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EVALUATION OF TRAFFIC LIGHT EFFECTIVENESS ON THE TOLL OVERPASS SEGMENT ON THE SIDODADI ROAD, CANDI DISTRICT, SIDOARJO REGENCY

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Abstrak
The evaluation of traffic light effectiveness is critical for optimizing road performance and minimizing congestion, particularly in high-traffic areas such as the overpass segment of Sidodadi Road, Candi District, Sidoarjo Regency. This study analyzes the performance of traffic lights in regulating vehicle flow at intersections and proposes improvements to enhance traffic efficiency and safety. Using the Indonesian Highway Capacity Manual (MKJI) 1997 as the analytical framework, this research examines traffic volume, degree of saturation, delays, and service levels under current traffic light configurations. Data were collected through traffic volume surveys during peak hours and included vehicle composition, intersection geometry, and traffic light cycle timing. The analysis revealed significant congestion during morning and evening peak hours, with a degree of saturation exceeding the recommended threshold. The delays and service levels indicated suboptimal performance, necessitating adjustments to traffic light timing and phase configurations. The study proposes two key alternatives to address these issues: short-term adjustments to traffic light cycles to accommodate peak-hour traffic and long-term solutions involving the redesign of intersection geometry and the implementation of adaptive traffic control systems. These recommendations aim to balance traffic flow, reduce delays, and prevent potential deadlock scenarios. This research underscores the importance of periodic evaluations and the integration of advanced technologies such as real-time adaptive traffic systems to optimize road performance and support regional economic activities. The findings contribute valuable insights for policymakers and stakeholders in improving traffic management strategies in similar urban settings

Keywords: Traffic light effectiveness, road performance, degree of saturation, adaptive traffic control, Sidodadi Road.

INTRODUCTION

Road performance reflects the ability of a road section to serve traffic flow efficiently, which is assessed through the Level of Service (LOS) (Fitriana, Suroto, & Kurniawan, 2017). LOS is used to measure the quality of road services from level A (smooth) to F (severe congestion), and is the basis for planning transportation policies aimed at improving traffic flow and safety (Shahin, 2013). One effort to optimize road performance is through the implementation of effective traffic lights, especially in locations with high potential for conflict such as the Sidodadi Toll Overpass, Candi District, Sidoarjo Regency.

According to the Regulation of the Minister of Transportation Number 96 of 2015, road management must meet minimum service standards, including road capacity, travel speed, and level of congestion. The implementation of traffic lights can reduce conflicts between vehicle flows, regulate movement turns regularly, and minimize delays during peak hours (Murat & Kikuchi, 2007). Periodic evaluation is very important to ensure that traffic light settings remain in accordance with the dynamics of vehicle flow.

Side obstacles, effective road width, and vehicle type and composition are significant factors in influencing road capacity (MKJI, 1997). Adjusting traffic light cycle times that consider vehicle movement patterns at various peak times can help overcome congestion at critical locations. This research is relevant in the context of the need for data-based traffic management to support community mobility and economic growth. Integration of adaptive technology into traffic light systems can be a long-term solution to optimize road performance and prevent potential for worse congestion.

Side obstacles are one of the main causes of decreased road capacity, including vehicles stopped on the road, activities entering and exiting commercial facilities, and pedestrians along the road. This condition reduces the effective width of the lane, increases the risk of conflict between vehicle flows, and worsens congestion. Inconsistent road widths also affect flow capacity, because narrowing in some segments forces drivers to slow down their vehicles (HCM, 2016; MKJI, 1997).

Vehicle type and composition also affect road capacity. Heavy vehicles such as trucks and buses slow down the flow because they require more space and have slow acceleration. In addition, the pattern of high economic activity in big cities tends to cause heavy traffic throughout the day, especially around business centers (Murat & Kikuchi, 2007) ; HCM, 2016).

Traffic management is an important strategy to reduce the impact of these obstacles. Strategies such as implementing traffic lights, regulating traffic light cycle times, controlling illegal parking, and restricting vehicle access on main roads can increase road capacity. Traffic lights help reduce conflicts between vehicle flows and minimize the risk of congestion, especially in locations with high vehicle volumes such as the Sidodadi Overpass (Indonesia, 1997); Akcelik & Besley, 2003).

In addition, smooth traffic flow contributes to economic growth through efficient distribution of goods, reduced operational costs, and increased productivity. Good road infrastructure supports new investment and increases regional income that can be allocated for further infrastructure development (World Bank, 2021). Therefore, periodic evaluation of traffic lights and the implementation of data-based access management are important solutions to maintain smooth traffic. The implementation of traffic lights at the Sidodadi Toll Overpass, Candi District, Sidoarjo Regency, is the main solution to regulate vehicle flow in areas with high traffic volumes. This location is an intersection point that connects local traffic, arterial roads, and toll access, so it often experiences vehicle congestion, especially during rush hour. Evaluation of traffic light performance is essential to ensure that the cycle time and light phase have been optimally adjusted according to current traffic movement patterns (Irianto et al., 2021).

Major obstacles such as heavy vehicles, which require more space and have slow acceleration, also worsen the situation. Access management, such as limiting vehicle entry and exit points and special lanes for heavy vehicles, can help reduce traffic conflicts and improve road efficiency (Indonesia, 1997). In addition, Adaptive Traffic Control System (ATCS) technology offers a modern solution by automatically adjusting traffic light duration based on real-time data. The implementation of ATCS in this overpass segment is expected to reduce queues, speed up travel time, and prevent potential deadlocks (HCM, 2016). The characteristics of this overpass segment, such as narrowing of the road, increase the risk of conflict between vehicle flows. Traffic lights that are not properly regulated can worsen the situation by creating long queues, especially during peak hours. Therefore, cycle time adjustments and periodic evaluations are very important to improve road performance and support community mobility and economic activities in the Sidoarjo area (Murat & Kikuchi, 2007). Based on the above phenomenon, the formulation of the problem in this study is: "How is the performance of the Sidodadi road section after the implementation of traffic lights in the Sidodadi Toll Overpass segment?". Based on the formulation of the problem above, the objectives of this thesis are: To analyze the performance of the Sidodadi road section related to the implementation of traffic lights, including the level of service (Level of Service/LOS) and delay time.

Research Benefits

1. For the Author

   The benefits of this research for the author include fulfilling the graduation requirements for the Master of Civil Engineering program at the Faculty of Engineering, Universitas 17 Agustus 1945 Surabaya, as well as gaining additional knowledge related to traffic management.
2. For Universitas 17 Agustus 1945 Surabaya

   This research serves as a scientific reference in the field of traffic management, contributing to the university's literature resources. It can enhance research materials and provide a basis for further studies, particularly in the area of transportation with a focus on analyzing road performance.
3. For Stakeholders in the Field of Traffic Management

   This research is expected to provide insights or considerations for traffic management planning and regulation, especially in addressing road narrowing that causes traffic delays and congestion. Additionally, it can serve as a source of information for readers to better understand traffic issues, particularly for the Sidoarjo Regency Government.

LITERATURE REVIEW

General Definitions and Terminology

Understanding or defining general terms related to intersection performance is crucial to make the study easier to comprehend for readers. Below are several key terms used in this research. According to various literature, these traffic-related terms are essential in analyzing intersection performance:

1. Intersection Leg:

   An intersection leg refers to the part of an intersection functioning as an approach for vehicles entering or exiting. This term is significant in analyzing vehicle flow patterns at intersections.
2. Three-Legged Intersection (T-Intersection):

   A T-intersection is an intersection with three legs. This type of intersection is commonly used to connect a major road with a minor road, facilitating simpler traffic flows compared to intersections with more legs.
3. Main Road:

   The main road is the most critical route in an intersection. In a T-intersection, the continuing road is typically designated as the main road to ensure smooth vehicle movement along this path.
4. Minor Road:

A minor road is the secondary road in a T-intersection that does not continue. It typically serves as an access road rather than a primary route.

5. Approach:
   An approach is the entry point for vehicles at an intersection leg. The approach plays a vital role in determining the capacity and efficiency of an intersection.
6. Approach Width:
   The approach width refers to the paved width of an approach, measured at its narrowest point and used by moving traffic. It is an essential factor in evaluating the capacity of an approach in an intersection.
7. Intersection Type:
   Intersection type is a code that indicates the number of legs and the number of lanes on both the minor and main roads of an intersection.
8. Total Flow (Qtot):
   Total flow represents the number of motor vehicles passing through an intersection, expressed in vehicles per hour or passenger car units (PCU) per hour.
9. Passenger Car Unit (PCU) Factor:
   The PCU factor is a conversion factor used to translate the motor vehicle flow from vehicles per hour into passenger car units per hour.
10. Degree of Saturation (DS):
    Degree of saturation is the ratio between the total flow and the intersection capacity. This ratio evaluates whether an intersection can accommodate the current traffic volume.
11. Delay:
    According to the Manual Kapasitas Jalan Indonesia (MKJI, 1997), delay is the additional travel time required by vehicles to pass through an intersection. Delay is measured in seconds per passenger car unit (PCU).
12. Traffic Delay:
    Traffic delay refers to the average delay experienced by all motor vehicles entering an intersection. It is expressed in seconds per passenger car unit (PCU) and serves as one of the primary indicators in evaluating intersection performance (HCM, 2016).

Traffic Flow Calculation

Traffic flow at an intersection is divided into several directions of movement according to traffic conditions and can be depicted in the form of a sketch. Here is an example of a traffic condition sketch:

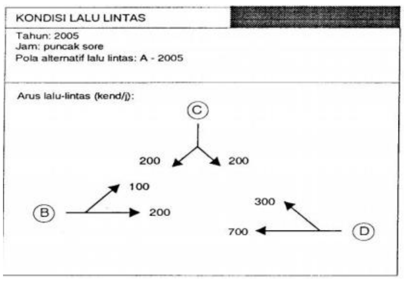

Figure 1 Traffic Condition Sketch Source: MKJI, 1997

The input data needed in calculating intersection traffic with units of vehicles/hour must be adjusted with the smp factor, namely the conversion value of vehicles/hour to passenger car units smp/hour. The following are the conversion values for motor vehicles.

Capacity Calculation

A signalized intersection is an intersection consisting of several arms and equipped with traffic light signal settings. Based on MKJI 1997, the purposes of using traffic light signals at intersections include:

1. To avoid intersection congestion due to traffic flow conflicts, so that a certain capacity can be maintained, even during peak traffic conditions.
2. To provide an opportunity for vehicles and/or pedestrians from (small) intersection roads to cut through the main road.
3. To reduce the number of traffic accidents due to collisions between vehicles from opposing directions.

For most road facilities, traffic capacity and behavior are primarily a function of geometric conditions and traffic demands. By using signals, designers or engineers can distribute capacity to various approaches by allocating green time to each approach (Nugroho et, al (2020).

The use of signals with three-color lights (green, yellow, red) is applied to separate the lanes of conflicting traffic movements in the time dimension. This is an absolute necessity for traffic movements coming from intersecting roads = major conflicts. Signals can also be used to separate turning movements from opposing straight traffic, or to separate turning traffic movements from pedestrians crossing = secondary conflicts. The sequence of signal changes with a two-phase system, including the definition of cycle time, green time and inter-green period, with the formula:

Traffic phases are stages or time periods set in the traffic light cycle at an intersection to control the flow of vehicles and pedestrians. Each phase gives priority to a particular direction of traffic or group of road users. Here are some common phases in a traffic light system, namely the Green Phase is that vehicles in a certain direction are allowed to move, the Yellow Phase is that the light will soon turn red. Vehicles must prepare to stop, and the Red Phase is that vehicles must stop (Apriyani, Mangontan, & Tato, 2023).

These traffic phases are designed to optimize traffic flow and improve safety at intersections. The first function is fulfilled by the yellow time, while the second is fulfilled by the all-red time which is useful as a clearing time between the two phases. All-red time and yellow time are generally applied in advance and do not change during the operating period. If the green time and cycle time are also set in advance, then the signal is said to be operated in a fixed-time control manner.

Table 1. Conversion of heavy vehicles, light vehicles and motorbikes to passenger car units

Vehicle Type	Emp for approach type	
	Protect	**Against**
Kendaraan Berat (HV)	1.3	1.3
Kendaraan Ringan (LV)	1	1
Sepeda Motor (MC)	0.2	0.4

Level of Service

Intersection service or Level of Service (LoS) is a descriptive description of the condition of an intersection. In this study, the level of road service used refers to the Regulation of the Minister of Transportation number 96 of 2015 concerning traffic engineering management. The following are the criteria for the level of intersection service.

Table 2. Level of Intersection Service

Level of Service *Level of Service* (LoS)	**Delay** (det/smp)
A	5
B	5-15
C	15-25
D	25-40
E	40-60
F	>60

Source: Permenhub, 2015

Minimum Standard of Service Level

Minimum standards at intersections are used as a reference for the minimum service that can be provided by an intersection. The following are minimum standards that are classified based on the function of the main road that is passed.

Table 3. Minimum Intersection Service Level

Road Function	**Level of Service Intersection** *Level of Service* (LoS)
Primer	
Primary Arterial Road: B	B
Primary Collector Road: B	B
Primary Local Road: C	C
Secondary Roads	
Secondary Arterial Road: C	C
Secondary Collector Road: C	C
Secondary Local Road: D	D
Residential Road: D	D

Source: Permenhub, 2015

From this basis, it can be determined to carry out traffic simulations to find out the minimum handling that needs to be achieved, with the hope that traffic management can overcome road performance to provide the best service to road users..

RESEARCH METHOD

The research design consists of three main stages:

1. Preparation Stage:

This stage involves determining the objectives, problem type, research scope, ideas for solutions, required data, and survey tools.

2. Implementation Stage:

   This stage includes conducting preliminary and literature surveys, collecting secondary data, conducting primary surveys (traffic and road capacity mapping), processing data, analyzing performance, and drawing conclusions from the findings.
3. Compilation Stage:

   This stage involves organizing the research findings to facilitate readers in understanding the results and fulfilling graduation requirements.

Subject and Location of the Study

This study focuses on vehicle traffic crossing Jalan Sidodadi, overpass segment, Sidodadi Village, Candi District, Sidoarjo Regency, East Java Province.

Time of Study

The study was conducted in 2024 as a reference for basic data, including traffic counting surveys and other supporting data collection.Prosedur Pengumpulan Data

1. Traffic Volume Data: Collected through a five-day traffic counting survey (3 days weekdays, 2 days weekends) during peak hours in the morning, afternoon, and evening.
2. Vehicle Composition: Grouping vehicles according to their type based on traffic volume data.
3. Road Dimension: Measuring road geometry, including the effective width of the road body and shoulder.
4. Road Capacity: Using primary data from field surveys and secondary data such as the population of Sidoarjo from BPS and road maps from the Transportation Agency.

Data Analysis Techniques

1. Traffic Data Analysis: Traffic volume data is converted to passenger car units (PCU) using the 1997 MKJI guidelines.
2. Road Section Performance Analysis: Calculating the degree of saturation using converted traffic data and intersection capacity based on the 1997 MKJI. Simulation is used to determine the intersection cycle time on the overpass segment with a three-arm signalized intersection approach.

RESULTS AND DISCUSSION

The performance analysis of the Sidodadi Road section was carried out based on traffic data during the morning, afternoon, and evening peak hours. The main parameters analyzed include delay (seconds/smp), degree of saturation (DS), and Level of Service (LOS) in accordance with the guidelines of the Indonesian Road Capacity Manual (Indonesia, 1997). During the morning peak hour, the East Arm showed a delay of 48 seconds/smp with a DS of 0.620, reflecting conditions approaching capacity with traffic flow that was starting to become unstable. In contrast, the West Arm had a higher delay, namely 67 seconds/smp with a DS of 0.870, indicating a severe level of congestion approaching saturation. During the afternoon peak hour, the condition of vehicle flow on both arms was more stable compared to the morning. The East Arm showed a decrease in delay to 46 seconds/smp with a DS of 0.595, while the West Arm recorded a delay of 48 seconds/smp with a DS of 0.621, both of which were in stable condition. However, during the afternoon peak, the delay on the East Arm increased to 64 seconds/pcu with a DS of 0.850, reflecting conditions approaching saturation. In contrast, the West Arm showed improvement with a lower delay of 44 seconds/pcu and a DS of 0.540, indicating relatively smooth traffic flow.

From a Level of Service (LOS) perspective, during the morning peak, the East Arm was at LOS D, reflecting conditions near capacity, while the West Arm was at LOS E, indicating significant congestion. During the afternoon peak, both arms were at LOS C, reflecting stable traffic flow with acceptable delays. However, during the afternoon peak, the East Arm again experienced a decline in performance with LOS E, while the West Arm showed improvement to LOS C compared to the morning.

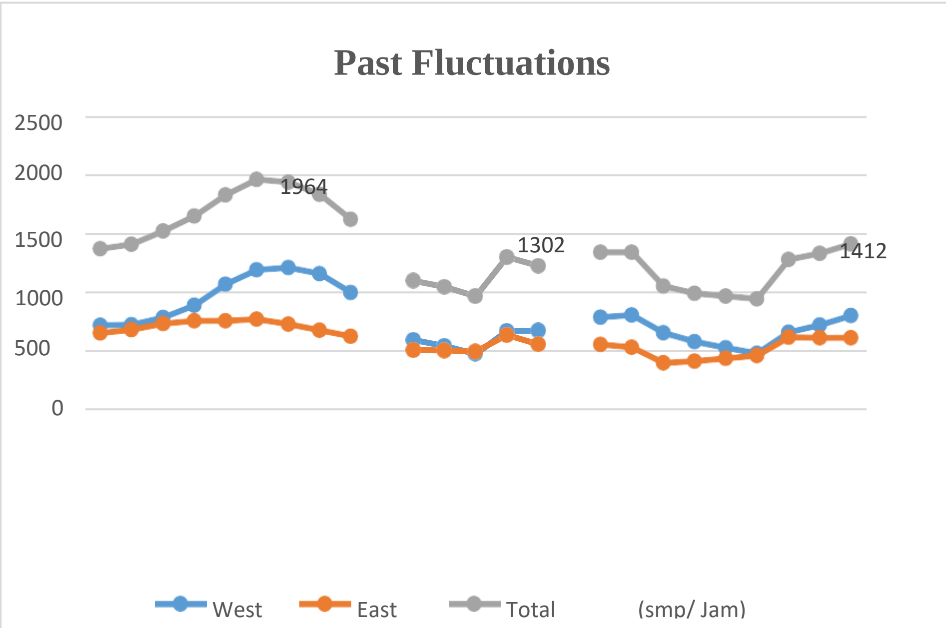

Figure 2. Traffic Fluctuation Graph Source: Data Analysis, 2024

From Graph 2, it can be seen that the Traffic Fluctuation Graph on the Sidodadi Road Section shows that the highest total traffic volume is during the morning peak hours 07.15 - 08.15 totaling 1,964 smp/hour, during the afternoon peak hours 11.45-12.45 totaling 1,302 smp/hour and the evening peak hours 18.00 - 19.00 totaling 1,412 smp/hour. The largest vehicle composition (split mode) is MC totaling 86%, LV totaling 10%, and MHV totaling 4%. To determine the capacity of a road section with the application of traffic lights, input data is used in the form of saturated flow (S), adjusted green time (g), and cycle time (c) and is carried out on each arm which in this study uses the direction of vehicle movement entering the Sidodadi Road section overpass segment.

Table 4. Saturation Current (S) Current Condition

Leg	Saturation Flow Rate (S) Under Current Conditions							
	Adjustment Factors							Adjusted Value pcu/hour green
	Basic Capacity (So)	City Size Adjustment Factor FCS	Side Friction Factor FSF	Gradient Factor FG	Parking Factor FP	Right Turn Factor FRT	Left Turn Factor	S
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9=2*3*4*5*6*7*8)
East	2100	1	0.89	0,96	1	1.00	1.00	1,794
West	2100	1	0.89	0,96	1	1.00	1.00	1,794

From Table 4, it can be seen the magnitude of the saturation flow in the current condition which is stated in units of passenger cars per hour with a value of 1,794 pcu/hour.

The performance of the road section is the ability of the road section to serve the traffic flow that occurs, the performance results are in the form of a degree of saturation (DS). The performance of the Sidodadi Road section with the current traffic light is as follows:

Table 5. Current performance of Sidodadi Road Traffic Light

Peak Hour	Leg	Traffic Flow (smp/hour) Q	Capacity (smp/hour) C	Degree of Saturation DS (Q/C)	Delay (seconds/smp) DT
Morning	East	513	897	0,620	48
	West	719	897	0,870	67
Afternoon	East	492	897	0,595	46
	West	513	897	0,621	48
Evening	East	703	897	0,850	64
	West	446	897	0,540	44

Based on Table 5, the current performance of the Sidodadi road traffic light during peak hours shows varying levels of delay and degrees of saturation. During the morning peak hours, the eastbound direction experiences a delay of 48 seconds per smp with a degree of saturation (DS) of 0.620, while the westbound direction faces a higher delay of 67 seconds per smp with a DS of 0.870. In the afternoon peak hours, the eastbound direction shows an improved delay of 46 seconds per smp with a DS of 0.595, and the westbound direction records a delay of 48 seconds per smp with a DS of 0.621. However, during the evening peak hours, the eastbound direction sees an increased delay of 64 seconds per smp with a DS of 0.850, whereas the westbound direction improves with a delay of 44 seconds per smp and a DS of 0.540.

The analysis reveals that the current traffic light cycle timing is insufficient to fully accommodate the variation in traffic patterns, especially during the morning and evening peak hours. High delays are evident in the westbound leg during the morning and the eastbound leg during the evening, which result in a Level of Service (LOS) in category E. To address this issue, optimizing the traffic light cycle timing is crucial, with adjustments tailored to the traffic volume on each leg. Implementing advanced technologies such as Adaptive Traffic Control System (ATCS) could provide a more dynamic solution by automatically adjusting the cycle timing based on real-time traffic data, thereby improving traffic flow efficiency.

Furthermore, the high proportion of heavy vehicles during the morning and evening peak hours exacerbates delays, particularly in the westbound leg. Heavy vehicles require larger spaces and exhibit slower acceleration, which significantly raises the degree of saturation. Limiting the operational hours of heavy vehicles during peak times or allocating dedicated lanes for them could mitigate conflicts and improve overall traffic flow. Additionally, the road narrowing on the overpass segment is a major factor contributing to delays, particularly in the eastbound leg during the evening. To alleviate this, road widening or adding lanes in this segment could enhance road capacity and reduce congestion risks.

Regular traffic monitoring is vital to detect changes in traffic patterns and reevaluate the traffic light settings. Data obtained from monitoring can support the development of strategies to adjust traffic light cycles to align with real-world conditions.

This approach ensures that traffic arrangements remain relevant to the dynamic demands of vehicle flows, ultimately supporting smoother mobility and improving road user safety.

Table 6. Recapitulation of Current Capacity Conditions

Peak Hour	Leg	Traffic Flow (smp/hour) Q	Capacity (smp/hour) C	Degree of Saturation DS (Q/C)	Delay (seconds/smp) DT
Morning	East	513	723	0,770	35
	West	719	1071	0,671	30
Afternoon	East	492	897	0,548	23
	West	513	897	0,572	25
Evening	East	703	1071	0,656	29
	West	446	723	0,617	28

From Table 6. it can be seen that the current performance of the Sidodadi Traffic Light road during the morning peak hour towards the east with a delay of 35 sec/smp DS 0.770 while towards the west with a delay of 30 sec/smp DS 0.671. at the afternoon peak hour towards the east with a delay of 23 sec/smp DS 0.548 while towards the west with a delay of 25 sec/smp DS 0.572. at the evening peak hour towards the east with a delay of 29 sec/smp DS 0.656 while towards the west with a delay of 28 sec/smp DS 0.617.

Determination of Alternative Handling

In an effort to improve traffic performance on the Sidodadi Road section, two alternative handlings were carried out, namely regulating the traffic light cycle time (Alternative 1) and building a new overpass (Alternative 2). Alternative 1 aims for short-term handling by adjusting the cycle time based on traffic patterns, while Alternative 2 is a long-term solution by building a new overpass to accommodate traffic needs.

Alternative 1: Short-Term Handling

Traffic light cycle time is done by adjusting the time during peak hours in the morning, afternoon, and evening to increase road capacity. From the analysis results, the capacity on the east arm increased from 897 pcu to 1071 pcu in the afternoon, while the capacity on the west arm reached 1071 pcu in the morning. However, the evaluation results showed that Alternative 1 still did not meet the minimum service standards according to PM 96 of 2015, especially on the east arm in the morning (DS 0.770, LOS D). This indicates that this handling is not optimal in overcoming congestion as a whole.

Alternative 2: Long-Term Handling

Alternative 2 involves the construction of a new overpass designed to accommodate current and future traffic volumes. This overpass is designed without using traffic lights and is divided based on the direction of vehicle movement (west-east and east-west). The capacity of the existing (old) overpass is 1977 smp/hour, while the planned (new) overpass has a capacity of 2595 smp/hour. The analysis results show that traffic performance on the old and new overpasses has met the minimum service standards with a low degree of saturation (DS) value and a category B level of service (LOS) during all peak hours. With the construction of the new overpass, traffic becomes smoother, exhaust emissions can be reduced, and driver comfort increases. Periodic evaluation is still needed to ensure the continued effectiveness of this handling. From the implementation results, Alternative 2 is proven to be more effective than Alternative 1 and is able to meet the minimum service standards based on PM 96 of 2015.

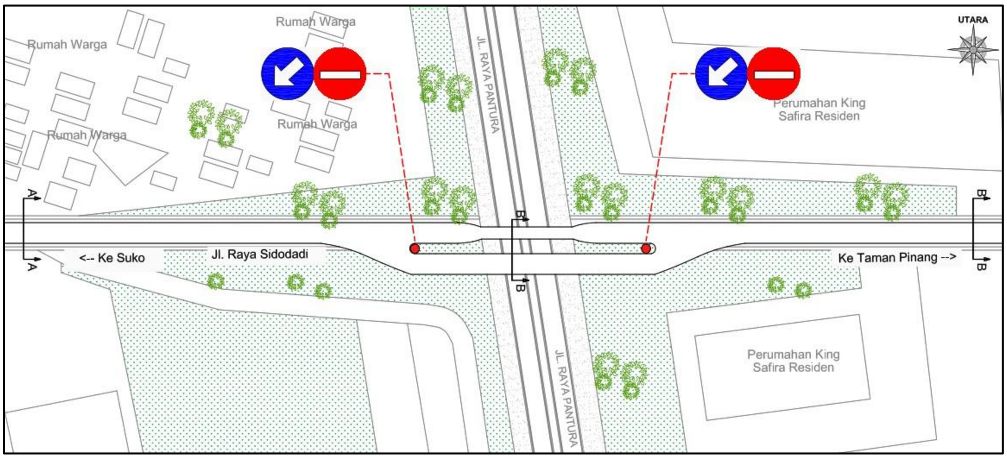

Figure 3. Addition of Planned Overpass on the South Side Source: Data Analysis, 2024

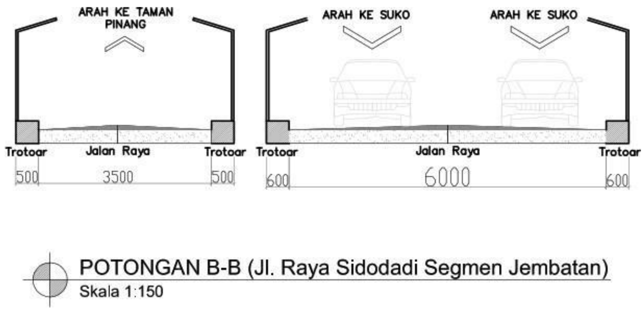

Figure 4. Cross Section of Planned Overpass Source: Data Analysis, 2024

CONCLUSION

Based on the data analysis and discussion, the presence of traffic lights plays a vital role in regulating vehicle flow, improving road user safety, and reducing potential congestion. However, the study results indicate that the traffic light configuration on Jalan Sidodadi, specifically at the overpass segment, requires further adjustments to optimize road performance.

Under the current conditions, the performance of Jalan Sidodadi with traffic lights exhibits significant variations between the two main legs. The East Leg experiences a delay of 48 seconds per passenger car unit (pcu) with a Level of Service (LOS) categorized as E. LOS E reflects unstable traffic conditions, where the traffic volume approaches road capacity, vehicle speed frequently halts, and delays range between 40 and 60 seconds per pcu. This condition indicates a relatively high level of congestion, necessitating adjustments to the traffic light cycle timings to reduce delays.

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