dd values for the projected year. This was followed by the evaluation of the Cid value for 2048 by repeating the same process used to determine the value for the existing year. The Oi, Dd, and Cid values obtained were further applied as a prior Matrix using the same process used to determine the 2022 Gravity Model. This led to the production of the Origin-Destination Matrix for the 2048 Gravity Model which was subsequently assigned to the road network sections to determine the segments to be optimized.

3.2.9 Road Network Performance

The traffic volume in 2022 and 2048 was determined by imposing the origin-destination (OD) matrix for the respective years on the road. The value of the volume-capacity ratio was later calculated by comparing the year's traffic volume to the road capacity.

4 RESULTS AND DISCUSSION

4.1 Level of Road Network Performance

The data obtained showed several Volume-Capacity Ratio values on each section of the national and toll roads in Central Java Province. It is important to reiterate that those with values ≤ 0.8 are considered stable and do not need optimization. Meanwhile, the roads with values ≥ 0.8 are unstable and even critical, thereby, requiring handling due to several consequences such as the reduction in the quality of road services, delays, decreased speed, and increased travel time. This means there is a need to employ either management or engineering practices to improve or optimize the road network.

The Volume-Capacity Ratio values obtained for different road sections in 2022 and 2048 are stated as follows:

1. 2022 Volume-Capacity Ratio Value
   a. Road sections with values 0 ≤ VCR < 0,4 = 74,02%
   b. Road sections with values 0,4 ≤ VCR < 0,8 = 25,98%
   c. Road sections with values 0,8 ≤ VCR < 1 = 0%
   d. Road sections with values VCR ≥ 1 = 0%
2. 2048 Volume-Capacity Ratio Value
   a. Road sections with values 0 ≤ VCR < 0,4 = 8,37%
   b. Road sections with values 0,4 ≤ VCR < 0,8 = 10,59%
   c. Road sections with values 0,8 ≤ VCR < 1 = 4,63%
   d. Road sections with values VCR ≥ 1 = 76,41%

The comparison of the Volume-Capacity Ratio values from 2022 to 2048 is presented in the following Table 3 and Figure 2.

Table 3. The VCR Road Network with Toll Roads from 2022 to 2048

Year	V/C with Toll Road			
	0 < VCR < 0,40	0,41< VCR < 0,80	0,81 < VCR < 1,00	VCR > 1,00
2022	496	174	0	0
2025	326	135	41	168
2030	225	179	41	225
2035	168	147	65	290
2040	104	106	71	389
2045	80	77	34	479
2048	56	71	31	512

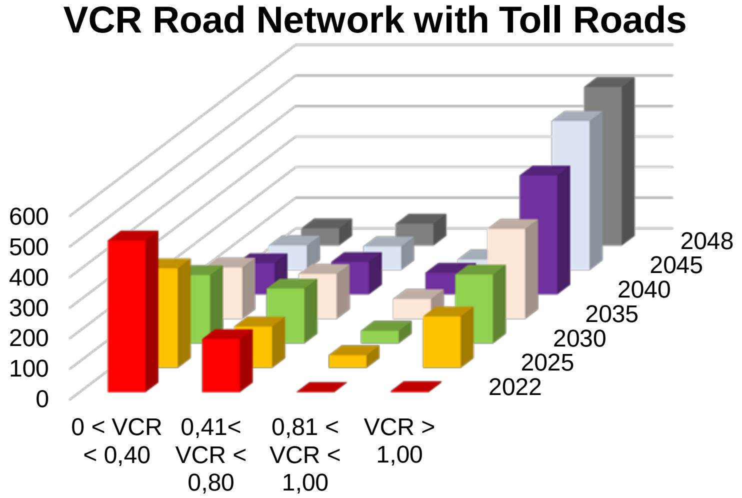

Figure 2. The VCR Road Network with Toll Roads

The Volume-Capacity Ratio values on the national roads in Central Java Province in 2022 values ≤ 0.8 are considered stable. There are no roads that have a value ≥ 0,8. The road still has enough capacity to serve traffic. In this road condition, further handling is not needed, such as increasing capacity in the form of widening roads. Meanwhile, the Volume-Capacity Ratio values in 2048 were unstable condition. 512 roads have a value ≥ 1. So, there is a need for increased capacity in the form of widening roads. This means there is a need to employ either management or engineering practices to improve or optimize the road network.

4.2 Travel Speed

The average travel speed on national roads with toll was found to be from 61 km/hour to 80 km/hour in 2022 and the value was stable up to 2030 but started reducing from 2035 to 2048 as observed by less than 40 km/hour recorded. The reduction was due to the annual increase in traffic flow more than the planned capacity of the road, thereby, decreasing the speeds to 0 km/hour causing queues on the road. This is in line with the condition stated in the MKJI regarding the level of service on a road based on the traffic flow. The percentage incremental change in vehicle speed each year is presented in the following table.

Table 4. The speed of travel on national roads with tolls from 2022 to 2048

Year	Speed by Highway (km/h)			
	0 - 40	40 - 60	60 - 80	> 80
2022	4	7	484	181
2025	132	84	345	116
2030	202	0	326	96
2035	261	87	0	76
2040	348	89	186	46
2045	453	59	128	31
2048	492	57	103	23

The average travel speed was also used to determine the travel time from the point of origin to the destination in the region and the results are expected to be used in selecting a travel route and for economic analysis. Moreover, the speed value was obtained from the O-D Matrix loading on the road network using EMME/3 software, and the annual percentage increase in the vehicle speed is presented in the following Figure 3.

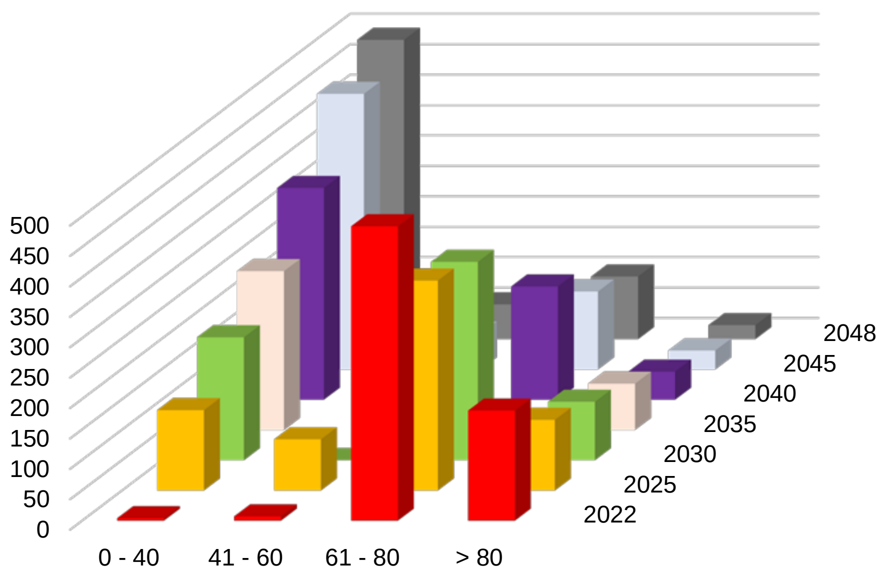

Figure 3. Percentage change in vehicle speed with toll roads

The average travel speed on national roads in Central Java Province in 2022 is considered stable, 661 roads have above speed 60 km/h. Almost the travel speed was found to be from 61 km/hour to 80 km/hour in 2022. The road still has enough capacity to serve traffic. Meanwhile, the average travel speed on national roads in 2048 was unstable condition, 492 roads have speeds below 40 km/h. Most vehicles have speeds below 40 km/h. So there is a need for increased capacity in the form of widening roads. This means there is a need to employ either management or engineering practices to improve or optimize the road network.

5 CONCLUSION

The analysis and discussion led to the following conclusion:

1. The Volume-Capacity Ratio values on the national roads in Central Java Province in 2022 values ≤ 0.8 are considered stable. There are no roads that have a value ≥ 0,8. The road still has enough capacity to

serve traffic. Meanwhile, the Volume-Capacity Ratio values in 2048 were unstable condition. 512 roads have a value ≥ 1. So, there is a need for increased capacity in the form of widening roads.

2. The average travel speed on national roads in Central Java Province in 2022 is considered stable, 661 roads have above speed 60 km/h. The road still has enough capacity to serve traffic. Meanwhile, the average travel speed on national roads in 2048 was unstable condition, 492 roads have speeds below 40 km/h. So, there is a need for increased capacity in the form of widening roads.
3. The Volume-Capacity Ratio value of the national road network and toll roads passing through Central Java Province as a whole are projected to have a stable condition in 2022 and 2048 with a percentage increase of 2 links.
4. The average travel speed on national roads with tolls was found to be 61 km/hour to 80 km/hour in 2022 and this was stable up to 2030 before declining from 2035 to less than 40 km/hour in 2048.

6 SUGGESTION

1. The results of traffic network modeling in 2048 obtained unstable values. The value of road conditions in 2048 with VCR ≥ 0.8 means that road conditions are unstable and even critical, so the government needs to provide policies to increase road capacity by widening roads.
2. Furthermore, the study can take into account regional roads or local roads that are included in the research zone.

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