

ANALYSIS OF SIGNALIZED INTERSECTION PERFORMANCE AND FACTORS THAT INFLUENCE TRAFFIC DELAYS IN URBAN AREAS

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ABSTRACT

Signalized intersections are among the most important nodes in urban road networks due to the fact that traffic delays mainly occur at these points. The purpose of this paper is to evaluate the performance of signalized intersections and to determine the factors impacting traffic delays in urban areas through the methodology of Systematic Literature Review. 24 scientific papers were selected from those published in the last ten years and were used for data collection and analysis. All the sources used were openly accessible and could be downloaded anytime, including indexed national journals, conference proceedings, and university libraries. Every factor found was then extracted, documented on a worksheet, and categorized into six groups, namely traffic volume and mix, signal timing, intersection capacity and design, side friction around intersection, drivers' behavior, and traffic engineering and management. Analysis was done through frequency counts. The findings indicate that traffic volume and mix has the first rank with 20 mentions (27.4 percent), while signal timing is the second one with 16 mentions (21.9 percent). Intersection capacity and geometry takes the third place with 14 mentions (19.2 percent), while traffic management and engineering is the last one with 12 mentions (16.4 percent). It is noted that almost all the articles indicate the presence of saturation more than 0.85 in peak hours with level of service E to F. This means that the findings confirm that the delay at the signalized intersections is caused by high traffic volumes and inappropriate signal timing relative to the real traffic flow.

Keywords: *Signalized intersection, traffic delay, degree of saturation, cycle time, systematic literature review.*

I. INTRODUCTION

Intersections are the most vulnerable points in a road network where a decline in performance is likely to occur. This is where traffic flows from various directions converge, cross paths, and must be accommodated one at a time; consequently, the

capacity of an intersection is always smaller than the capacity of the roads leading up to it. If the number of vehicles increases, the queues that form near the intersection will become the primary source of delays experienced by road users (Ariandi, 2025), (Nugraha et al., 2026).

Delays at signalized intersections result from two factors. The first is geometric delay, caused by the deceleration and acceleration of vehicles passing through the intersection. The second factor is traffic delay, caused by traffic signals and interactions between vehicles. These two factors have been calculated in accordance with the Indonesian Road Capacity Guidelines and are used to determine the level of service at intersections (Winarko, 2023). The higher the average delay per light vehicle, the lower the level of service.

The situation observed on the ground indicates that traffic at many urban intersections has now exceeded the recommended levels. For example, a study at the Tobek Godang intersection in Pekanbaru found congestion values of 1.04 in the northbound direction, 1.22 in the eastbound direction, and 1.28 in the westbound direction, meaning that traffic entering the intersection exceeds the capacity of the access roads (Ariandi, 2025). A study at the Padang Galak intersection in Denpasar also found that the average maximum wait time was 112.54 seconds on weekdays, with the access roads at Service Level F (I M. Kariyana, T. H. Pamungkas, 2025).

Traffic signal timing is the easiest factor to adjust because it is cost-effective and quick to modify. Several studies have shown that extending the green light duration and reducing the cycle time can effectively reduce queue length and delays (A. Cahya, E. Gracia, D. Setijowarno, 2024), (N. Aisha, C. Octaviani, 2024). However, these changes are not always sufficient because they merely shift queues from one entrance to another without increasing capacity (I M. Kariyana, T. H. Pamungkas, 2025), (Padmini, 2025).

Geometric factors also influence the amount of saturated flow that can be accommodated. Narrow road entrances, the absence of dedicated left-turn lanes, and the distance between intersections result in a lower saturated flow value compared to the baseline assumption (Suartawan et al., 2022), (Lesmana et al., 2023). Delay calculations will yield higher results even if there is no increase in the number of vehicles due to these factors.

There are also several distinctive features of traffic in Indonesia. The high proportion of motorcycles affects how vehicles line up at entry points because they occupy the empty spaces between vehicles and form lines in front of the stop line (Surentu et al., 2025). Additionally, activities at intersections such as parking, public transit stops, and street vendors reduce the effective width of entry points, thereby decreasing intersection capacity (Setiawan, 2023), (A. Majid, R. B. Hamduwibawa, 2022).

Essentially, there is a significant body of literature on the performance of signalized intersections in Indonesia. However, these findings are scattered across various studies and locations. Furthermore, there have been few literature reviews that synthesize these findings to identify the factors that most significantly influence traffic congestion. Therefore, the objective of this study is to address this gap by analyzing the performance of signal-controlled intersections using the existing literature and identifying and ranking the factors that influence traffic congestion in urban areas. All references used here are from open-access sources to allow readers to locate and download the original papers anytime and anywhere.

II. RESEARCH METHODOLOGY

The following The method used in this study is a Systematic Literature Review (SLR). This method was chosen because of its ability to facilitate the systematic collection, evaluation, and analysis of previous research findings, which will enable the researcher to interpret the findings from various research contexts as a coherent whole. The reporting process is based on standard guidelines typically applied when conducting a systematic review (Page et al., 2021).

Data sources included scientific articles published in national journals indexed by Sinta and Garuda, proceedings of national seminars, and university repositories. The search was conducted via Google Scholar, Garuda, and the open-access journal portals of the respective publishers using the keywords “signal intersection,” “traffic delay,” “saturation level,” “cycle time,” “PKJI 2023,” and “PTV Vissim.” All sources used were free online resources and provided direct links to download the full text.

Four inclusion criteria were included in the list of inclusion criteria. First, the article discusses the performance of urban intersections or the factors causing delays at intersections. Second, the article was published within the last ten years. Third, the full text of the article is accessible online and can be downloaded. Fourth, the article contains a sufficient amount of data or information that can be extracted and considered as factors.

Paywalled articles, duplicate articles, and articles not based on urban areas were excluded from the study. As a result, 24 articles were selected.

The article has been reviewed, and the factors influencing delays or intersection performance have been extracted and listed in an Excel table for further analysis. These factors have been grouped into six categories: traffic volume and composition, signal timing, intersection capacity and geometry, lateral obstructions near the intersection, driver behavior, traffic management, and engineering. These factors were grouped based on their common significance across all study locations. The research phases are briefly illustrated in Figure 1.

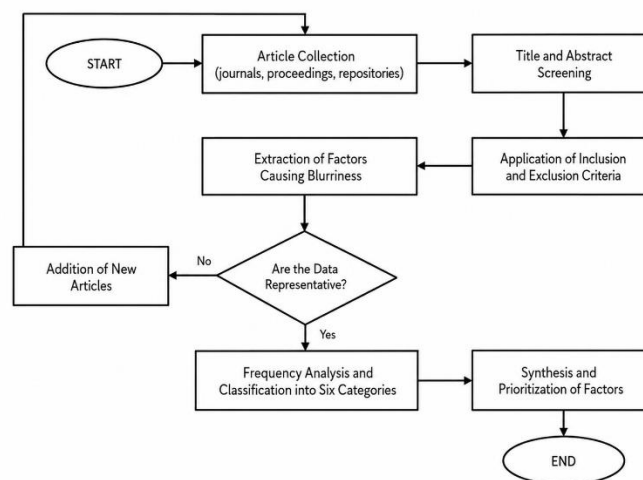


Figure 1. Flowchart of the research stages

The data was analyzed using frequency analysis. The number of articles mentioning each specific category was calculated and compared to the total number of mentions across all categories to determine the percentage. An article may fall into multiple categories because research articles typically discuss several factors related to traffic lights at a specific intersection; consequently, the total number of mentions is greater than the number of articles. The higher the total number of mentions for a category, the more attention the literature pays to it.

In addition to the factors mentioned in the articles, a number of performance characteristics such as saturation levels, average delay, and service levels were also taken into account. These were used to describe the overall situation at urban intersections that had been the subject of previous studies. If the number of articles is deemed unrepresentative, then the data collection and selection process must be repeated.

III. RESULT AND DISCUSSION

Based on the results of the analysis of 24 articles, all factors influencing signal-controlled intersection delays can be grouped into six categories. This grouping allows researchers to conduct a more focused factorial analysis, in which factors that have different names in the literature but share the same meaning can be considered as a single group. The factorial grouping for each article is shown in Table 1.

Table 1. Distribution of categories of factors influencing delays in the 24 articles reviewed

No	Ref	Researcher's Name	Volume and Composition	Signal Time	Capacity and Geometry	Side Obstacles	Driver Behavior	Management and Engineering
1	[1]	M. Z. Muttaqin, W. Ariandi	x	x	x			x
2	[2]	I M. Kariyana, T. H. Pamungkas, U. A. N. Fahmi	x	x	x			x
3	[3]	P. Alimukti	x	x	x		x	
4	[4]	W. P. Zayu, S. Sarda, W. Boy	x		x	x		
5	[5]	A. Cahya, E. Gracia, D. Setijowarno, D. Hartanto	x	x				x
6	[6]	M. Ramzy, B. Rahardjo, B. Supriyanto (2024)	x	x	x			
7	[7]	M. Ramzy, B. Rahardjo, B. Supriyanto (2025)	x	x				x
8	[8]	N. Aisha, C. Octaviani, E. A. Latifa	x	x				x
9	[9]	R. V. Surentu, S. Yacob, R. Rompis, L. I. Lefrandt	x				x	
10	[10]	A. Setiawan (2021)	x		x			
11	[11]	A. Setiawan, I. S. Soerjatmodjo, F. Mustakim			x	x		x
12	[12]	A. Setiawan, dkk. (2023)	x		x		x	
13	[13]	N. P. R. Anggayeni, K. R. Agastya, I. W. W. A. Tunas		x		x		x
14	[14]	A. A. Paendong, J. A. Tomboeleng, S. Y. R. Rompis	x		x			
15	[15]	K. S. Nugraha, Suryanto, M. Arifin	x	x	x			
16	[16]	P. E. Suartawan, P. A. Suthanaya, D. M. P. Wedagama	x		x			x
17	[17]	B. S. Lesmana, Y. Widhiastuti, A. N. Rahmawati		x	x			x
18	[18]	U. M. Hidayatulloh, T. A. Safara, D. Firmansyah	x	x	x		x	
19	[19]	A. S. Indrian, N. Sebayang, M. Erfan	x	x	x			
20	[20]	S. Nadia, A. Rachmawati, A.	x	x		x		

No	Ref	Researcher's Name	Volume and Composition	Signal Time	Capacity and Geometry	Side Obstacles	Driver Behavior	Management and Engineering
		Rahmawati						
21	[21]	D. W. Hidayat, A. B. Sulisty, Y. Oktopianto		x		x		x
22	[22]	A. Majid, R. B. Hamduwibawa, T. D. Kuryanto	x			x		
23	[23]	N. Padmini	x	x				x
24	[24]	M. O. P. Pangaribuan	x	x			x	x
Total	20	16	14	6	5	12		

Note: A checkmark (x) indicates that the article covers the listed category.

Overall, 73 factors were identified from the 24 articles discussed. This number is significantly higher than the number of articles because nearly all of the research papers addressed more than one factor at their respective study sites. Table 2 provides an overview of the frequency and ranking of each category.

Table 2. Ranking of factors influencing delays at signalized intersections

No	Factor Categories	Frequency	Percentage	Rankings
1	Traffic Volume and Composition	20	27,4 %	Rank 1
2	Signal Timing Settings	16	21,9 %	Rank 2
3	Capacity and Geometry of Interchanges	14	19,2 %	Rank 3
4	Traffic Management and Engineering	12	16,4 %	Rank 4
5	Side Barriers Around the Intersection	6	8,2 %	Rank 5
6	Driver Behavior	5	6,8 %	Rank 6
	Total number of occurrences of the factor	73	100 %	

“Traffic Volume and Composition” appeared 20 times, or 27.4 percent, and ranked first. Nearly all articles began their analysis with data on traffic volume during peak hours and linked it to congestion levels. Several studies indicate that congestion levels exceed one in certain approaches, meaning that traffic flow has exceeded capacity and queues do not dissipate within a single cycle (Ariandi, 2025), (Nugraha et al., 2026), (Endarto, Budi, 2024). Vehicle composition also plays a significant role, as a high percentage of motorcycles can influence the formation of queues at entry lanes and slow down the release of traffic flow after the light turns green (Surentu et al., 2025).

“Signal Timing Settings” ranked second in terms of the number of occurrences, with 16 instances, or 21.9 percent. Cycle duration, the distribution of green lights among approaches, and the number of phases are believed to determine vehicle wait times. Several studies have shown that excessively long cycle times result in additional delays

for entry lanes with low traffic flow, while green light durations that are disproportionate to traffic flow ratios cause congestion on one entry lane while other entry lanes remain empty (N. Aisha, C. Octaviani, 2024), (S. Hidayatulloh, 2025), (PANGARIBUAN, 2025). Adjusting green light durations emerged as the most frequently analyzed measure because it does not involve construction.

“Capacity and Geometry of Interchanges” ranked third with 14 mentions, or 19.2%. The width of the approach, the presence or absence of a left-turn lane, and the curvature radius will determine the traffic flow to be accommodated for each approach (Suartawan et al., 2022), (Lesmana et al., 2023). Uneven approach widths will create uneven delays because the narrower approach will become saturated first, even if it has the same green light duration as the other approaches (Paendong et al., 2020).

“Traffic Management and Engineering” were mentioned 12 times, or 16.4%. These measures involved implementing one-way systems, restricting heavy vehicles during peak hours, restricting certain turns, installing barriers, and plans to install traffic signal equipment at unsignalized intersections (A. Setiawan, I. Satya Soerjatmodjo, 2023), (Anggayeni et al., 2024), (Hidayat et al., 2020). The simulation results show that when several measures are combined, there is a significantly greater reduction in delays compared to when they are implemented separately (A. Cahya, E. Gracia, D. Setijowarno, 2024), (M. Ramzy, B. Rahardjo, 2025).

“Side Barriers Around the Intersection” account for 6 instances, or 8.2 percent. Parking at stop lines, public transportation passengers boarding vehicles right where the intersection begins, and street vendors occupying the road shoulder can reduce the effective width of the approach and, as a result, alleviate traffic congestion (W. P. Zayu, S. Sarda, 2023), (A. Majid, R. B. Hamduwibawa, 2022). The low incidence rates are not due to an insignificant effect of these parameters but primarily because the study’s focus was on signal timing calculations rather than on the mildness of the effects presented.

“Driver behavior” ranked lowest and occurred 5 times, or 6.8 percent. This included the initial delay when the green light turned on, the driver’s habit of stopping at the stop line, and violations during the final phase of the yellow light (Alimukti, 2022), (Setiawan, 2023) . Driver behavior is the least-studied parameter because it requires detailed behavioral observation, but this parameter also influences the results of the micro-simulation calibration model (U. M. Hidayatulloh et al., 2022). A comparison of the percentages across these six categories is presented in Figure 2.

**RANKING OF FACTORS INFLUENCING LANDSLIDES
AT SIGNALIZED INTERSECTIONS BASED ON 24 ARTICLES**

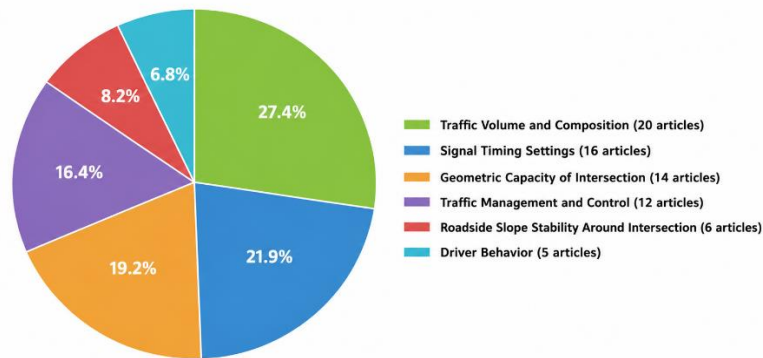


Figure 2. Percentage of occurrence of categories of factors influencing delays

The operating conditions described in the article under discussion have several unique characteristics. For most intersections, the focus is often on service levels E through F with high traffic density exceeding the recommended guideline of 0.85 during peak periods. Average delay values vary significantly, ranging from about ten seconds per light vehicle at intersections with low traffic volume to more than one hundred seconds at congested intersections (Ariandi, 2025), (I M. Kariyana, T. H. Pamungkas, 2025). This variability indicates that delay measurements are highly sensitive to specific conditions, so results obtained at one location cannot easily be generalized to other locations.

The ranking of these factors also has its own unique characteristics. The top three groups volume, signal timing, and intersection geometry account for 68.5 percent of all factor occurrences. These three factors are believed to be interconnected in terms of the parameters used to calculate the signalized intersection capacity (inflow, green time ratio, and saturated flow). In other words, most studies explain delays through the parameter values used in the calculations. On the other hand, behavioral factors and activities at the intersection edges are not often calculated directly in the field.

A comparison of methods also warrants attention. There are several cases where researchers often calculate delays using guidelines and then use microsimulation to verify the results. It has been shown that the delay values from the guidelines tend to be larger than those from the simulations (I M. Kariyana, T. H. Pamungkas, 2025), (Alimukti, 2022). The reason behind this is quite clear: guidelines use a deterministic approach based on average values, whereas microsimulation models the behavior of each vehicle separately using a random distribution. Thus, using both methods will yield better results—but only if the model has been calibrated and validated beforehand.

Based on the pattern described above, it can be concluded that optimizing cycle times and adjusting green light timing to match traffic flow at each intersection is the first step that should be taken, as these measures are relatively inexpensive and quick to implement. The second step is to regulate activities near the intersection, such as prohibiting parking near stop lines and relocating public transportation stops. If the two steps above do not resolve the problem, then geometric changes should be considered, such as widening the approach, adding a direct left-turn lane, or changing the direction of traffic flow near the intersection.

IV. CONCLUSION

A review of 24 open-access articles identified six categories of factors that influence traffic delays at signalized intersections in urban areas. Traffic volume and composition was the most frequently cited category, appearing 20 times (27.4 percent), followed by signal timing with 16 mentions (21.9 percent), intersection capacity and geometry with 14 mentions (19.2 percent), and traffic management and engineering with 12 mentions (16.4 percent). Side obstacles around intersections and driver behavior ranked last and second-to-last, respectively.

In terms of performance, most of the intersections analyzed showed ratings between E and F during peak hours, with congestion levels exceeding 0.85. This clearly indicates that the delays experienced are not caused by a single factor but result from the convergence of many factors, such as traffic volume, inappropriate signal timing, and approach capacity. Therefore, it is reasonable to begin the optimization process by improving cycle times and green times and by controlling traffic flow at the intersection entrances.

Limitations of this study include the number of sources used and the use of mention frequency as the sole criterion. Mention frequency does not account for the importance of a factor but only for how often it is mentioned. In the future, it is hoped that studies will increase the number of articles examined, classify results based on intersection type and city size, and apply additional criteria such as the analytic hierarchy process and regression models.

V. ACKNOWLEDGMENTS

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