

Performance evaluation of an unsignalized staggered junction using PKJI 2023 and PTV VISSIM

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ABSTRACT

A staggered junction is a configuration consisting of two closely spaced three-leg intersections in which traffic interactions between intersections may significantly affect the overall network performance. This study aimed to evaluate the performance of two unsignalized intersections located at Tirto Agung Intersection and Tusam Timur Raya Intersection along the Durian Raya Corridor in Banyumanik District, Semarang City, using the Indonesian Road Capacity Guidelines (PKJI 2023) and a microscopic simulation with PTV VISSIM. The analysis indicated that Tirto Agung and Tusam Timur Raya Intersection had a Degree of Saturation of 0.94 and 0.99, respectively, indicating saturated operating conditions at both intersections. Improvement alternative treatments including the formalization of a right turn pocket, approach widening, enhanced lane discipline, and reduction of side friction, were developed and assessed through PTV VISSIM simulations. The simulation results demonstrated improvements in the operational balance of the staggered junction system. Particularly through reduced delay at Tusam Timur Raya Intersection and reduced maximum queue lengths at both intersections.

Keywords: Intersection performance; microscopic simulation; PKJI 2023; staggered junction; unsignalized intersection

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INTRODUCTION

Traffic congestion remains a common urban transportation problem. Population growth, economic activity, and vehicle ownership have increased traffic demand, particularly at intersections where movements from different directions interact. Intersections often become bottlenecks, significantly affecting travel time, delays, queues, and overall traffic performance. [1-3].

Semarang is a rapidly developing city in Central Java. According to Statistics Indonesia, its population increased from 1.66 million in 2022 to 1.69 million in 2023 [4]. Population growth and urban activities have increased travel demand across city roads. Banyumanik District, a commercial, educational, and residential area, has experienced considerable traffic growth. Diponegoro University, Semarang State Polytechnic, and supporting facilities have encouraged student housing, commercial establishments, and other urban activities in the surrounding area [5].

These developments affect Durian Raya Road, a main collector road in Banyumanik District. Two unsignalized intersections on this corridor, Tirto Agung–Durian Raya and Tusam Timur Raya–Durian Raya, frequently experience peak-hour congestion. Separated by 170 m, they operate as a staggered junction. Traffic operations are affected by high volumes, intensive roadside activities, turning maneuvers, and insufficient lane discipline. These conditions often cause long queues and delays, particularly during morning and afternoon peaks. Figure 1 illustrates the staggered junction configuration examined in this study.

According to the Indonesian Road Capacity Guidelines (PKJI 2023), unsignalized intersection performance can be evaluated using degree of saturation, delay, and queue probability [6]. A high degree of saturation generally indicates insufficient capacity to accommodate traffic demand. Under these conditions, operational improvements are required to reduce vehicle conflicts and improve traffic flow.

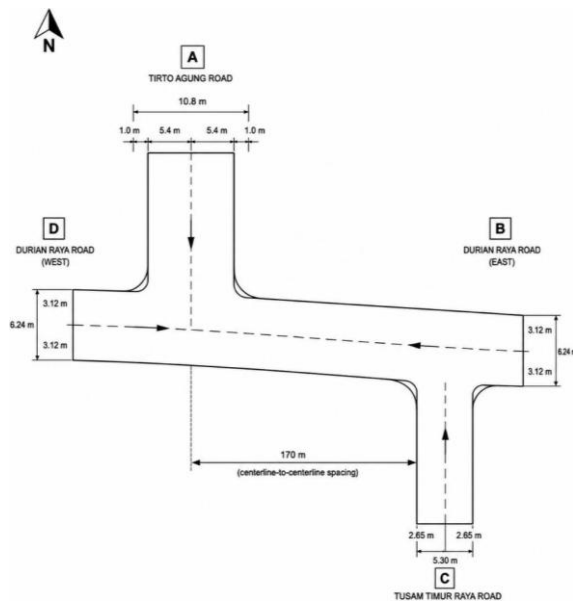


Figure 1. Existing staggered junction.

In urban areas, intersection performance is influenced by traffic volume, geometry, and side friction, including roadside parking, vehicles entering and exiting commercial areas, pedestrian movements, and informal roadside activities. These may reduce effective road capacity and disrupt traffic operations. Traffic engineering measures addressing these issues include channelization, geometric modification, lane management, and access control [7,8].

Microscopic traffic simulation has become a useful tool for evaluating traffic operations and testing improvements before implementation. PTV VISSIM is widely used to represent detailed vehicle interactions and driver behavior, enabling more realistic analysis than conventional analytical methods alone [9]. Several studies have combined PKJI-based analysis with PTV VISSIM to evaluate intersection performance and traffic engineering treatments. Previous studies reported that operational and geometric improvements can reduce delays and improve service levels at urban intersections [10-13].

However, most previous studies focused on single intersections without specifically examining closely spaced unsignalized intersections operating as a staggered junction system. Studies evaluating combined right-turn pockets, approach widening, lane discipline management, and side friction reduction remain limited, especially under Indonesian urban traffic conditions.

This study evaluated two unsignalized staggered T-intersections on the Durian Raya Corridor, Banyumanik District, Semarang, using PKJI 2023 and PTV VISSIM microscopic simulation. Proposed improvements included a right-turn pocket, approach widening, and side friction elimination at Tirta Agung Intersection, plus lane discipline management and side friction reduction at Tusam Timur Raya Intersection. These alternatives were assessed through simulation.

The main contribution is evaluating two adjacent unsignalized intersections as a staggered junction system and examining combined geometric and operational improvements under actual traffic conditions. This study therefore aims to evaluate existing performance at Tirta Agung and Tusam Timur Raya Intersections and assess the proposed alternatives using PKJI 2023 and PTV VISSIM.

RESEARCH METHODS

The research method combined capacity analysis using the Indonesian Road Capacity Guidelines (PKJI 2023) and microscopic traffic simulation with PTV VISSIM. The study involved field data collection, existing condition analysis, simulation modeling, model validation, and evaluation of proposed improvements. Primary data included traffic volume, vehicle composition, intersection geometry, vehicle movement patterns, and roadside conditions. Surveys covered weekdays and weekends to capture representative traffic conditions. Traffic volumes were recorded at 15-minute intervals and converted into passenger car units per hour (pcu/h) following PKJI 2023. The analysis peak hour was selected based on the highest observed traffic volume.

Existing intersection conditions were evaluated using PKJI 2023 by calculating capacity, degree of saturation, average delay, and queue probability. Basic capacity was adjusted for approach width, city size, side friction, and traffic flow characteristics. These results described intersection performance under existing conditions.

A microscopic simulation model was developed in PTV VISSIM using a road network re-

flecting field conditions. Model validation compared simulated and observed traffic volumes using GEH and MAPE. Following validation, improvement alternatives were tested and assessed through changes in delay, queue length, and level of service.

RESULTS AND DISCUSSION

Existing Traffic Condition

Traffic surveys showed peak volumes at both locations on Saturday, 4:30–5:30 PM. Tirto Agung Intersection recorded 2,288 pcu/h and Tusam Timur Raya Intersection 2,453 pcu/h. These indicate high peak-hour demand, affecting operational performance. Figure 2 shows peak-hour traffic flow patterns at both intersections.

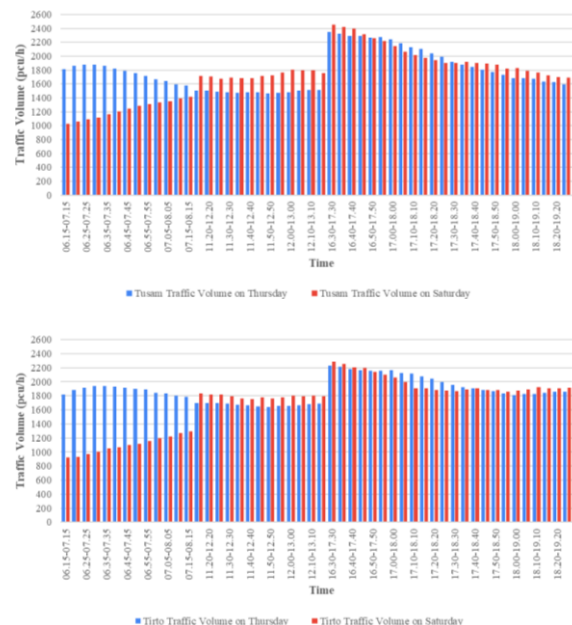


Figure 2. Peak hour traffic flow diagram at Tirto Agung and Tusam Timur Raya intersections.

Table 1. Existing traffic performance at both intersections based on PKJI 2023.

Interaction	Traffic volume (pcu/h)	Capacity (pcu/h)	Degree of saturation	Delay (s/veh)	Queue probability (%)	Performance condition
Tirto Agung	2,288	2,431	0.94	16.88	35.55 – 70.15	Saturated
Tusam Timur Raya	2,453	2,449	0.99	18.59	39.36 – 77.84	Saturated

Intersection performance was evaluated using PKJI 2023 based on capacity, degree of saturation, delay, and queue probability. Tirto Agung had a capacity of 2,431 pcu/h, a degree of saturation of 0.94, an average delay of 16.88 s/veh, and a queue probability of 35.55–70.15%. Tusam Timur Raya had a capacity of 2,449 pcu/h, a degree of saturation of 0.99, an average delay of 18.59 s/veh, and a queue probability of 39.36% – 77.84%. Table 1 summarizes existing performance at both intersections.

Identification of Traffic Problems

Traffic problems along Durian Raya Corridor were influenced by high demand, traffic movement characteristics, and roadside activities. Located only 170 m apart, Tirto Agung and Tusam Timur Raya Intersections may affect each other's operations. At Tirto Agung, the main issue was the high proportion of right turns from the minor approach. Surveys showed that 52.4% of vehicles from Jalan Tirto Agung

turned right onto Jalan Durian Raya. Under unsignalized conditions, right-turning vehicles must wait for acceptable gaps in both directions of major-road traffic, causing longer waits than other movements. Heavy vehicles further increased waiting times because they required longer to complete turns.

Field observations identified roadside activities near both intersections. Vehicles entering and exiting commercial areas, roadside parking, and pedestrian movements reduced effective road space and disrupted traffic, particularly during peak hours. At Tusam Timur Raya, the main issue was side friction along Jalan Durian Raya. On-street parking and vehicles stopping to pick up or drop off passengers reduced effective road width and disrupted major- and minor-road movements.

Although their dominant issues differed, both intersections operated within the same staggered junction system. Operational changes at one could therefore influence the other. A combined network model was used to capture these interactions.

Model Validation and Development of Improvement Alternative

A combined network model was developed using PTV VISSIM to represent traffic operations within the staggered junction system. Unlike conventional analysis that evaluates intersections separately, the model incorporated Tirta Agung and Tusam Timur Raya Intersections into a single

simulation network to capture traffic interactions between the closely spaced intersections.

Model validation compared simulated and observed traffic volumes using GEH and MAPE indicators. The results indicated that the model reasonably represented actual traffic conditions and was suitable for evaluating alternative traffic management strategies. Table 2 presents the validation results.

Table 2. GEH and MAPE validation results of existing traffic volume condition.

Tirta Agung intersection							
Approach code	Observed volume (veh/h)	Observed volume (600 s)	Simulation volume (600 s)	GEH value	Assessment	MAPE value (%)	Assessment
U	2110	352	333	1.03	Accepted	5	Precise
T	1507	251	272	1.30	Accepted	8	Precise
B	1273	212	178	2.43	Accepted	16	Reliable
Tirta Agung	4890	815	783	1.13	Accepted	4	Precise

Tusam Timur Raya intersection							
Approach code	Observed volume (veh/h)	Observed volume (600 s)	Simulation volume (600 s)	GEH value	Assessment	MAPE value (%)	Assessment
U	2110	352	333	1.03	Accepted	5	Precise
T	1507	251	272	1.30	Accepted	8	Precise
B	1273	212	178	2.43	Accepted	16	Reliable
Tusam Timur Raya	4890	815	783	1.13	Accepted	4	Precise

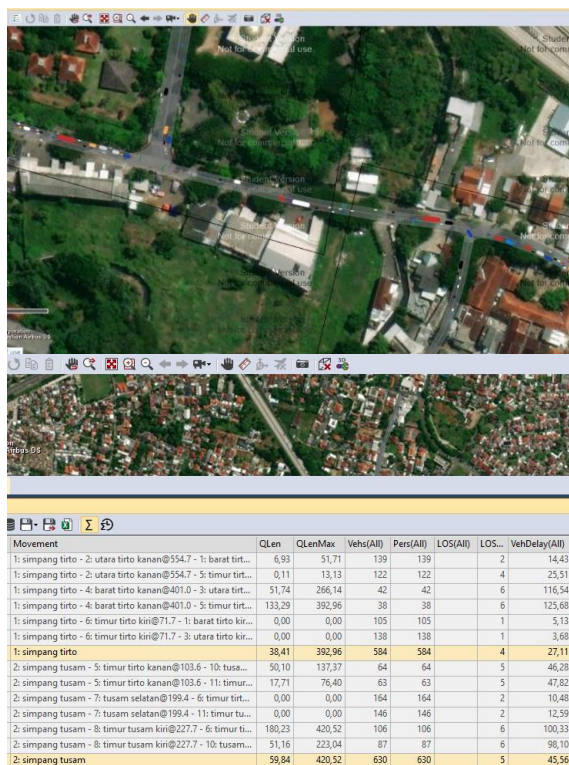


Figure 3. Model result of existing condition.

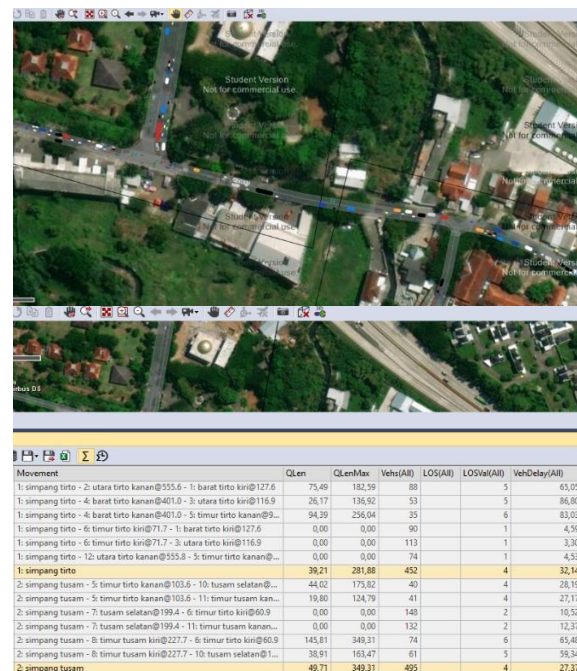


Figure 4. Model result of alternative condition.

Based on the identified traffic issues, several improvements were proposed. At Tirta Agung

Intersection, these included approach widening, side friction elimination, and a right-turn pocket. At Tusam Timur Raya Intersection, widening was considered infeasible due to roadside constraints. Improvements therefore focused on lane discipline management and side friction elimination through parking and stopping controls near the intersection. These measures were implemented simultaneously in the combined network model to evaluate individual intersection performance and the overall operational

response of the staggered junction system. [Figures 3](#) and [Figures 4](#) show the existing and alternative model conditions, respectively.

Evaluation of Improvement Alternatives

Staggered junction performance was evaluated using PTV VISSIM outputs, including average delay, queue length, maximum queue length, and Level of Service (LoS). [Table 3](#) compares existing and alternative conditions.

Table 3. Comparison of existing and alternative conditions based on PTV VISSIM outputs.

Parameter	Existing		Alternative	
	Tirto Agung	Tusam Timur Raya	Tirto Agung	Tusam Timur Raya
Level of service	D	E	D	E
Delay (s/veh)	27.11	45.56	27.11	45.56
Q length (m)	39.21	49.71	39.21	49.71
Q length max	281.88	379.31	281.88	379.31

Under existing conditions, Tirto Agung Intersection operated at LoS D with an average delay of 27.11 s/veh, while Tusam Timur Raya operated at LoS E with 45.56 s/veh. The higher delay at Tusam Timur Raya indicated the most critical location within the staggered junction system. Its maximum queue length reached 420.52 m, compared with 392.96 m at Tirto Agung.

The proposed alternatives produced different operational responses at both locations. At Tusam Timur Raya, average delay decreased from 45.56 to 27.37 s/veh, improving LoS from E to D. Maximum queue length also decreased from 420.52 to 379.31 m, indicating reduced peak-period congestion.

At Tirto Agung, average delay increased from 27.11 to 32.14 s/veh, while maximum queue length decreased from 392.96 to 281.88 m. This suggests that the alternative altered traffic distribution within the staggered junction. Despite increased delay, LoS remained D, with reduced maximum queue extent.

Overall, delay decreased substantially at Tusam Timur Raya but increased at Tirto Agung, while maximum queues shortened at both intersections. These findings suggest that operational changes within the staggered junction affect network traffic, reflecting interactions between the two unsignalized intersections.

CONCLUSION

The simulation results indicate that the alternatives did not improve every performance indicator at each intersection. However, the treatments produced more balanced network operations within the staggered junction. Reduced delay at Tusam Timur Raya and shorter maximum queues at both intersections suggest that the treatments mitigated operational problems along Jalan Durian Raya.

These findings highlight the importance of evaluating closely spaced intersections as an integrated system. Improvements at one location may influence adjacent intersections. Combined network assessment therefore provides a more comprehensive representation of traffic operations than evaluating intersections independently.

AUTHOR CONTRIBUTIONS

Novalin Putri: Investigation, data curation, formal analysis, simulation, visualization, and original draft. Bagus Hario Setiadji: Conceptualization, methodology, supervision, review and editing. Bambang Riyanto: Validation, supervision, review and editing. All authors approved the manuscript.

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DECLARATION OF AI USE

The authors declare that no AI tools were used to prepare this manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All supporting data are included in this article. No additional datasets are available.

ETHICAL APPROVAL

Ethical approval was unnecessary, as no humans or animals were involved.

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