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DECREASED PERFORMANCE AT UNSIGNALED INTERSECTIONS AFFECTS THE CONSTRUCTION OF THE SOLO-YOGYA ROAD WITH THE LEAST SQUARE METHOD

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The construction of the Solo-Yogyakarta toll road is part of the National Strategic Project. At the development stage, toll road infrastructure needs to assess the impact of traffic, considering many security and safety disturbances. Road performance evaluation is essential to overcome traffic problems during toll road operations in the future. The purpose of the study was to calculate traffic performance at the unsignaled intersection affecting the construction of the Solo-Yogya toll road. The locations studied were four Solo-Yogya toll road access intersections using primary data on the condition of existing non-toll roads. Carry out traffic surveys of the number of vehicles, travel time, and vehicle speed. The performance of the unsignaled intersection was calculated using Jica Strada's modeling with applicable toll road tariffs and traffic growth of 5.6% per year. The performance of the unsignaled intersection at the construction of the Solo-Yogya toll road in 2022 has an average Volume-Capacity Ratio (VCR) value of 0.61. In 2046, it has an average Volume-Capacity Ratio value of 0.99. At the intersection of Boyolali-Kartosuro-Banyudono and the intersection Kartosuro-Klaten-Ngaron, it is recommended to make an Interchange before 2032. The recommendation for making the Kartosuro and Boyolali Interchange is because in 2032 the Volume-Capacity Ratio is more than 0.8 to reduce vehicle delays.

Keywords: Jica Strada, traffic performance, least square method

1 INTRODUCTION

The government carries out infrastructure development every year. Product equity can be accelerated with sustainable infrastructure development [1]–[5]. The construction of the 96.51 Km Solo-Yogyakarta toll road is part of the National Strategic Project following Presidential Regulation Number 56 of 2018. The increasing development of toll road infrastructure affects traffic performance and improves road services [6]–[9]. In the future, the traffic network will change along with changes in the loading of vehicles that are part of the road [10], [11]. At the development stage, toll road infrastructure must assess traffic impacts considering many security and safety disturbances. Traffic volume in recent years has increased by an average of 4.13%, leading to decreased service levels, longer travel times, and increased security intrusions [12]–[14]. The existence of new road infrastructure, such as toll roads, provides alternative routes that the community will use to reach travel destinations. Anticipating the impact of traffic is carried out by carrying out traffic management and engineering. Road performance evaluation is essential to overcome traffic problems during toll road operations in the future [15], [16]. Transportation problems are caused also due to increased development activities and traffic congestion. Good planning is needed to overcome transportation problems [17].

However, the saturation point of road congestion is unpredictable when it will occur. Poor transport infrastructure results in poor accessibility to livelihoods and adds to congestion problems [18]–[21]. In addition, the assessment of investment plans has not been adequate to prevent traffic problems [22]–[24]. The government only calculates the concession period by determining the investment value. The impact of infrastructure construction has not been considered for vehicle delays on road access around the development. Vehicle delays result in users spending more funds on vehicle operational costs.

Therefore, the purpose of the study was to calculate the traffic performance of the unsignaled intersection influence of the construction of the Solo-Yogya toll road. It is important to analyze the estimated amount of movement and increase in traffic in the future. Gravity models can be used to parameterize the relationship of movement between zones [25].

This research is vital to determine the performance of the unsignaled intersection due to the construction of the Solo-Yogya toll road and determine the amount of vehicle traffic using the estimated Destination Origin Matrix (OD) using JICA STRADA software and gravity models [26].

2 BASIC THEORY

2.1 Unsignaled Interchange

Unsignaled intersections are the most common type of intersection in urban areas. Performance measures of unsignaled intersections are related to geometrical, environmental, and traffic conditions [27]. Geometric conditions are depicted in the form of sketches that provide information on road width, roadside boundaries, shoulder width, road median width, and directions. Environmental conditions are calculated based on the type of road environment, the class of side obstacles, and the size of the city class. The method of determining the performance of unsignaled intersections is reviewed from the value of capacity, degree of saturation, delay time, and queue opportunity.

2.2 Model Gravity

The distribution of the destination matrix with the transport model generates movement in the planning year. The process of distributing the Origin-Destination Matrix means is the main component of the Origin-Destination Matrix data needed in the process of planning and modeling transportation systems [28].

Gravity models are used to model movement between zones with a matrix of destination origin [29], [30]. Tamin (2000)

This combined model of the distribution of traffic movement and accessibility between zones can be modeled with Gravity. The movement of transportation is influenced by the movement between road zone. In this movement pattern, a balancing factor can be formed within the limits of increase and pull in the equation:

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

Information:

O_i = Total movement from the origin zone

D_d = Total movement from the destination zone

A_i, B_d = Zone balancing factor

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

T_{id} = Total movement between zones

Determination of the value of movement accessibility between zones using distance, time, and cost functions. Several types in the model of gravity as a function of resistance, which include [31]: Rank Barrier Function, the Tanner Barrier Function, and The Exponential-Negative Resistance Function.

2.3 Least Squares Method

The Least Squares method allows us to determine the value of a β parameter in the equation of the Gravity model that is unknown in the equation. The use of the Least Squares method minimizes the difference in the results of observation data and modeling of traffic movements. The Least Squares Method model uses the equation:

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

2.4 Traffic Forecasting

The design process of the road facilities is from the investment feasibility study, it can be used for traffic forecasting. The factors involved in the determination of complex road networks can be done with proper modeling [30]. JICA STRADA software and a gravity mathematical are used as future traffic modeling.

2.5 Statistical Test Indicator

Linear regression analysis is used to obtain the results of traffic flow modeling with the actual amount of traffic based on survey data. The similarity value of this modeling uses the value of the coefficient of determination (R^2).

$$R^2 = \frac{\Sigma_i(\hat{Y}_i - \bar{Y}_i)^2}{\Sigma_i(Y_i - \bar{Y}_i)^2} \quad (3)$$

2.6 Volume-Capacity Ratio (VCR)

Traffic parameters such as traffic density, speed, and Volume-Capacity Ratio can be used to assess traffic performance. The main factor for the determination of the level of performance of road intersections using the ratio of traffic volume to road capacity based on the Indonesian Road Capacity Manual [27].

The volume-capacity ratio formula is as follows

$$VCR = \frac{V}{C} \quad (4)$$

Where:

V = Traffic Volumes

C = Capacity (pcu/hour)

VCR = Volume-Capacity Ratio

Traffic forecasting can be used for better development analysis and recommendations in the future to address road problems. [32]. The Volume-Capacity Ratio was observed to have quoted the findings from the empirical studies Tamin (2000). The various conditions are listed in the following table.

Table 1. The various conditions Volume-Capacity Ratio Values

VCR	Explanation
>1,0	Critical road condition
0,8 – 1,0	Unstable road condition
< 0,8	Stable road condition

2.7 Average Delay Time (sec/pcu)

According to (MKJI, 1997), traffic behavior is represented by the level of service (LOS), a qualitative measure that reflects the driver's perception of the quality of driving a vehicle. Service Level of Service (LOS) is classified as service levels A through F. The service level relationship and ratio are described as follows:

Table 2. The service level relationship and ratio

Level Service	Road Conditions	Ratio Q/C
A	Free flow at high speed, the driver can choose the desired speed without delay	0,00 – 0,20
B	The flow is stable, traffic conditions limit speed, and the driver has the freedom to choose the speed	0,20 – 0,44
C	The flow is stable, and the speed and movement of vehicles are limited to traffic conditions	0,45 – 0,74
D	The approaching current is unstable; traffic flow conditions still control the speed, and the Q/C ratio can still be tolerated	0,75- 0,85
E	The flow is unstable, traffic volume is close to capacity, and speed sometimes stalls	0,85 – 1,00
F	Traffic jams, low speeds, significant obstacles or delays	> 1,00

3 RESEARCH METHODS

3.1 Research sites

The study was conducted in 2022 using quantitative methods by analyzing all traffic movements at four unsignaled intersections of the Solo-Yogya toll road. The unsignaled intersection of the Solo-Yogya toll road is Intersection 3 of Boyolali-Kartosuro-Banyudono, intersection 3 of Kartosuro-Klaten-Ngaron, intersection 3 of Kartosuro-Klaten-Ceper, and intersection 4 of Karangnongko-Toyan. The total length of the Solo-Yogyakarta toll road along 96.51 Km. The modeling zoning is divided into sixteen zones of, eleven inner and five outer zones.

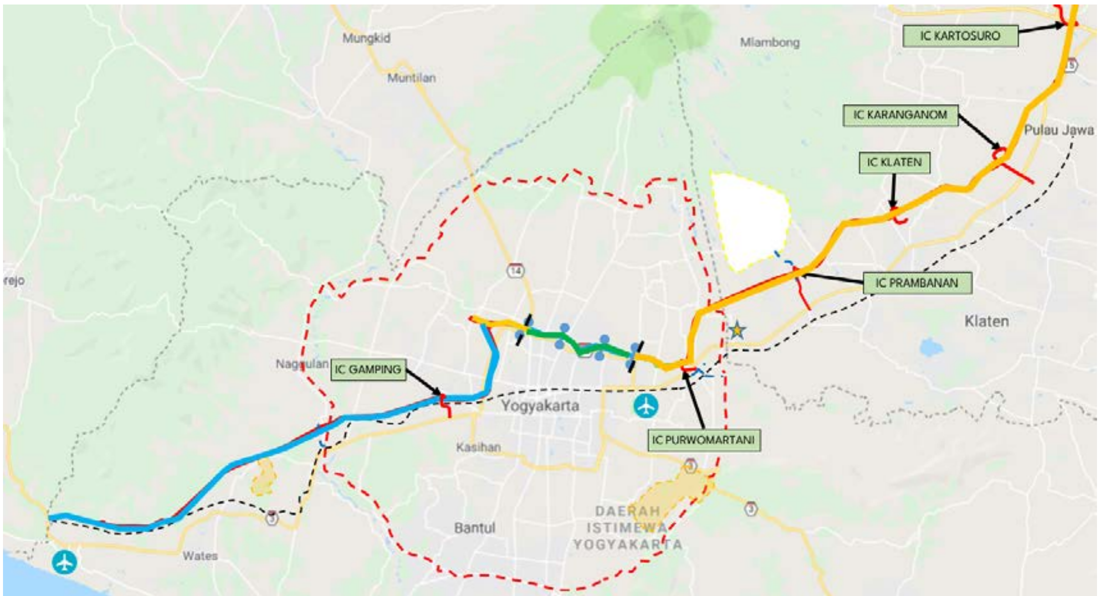

Figure 1. Research location at four unsignaled intersections of the Solo-Yogya toll road

3.2 Data analysis method

The distribution of future movements can be estimated with JICA STRADA Software and Gravity models. In the equation of the Gravity model, there are parameter values to estimate the distribution of activities in the coming year.

Gravity models for future traffic calculations have been widely used for commuter travel and can describe behavior that follows a pattern similar to Newton's famous law of gravity [29], [33].

The instrument as a tool to obtain data is carried out by entering traffic calculation data, side obstacle data, road network data, road capacity calculation, and travel time by the standards of the Indonesian Road Capacity Guidelines (MKJI) 1997, creating a road network database and estimating the destination origin (OD) matrix with JICA STRADA software and Gravity models.

The case study was conducted with the Gravity Model approach to estimate the magnitude of the movement pattern of the destination origin, where the obstacle function used is Exponential-Negative with completion using the Least Squares method.

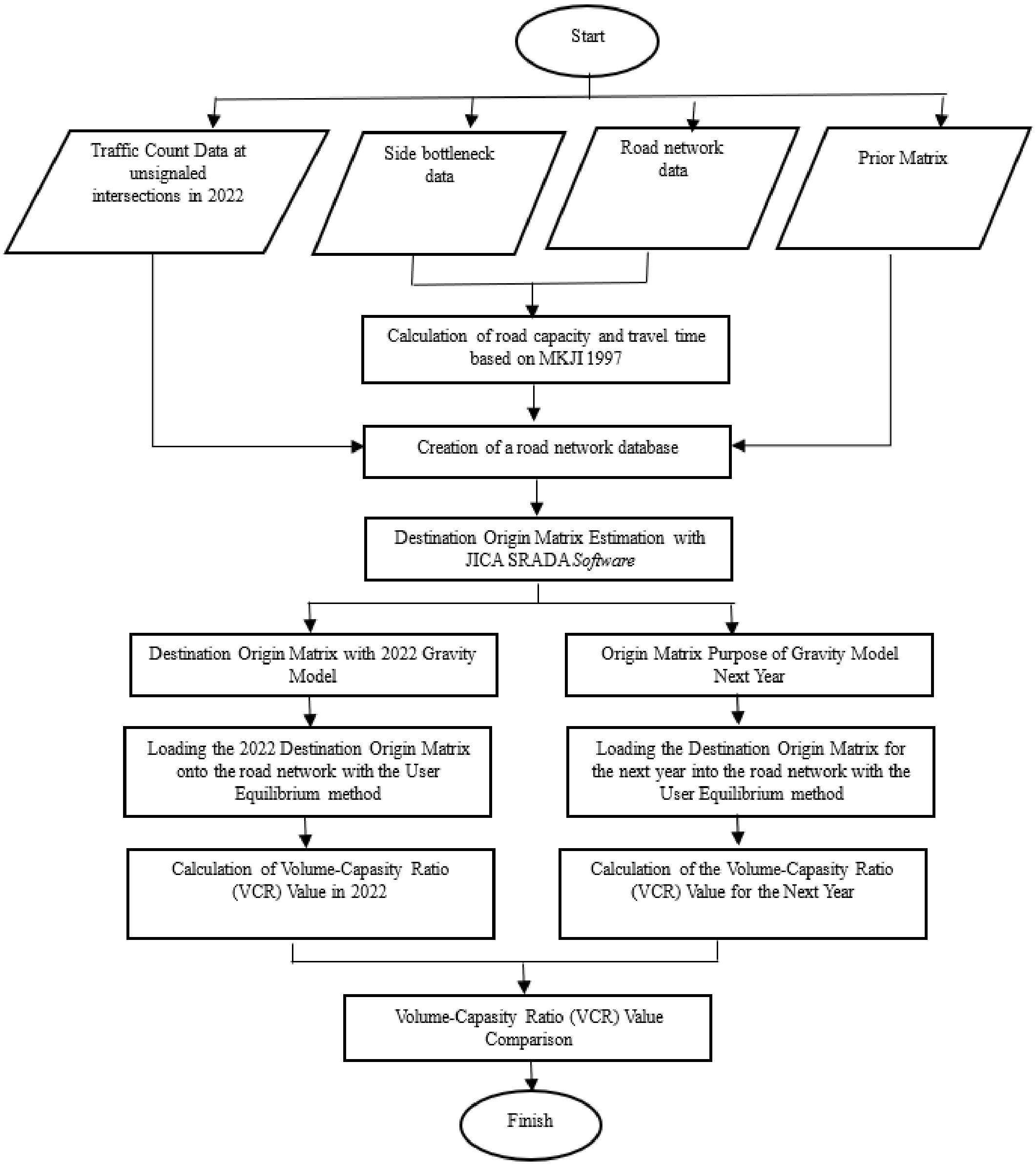

Figure 2. The flow chart of the development models

3.2.1 *Database Processing*

The road network can be processed or formed using JICA STRADA software. Processing road network data by city/district begins with the division of zones. ArcGIS is used to determine the coordinate data of the volume of traffic to be entered into the road network. Matrix value data from the previous stage calculation is then used as input data in JICA STRADA software to further produce traffic modeling analysis. The destination origin matrix with the Gravity model is pre-calibrated with a value of β.

3.2.2 *Origin–Destination Matrix Estimation*

The assessment of road performance for the next few years is obtained from the value of the destination origin matrix modeling using a traffic growth rate of 5.6%. This goal origin matrix uses the Gravity model to calculate the Cid value of 2046. The origin-destination (OD) matrix for 2022 and 2046 respectively is used to calculate Traffic volume. using traffic growth values. The volume of traffic passing through a road section divided by the road capacity gets the value of the Volume-Capacity Ratio.

4 RESULTS

4.1 Road Performance

The decline in road performance is caused by several things including an increase in the number of road user traffic. Decreased performance results in decreased service quality, decreased speed, and increased travel time. Services to road users can be improved by providing road infrastructure with good road performance. The value of the Volume-Capacity Ratio at the Solo-Yogya toll road intersection that has not been signaled can be seen from the current and future road performance and planning. Road conditions that have a VCR value of ≤ 0.8 are considered stable and do not need to be optimized. Meanwhile, roads with a value of ≥ 0.8 are categorized as unstable and even critical roads. Critical roads require handling in the form of road widening or improved road management or engineering capacity to repair or optimize the road network.

Table 3. Volume-Capacity Ratio Value at four unsignaled intersections of the Solo-Yogya toll road in 2022

Location	The year 2022					
	Traffic Flow (SMP/hour)	Capacity (SMP/hour)	DS	Delay Average (det/SMP)	Queuing Opportunities (%)	LOS
Intersection 3 of Boyolali-Kartosuro-Banyudono	2828	4978	0.57	10	14-30	B
Intersection 3 of Kartosuro-Klaten-Ngaron	4096	4568	0.90	15	32-64	C
Intersection 3 of Kartosuro-Klaten-Ceper	3528	4684	0.75	12	32-46	B
Intersection 4 of Karangnongko-Toyan	1051	5310	0.20	6	3-9	B

Table 4. Volume-Capacity Ratio Value at four unsignaled intersections of the Solo-Yogya toll road in 2046

Location	The year 2046					
	Traffic Flow (SMP/hour)	Capacity (SMP/hour)	DS	Delay Average (det/SMP)	Queuing Opportunities (%)	LOS
Intersection 3 of Boyolali-Kartosuro-Banyudono	4823	4611	1.05	21	44-88	C
Intersection 3 of Kartosuro-Klaten-Ngaron	5326	4578	1.16	33	55-111	D
Intersection 3 of Kartosuro-Klaten-Ceper	4586	4686	0.98	18	38-76	C
Intersection 4 of Karangnongko-Toyan	4204	5328	0.79	13	25-50	B

At four unsignaled intersections of the Solo-Yogya toll road in 2022 the values of road sections 0 ≤ VCR < 0,4 is 25,0 % and in 2046 is 0 %. While in 2022 the values of road sections VCR ≥ 0.8 = 25,0 % and in 2046 is 75,0%.

Table 5. Volume-Capacity Ratio Value at four unsignaled intersections of the Solo-Yogya toll road in 2022-2046

Location Intersection	Volume-Capacity Ratio (Year)					
	2022	2025	2026	2027	2032	2046
Boyolali-Kartosuro-Banyudono	0.57	0.32	0.52	0.62	0.72	1.05
Kartosuro-Klaten-Ngaron	0.90	0.97	0.75	0.81	0.96	1.16
Kartosuro-Klaten-Ceper	0.75	0.83	0.53	0.68	0.81	0.98
Karangnongko-Toyan	0.20	0.32	0.33	0.37	0.49	0.79

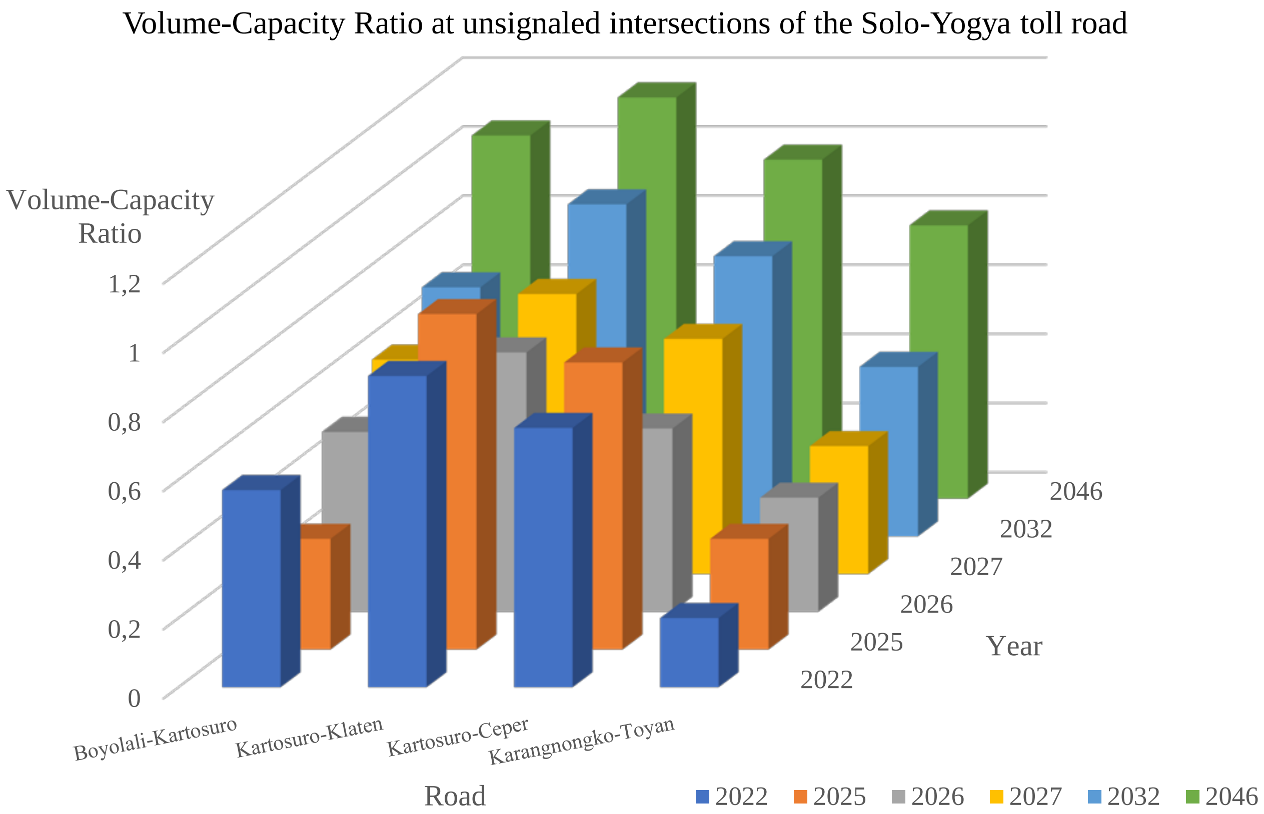

Figure 3. The VCR at unsignaled intersections of the Solo-Yogya toll road in 2022-2046

The construction of the Solo-Yogya toll road will be carried out from 2023 to 2025. Next in 2026 is the operational period of toll roads. The calculation of traffic forecasting is carried out starting from the beginning of the operation of the Solo-Yogya toll road, namely in 2026, and ending in 2046, named after the concession period for the construction of the Solo-Yogya toll road ends for twenty years.

The traffic performance of the unsignaled intersection at the construction of the Solo-Yogya toll road in 2022 has an average Volume-Capacity Ratio (VCR) value of 0.61 with the highest value at intersection 3 of the Boyolali-Kartosuro-Banyudono of 0.90 and the lowest value at intersection 4 Karangnongko-Toyan of 0.20. In 2046, the unsignaled intersection in the construction of the Solo-Yogya toll road has an average Volume-Capacity Ratio (VCR) value of 0.99 with the highest value at intersection 3 of Kartosuro-Klaten-Ngaron of 1.16 and the lowest value at intersection 4 Karangnongko-Toyan of 0.79.

4.2 Average Delay Time

Essential parameters in road design include speed. This speed parameter is information about travel conditions and service levels. A vehicle that stops or cannot run at the desired speed is a delay that causes an increase in travel time for a trip. The Average Delay Time at four unsignaled intersections of the Solo-Yogya toll road in 2022 and 2046 are as follows:

Table 6. Average Delay Time

Location Intersection	Interchange Delay (seconds) (Years)					
	2022	2025	2026	2027	2032	2046
Boyolali-Kartosuro-Banyudono	10	7	9	10	12	21
Kartosuro-Klaten-Ngaron	15	18	12	13	17	33
Kartosuro-Klaten-Ceper	12	14	10	11	13	18
Karangnongko-Toyan	6	7	7	8	9	13

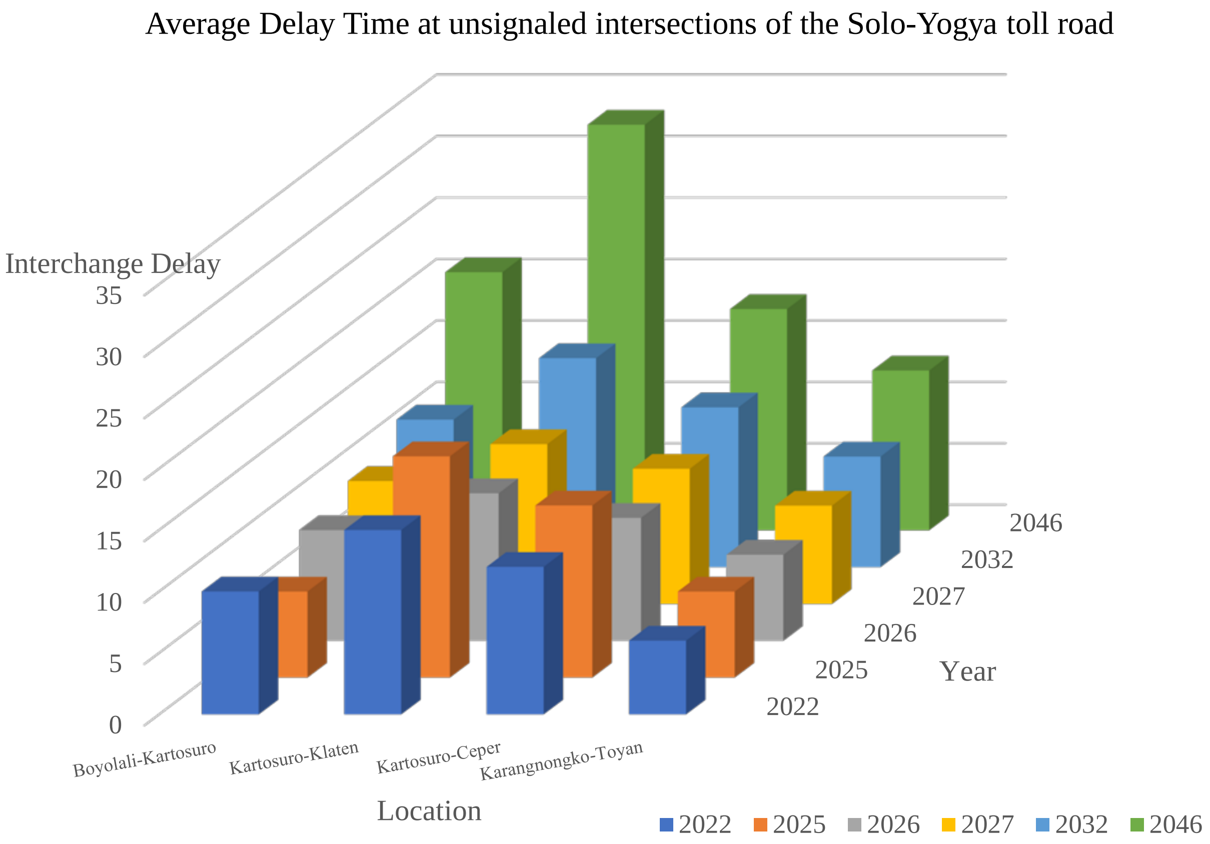

Figure 4. Average delay time in 2022 – 2046

The delay time at the unsignaled intersection in the construction of the Solo-Yogya toll road in 2022 averages 11 seconds and is included in the service level B category. Category B at the Level of Service (LoS) means steady flow, speed slightly limited by traffic and volume of services used for roads outside the city. The delay time at the unsignaled intersection in the construction of the Solo-Yogya toll road in 2046 was an average of 21 seconds. They are included in the service level category C. Category C at the Level Of Service (LOS) means the flow is stable, the speed is controlled by traffic, and the volume of services is used for the design of city roads. The biggest delay time at intersection 3 of Kartosuro-Klaten-Ngaron in 2022 is 15 seconds and in 2046 it is an average of 33 seconds.

5 CONCLUSION

The conclusions obtained from the research analysis are:

1. The traffic performance of the unsignaled intersection at the construction of the Solo-Yogya toll road in 2022 has an average Volume-Capacity Ratio (VCR) value of 0.61 with the highest value at intersection 3 of the Boyolali-Kartosuro-Banyudono of 0.90 and the lowest value at intersection 4 Karangnongko-Toyan of 0.20.
2. In 2046, the unsignaled intersection in the construction of the Solo-Yogya toll road has an average Volume-Capacity Ratio (VCR) value of 0.99 with the highest value at intersection 3 of Kartosuro-Klaten-Ngaron of 1.16 and the lowest value at intersection 4 Karangnongko-Toyan of 0.79.
3. At the intersection of Boyolali-Kartosuro-Banyudono and the intersection Kartosuro-Klaten-Ngaron, it is recommended to make an Interchange before 2032 because in 2032 the value of the Volume-Capacity Ratio is more than 0.8 to reduce vehicle delays.
4. The delay time at the unsignaled intersection in the construction of the Solo-Yogya toll road in 2022 averaged 11 seconds and in 2046 was an average of 21 seconds. The biggest delay time at intersection 3 of Kartosuro-Klaten-Ngaron in 2022 is 15 seconds and in 2046 it is an average of 33 seconds.

6 SUGGESTION

1. The government needs to implement traffic management and widen road sections starting in 2032 at the location of road sections that have a VCR value of ≥ 0.8. The condition in 2046 is that most roads have unstable and critical condition values.
2. Further research can also include data on local road sections located at the research location.

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