OPEN ACCESS

Vol. 22, No. 2, 2026, 317 – 333

Jurnal Pembangunan Wilayah dan Kota
P-ISSN: 1858-3903 and E-ISSN: 2597-9272
https://ejournal.undip.ac.id/index.php/pwk/index

ENHANCING URBAN MOBILITY EFFICIENCY THROUGH INTERSECTION COORDINATION IN THE CONTEXT OF SUSTAINABLE URBAN DEVELOPMENT

MENINGKATKAN EFISIENSI MOBILITAS PERKOTAAN MELALUI KOORDINASI PERSIMPANGAN DALAM KONTEKS PEMBANGUNAN PERKOTAAN BERKELANJUTAN

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Article Info:
- Received: 30/01/2026
- Accepted: 29/06/2026
- Available Online: 30/06/2026

ABSTRACT
Intersection coordination is a strategic approach in traffic management that aims to manage signal timing in an integrated manner at several adjacent intersections to improve the smooth flow of vehicles. This study focuses on evaluating the performance of intersection coordination using Transyt software as an optimization tool. The study was conducted at two major intersections, namely the Stadion intersection and the RSUD Sayyidiman intersection in Magetan Regency, Indonesia, which are experiencing increasing traffic activity as the area grows. Before coordination, both intersections showed levels of delay, queue length, and saturation levels that indicated a decrease in mobility efficiency. Through a process of optimizing cycle times and signal phases, a green wave system was implemented between intersections to smooth the movement of vehicles within a single corridor. The results showed significant improvements in intersection performance, including reduced delays, shortened queues, and an overall increase in the level of service. This study confirms that intersection coordination not only improves the efficiency of urban mobility but also contributes to the goal of sustainable urban development by reducing the environmental impact of congestion and excessive fuel consumption.
Kata Kunci: *Intersection Coordination, Mobility Efficiency, Sustainable Urban Development, Intersection Performance, Urban Mobility*

ABSTRAK
Koordinasi persimpangan adalah pendekatan strategis dalam manajemen lalu lintas yang bertujuan untuk mengatur waktu sinyal secara terintegrasi di beberapa persimpangan yang berdekatan untuk meningkatkan kelancaran arus kendaraan. Studi ini berfokus pada evaluasi kinerja koordinasi persimpangan menggunakan perangkat lunak Transyt sebagai alat optimasi. Studi ini dilakukan di dua persimpangan utama, yaitu persimpangan Stadion dan persimpangan RSUD Sayyidiman di Kabupaten Magetan, Indonesia, yang mengalami peningkatan aktivitas lalu lintas seiring pertumbuhan wilayah tersebut. Sebelum koordinasi, kedua persimpangan menunjukkan tingkat keterlambatan, panjang antrian, dan tingkat kejenuhan yang mengindikasikan penurunan efisiensi mobilitas. Melalui proses optimasi waktu siklus dan fase sinyal, sistem gelombang hijau diimplementasikan antara persimpangan untuk memperlancar pergerakan kendaraan dalam satu koridor. Hasil menunjukkan peningkatan signifikan dalam kinerja persimpangan, termasuk pengurangan keterlambatan, pengurangan antrian, dan peningkatan keseluruhan tingkat pelayanan. Studi ini menegaskan bahwa koordinasi persimpangan tidak hanya meningkatkan efisiensi mobilitas perkotaan tetapi juga berkontribusi pada tujuan pembangunan perkotaan berkelanjutan dengan mengurangi dampak lingkungan dari kemacetan dan konsumsi bahan bakar yang berlebihan.
Keywords: *Koordinasi Persimpangan, Efisiensi Mobilitas, Pembangunan Perkotaan Berkelanjutan, Kinerja Persimpangan, Mobilitas Perkotaan*

1. INTRODUCTION

The study supporting mobility efficiency with intersection coordination encompasses the concept of urban traffic management (Bahamazava, 2025), green wave theory (Brand et al., 2024), and the basic principles of traffic signal coordination (Huang et al., 2025), which emphasize the importance of synchronized traffic signal timing across intersections to create more efficient vehicle flow (Shen et al., 2025). In the context of sustainable development, this aligns with the sustainable urban mobility approach (Hwang et al., 2025), which emphasizes emission reduction (Nguyen & Kim, 2024), increased travel efficiency (Yu et al., 2025), and reduced energy consumption (Hou et al., 2025; Sarjana et al., 2024). Supporting analysis is conducted using simulations that can evaluate intersection performance based on parameters such as saturation level, queue length, and delay (Aydin & Aydoğdu, 2025). Moblity efficiency impacts time and fuel savings, and contributes to carbon emission reduction, supports environmental quality, and creates more livable urban spaces.

Intersection coordination reduce waiting times and improve service levels (Reddy et al., 2023; Sakakibara & Oguchi, 2025), thus strengthening the argument that coordinated intersection management plays a vital role in creating an efficient and sustainable urban transportation system (Prapaporn et al., 2025). Coordination between signalized intersections is a crucial strategy in managing traffic flow more smoothly, minimizing delays, and reducing vehicle queue lengths, thereby improving the efficiency of people's daily mobility (Yasa et al., 2024; Su et al., 2025). Coordination between intersections is generally intended to improve the service of a road network, reduce delays and vehicle stopping times (Freire et al., 2025). The signal coordination system at intersections according to (Kirono et al., 2018) includes a simultaneous system where all color phases in a road corridor light up at the same time or can be said to be the same as the green wave concept, an alternate system where all signal indications change at the same time but the signal groups at nearby intersections show different colors, a simple progressive system has guidelines on the cycle in general and has separate road signal indications, a flexible progressive system has a master control mechanism that not only provides good coordination between signals but also allows cycle retrieval at intervals throughout the day.

This study is necessary due to the limited research analyzing integrated signalized intersection coordination in urban areas characterized by close intersection spacing and high land use activity. Previous studies have focused on evaluating intersection performance in partial or isolated sections, such as analyzing saturation levels, delays, and queue lengths at a single intersection without considering the relationships between intersections within a road corridor. They generally focus solely on optimizing cycle times at each intersection. One of the challenges faced is traffic management at intersections, making intersections a crucial area to avoid delays and queues that can lead to traffic congestion (Chun & Rouphail, 2025). As the meeting point of two or more roads, intersections are critical areas in the road network system (Jin et al., 2025), becoming points of conflict and potential traffic congestion (Setiawan et al., 2023; Salas & Sarjana, 2024). Congestion, which has the potential to cause accidents, can increase at intersections with heavy traffic, requiring immediate solutions (Veronica et al., 2023; Kaya & Kabakuş, 2025). The mechanism for addressing conflict points at intersections is to reduce existing conflicts by regulating the intersection (Park et al., 2025; Hua et al., 2025). One mechanism for regulating intersections is the installation of traffic lights or traffic signals (Sheykhfard et al., 2021; Radivojević et al., 2021).

There is a lack of studies addressing integrated signalized intersection coordination in urban corridors with close proximity and high traffic volumes due to the dominance of office, government, commercial, and public service areas. This study aims to fill a gap unexplored by previous research. Many previous studies have focused on evaluating individual intersection performance or isolated optimization without considering the operational interconnections between intersections within a road network. Studies on the application of green wave-based signal coordination related to urban mobility efficiency and sustainable urban development are still relatively limited, particularly in developing urban areas. There is limited use of a traffic network simulation approach using Transyt 14.1 software to evaluate the impact of signal coordination on changes in saturation levels, queue lengths, delays, and the overall level of service at intersections. Intersection coordination is a crucial strategy for improving mobility efficiency in urban areas facing increased traffic volumes due to regional growth and increased mobility (Qonita et al., 2025; Pelosi et al., 2020). In the context of sustainable urban development, mobility efficiency achieved through intersection coordination not only reduces congestion and travel times but also reduces emissions and energy consumption. To understand the concrete impact of this approach, it is necessary to analyze traffic performance both under existing conditions and after the implementation of isolated and coordinated optimizations. The comparative results provide an evaluative basis for demonstrating that coordinated optimization significantly improves traffic flow compared to localized or separate approaches, thus strengthening the argument that intersection coordination is an integral component in promoting sustainable urban development. Despite the installation of traffic signals, problems at intersections still frequently occur (Elidrissi et al., 2020; Zou et al., 2024). This commonly occurs at intersections located on one consecutive section with relatively close distance between intersections with different cycle time settings for both intersections, thus causing delays or stopping of vehicles again at the next intersection, thus causing longer queues and longer delays (Yasa et al., 2024; Budiman et al., 2013).

The Stadion intersection and the RSUD Sayyidiman intersection were chosen because they play a crucial role in the urban road network system in Magetan Regency. Both intersections are located on the Jalan Pahlawan corridor, which is a center of community activity and traffic movement in the urban area. The areas surrounding both intersections are within the Central Business District (CBD), which serves as the center of economic activity, government, and public services. Land use around the study locations is dominated by offices, government facilities, trade areas, and healthcare facilities, which generate high trip generation and attraction. These characteristics cause traffic volumes at both intersections to be quite high throughout the day, making them representative locations for transportation and traffic performance studies. The relatively close distance between the two intersections causes the interaction of vehicle flows to be very strong so that uncoordinated signal arrangements have the potential to cause queues, delays, and repeated traffic obstacles on the connecting sections. This condition makes both intersections very relevant to be studied in intersection coordination research, because they can represent urban mobility problems and provide an overview of the effectiveness of signal optimization and coordination in improving the efficiency of the urban road network. The condition of this intersection is increasingly relevant to the increasing need for urban mobility and the growth of regional activities that impact the increasing traffic load in the city center area. Therefore, these two intersections were selected because they represent real urban traffic problems that require an integrated signal coordination approach. Therefore, the study results have academic value and provide a practical contribution to supporting mobility efficiency, congestion reduction, and the development of more sustainable urban transportation.

This condition occurs in Magetan Regency on Jalan Pahlawan where there are intersections that are close to each other, the Stadion intersection and the RSUD Sayyidiman intersection where the distance between these intersections is 400 meters. The Stadion intersection connects Gubernur Suryo street, Yosonegoro street, and Pahlawan street. The Stadion intersection has a saturation degree indicator of 0.65, a queue length of 33.41 meters and a delay of 29.64 sec/pcu. While the RSUD intersection is a connector between Pahlawan street, S Parman street and Sudirman street. The RSUD intersection has a saturation degree of 0.48, a queue length of 26.58 m and a delay of 25.51 sec/pcu. This study aims to analyze the traffic performance of the Stadion intersection and the RSUD Sayyidiman intersection, both under existing conditions and after isolated and coordinated optimization. This study supports sustainable urban development through data and technology-based transportation infrastructure optimization. Transportation is inseparable from people's lives, allowing the movement of both people and goods to facilitate development, the economy, and all aspects of life (Bennett & Vijaygopal, 2024). The increasing need for transportation can trigger problems in the areas of traffic and road transportation (Wood & Jones, 2025).

2. DATA AND METHODS

Research on intersection coordination falls into the quantitative research category, focusing on testing theories through measuring variables with numerical data and analyzing them using statistical procedures. The approach used is deductive, aiming to solve previously formulated problems. Quantitative research seeks to define a phenomenon so that it can be measured objectively and systematically (Fachri & Sarjana, 2022). This method utilizes standardized measurement instruments or those based on specific data scales to ensure the validity of the results. Thus, quantitative research is essentially the process of collecting and analyzing numerical data to explain a particular phenomenon rationally and measurably.

Primary data includes direct survey data related to the study location's problems (Haxhija et al., 2025). The survey used as primary data in this study was conducted from October to December 2024 at the Stadion intersection and the RSUD Sayyidiman intersection, located in Magetan Regency, East Java Province. Intersection geometric data were obtained from an intersection inventory survey conducted by recording signs and markings, approach widths, side barriers, and pedestrian facilities at the intersection. Traffic volume data were obtained from a Classified Turning Movement Counting (CTMC) survey. The standard used in determining vehicle classification is the Indonesian Road Capacity Guidelines (PKJI) (Maulana et al., 2024). The CTMC survey was conducted in one day during the morning peak period, afternoon peak period, and evening peak period for 2 hours each with a 15-minute time interval. This was done by recording vehicles exiting each approach, whether turning right, turning left, or going straight, which were divided according to the vehicle classifications specified in the survey form. The CTMC survey data represents typical traffic conditions, which directly impact the validity of the analysis results and the reliability of the intersection coordination model developed. The survey was conducted over a single day during the morning, afternoon, and evening rush hours, reflecting normal traffic conditions, not holidays, weekends, or special conditions that could cause unusual fluctuations in traffic volume.

Data on the phase and cycle time of traffic signal devices for each intersection leg at the study intersection location were obtained through an intersection inventory survey. The intersection inventory survey was conducted with the aim of determining the phase and cycle time at the intersection being studied. The queue and delay data survey conducted to determine the length of the queue of vehicles entering the intersection and to determine how long vehicles experience delays before entering the intersection. Speed data was obtained through a spot speed survey in the study area. The speed data survey was conducted using a speed gun to determine the speed of vehicles passing on the road section. Meanwhile, secondary data is research data developed and presented by relevant agencies related to this research (Pranita & Sarjana, 2025), including road network data and intersection location data.

The signal parameters optimized in this study include cycle time, green time, inter-green time (yellow time and all-red time), signal phase distribution, and offset values between intersections to create vehicle flow coordination. Optimization was performed using TRANSYT 14.1 software by inputting data on traffic flow, saturation flow, intersection capacity, vehicle speed, connecting section length, and geometric conditions and signal phases at each intersection. The intersection coordination strategy is implemented by equalizing the cycle time between the Stadion intersection and the RSUD Sayyidiman intersection so that a synchronous vehicle movement pattern or green wave is formed. Data analysis techniques are analyzed using various methods to adjust the type of data so that it can complete the signal coordination stages for intersections in the study area. The data processing process is carried out systematically to obtain the right problem-solving solutions. Some of the analyses carried out include intersection performance analysis in existing conditions, optimization of intersection performance in isolated and coordinated ways using Transyt 14.1 software, and conducting a comparison of existing and after-coordinated performance. The intersection performance evaluation criteria in this study are based on several traffic indicators used in signalized intersection analysis, including saturation level, queue length, delay time, capacity, and level of service. Saturation level measures the ratio between traffic volume and intersection capacity; queue length assesses vehicle accumulation in each approach lane; delay time represents the average additional travel time experienced by vehicles passing through the intersection; cycle time, green time allocation, phase

DOI: 10.14710/pwk.v22i2.82082

arrangement, and traffic flow characteristics are analyzed as supporting parameters in evaluating signal performance and coordination effectiveness.

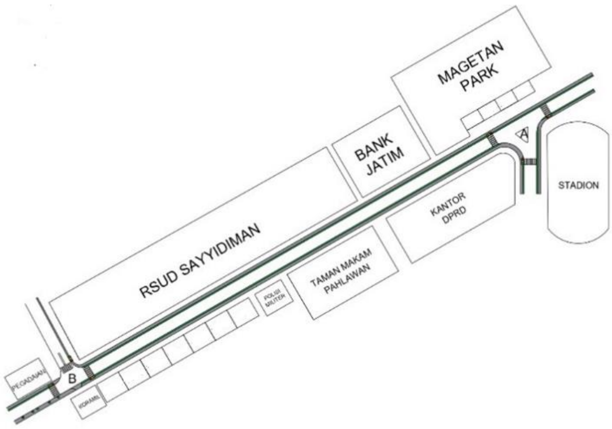

Figure 1. Layout of the Stadion intersection and the RSUD sayyidiman intersection at Magetan Regency

The research location was carried out in Magetan Regency, East Java Province, precisely at two intersections on Pahlawan street, the Stadion intersection and the RSUD Sayyidiman intersection. Both intersections are signalized intersections with a distance of 400 meters, where the intersection cycle time arrangement has not been coordinated, causing several problems and reducing intersection performance. Fig 1 provides a map showing the location, position of road corridors, distances between intersections, land use around the intersections, and road functions. This helps demonstrate why the Stadion (A) and RSUD Sayyidiman (B) intersections were selected as relevant research locations. This information illustrates existing traffic conditions, the level of activity in the area, and the interconnectedness between the intersections, which necessitates signal coordination. The visual presentation of the map helps understand the spatial relationship between the two intersections, the direction of vehicle movement, and the effect of proximity on queue formation and delays.

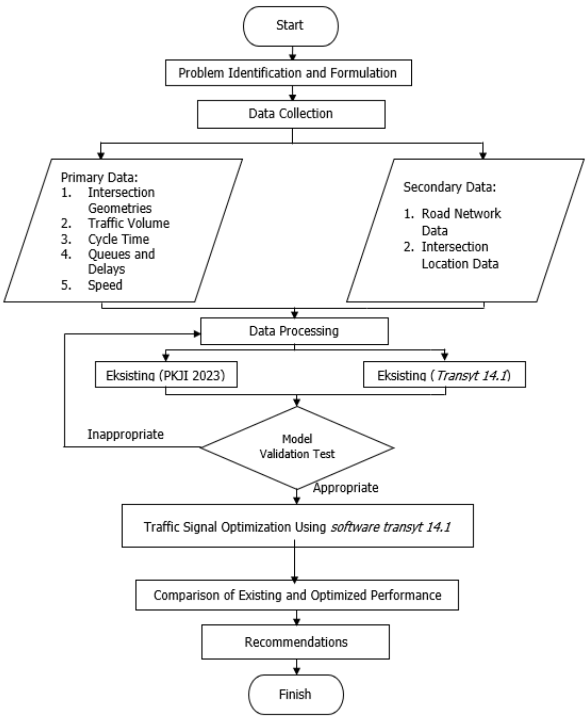

Figure 2. Intersection coordination analysis flowchart

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Intersection coordination using Transyt plays a crucial role in improving traffic efficiency in urban areas, particularly on road networks with close intersections. Transyt is a traffic simulation and optimization software capable of accurately modeling intersection performance based on input data such as traffic volume, saturation flow, cycle time, traffic light phase, and vehicle speed. Using this program, traffic planners can determine optimal cycle and phase timings for each intersection, and align these timings to create a green wave. This allows vehicles to traverse multiple intersections with minimal stops, reducing delays, queues, fuel consumption, and vehicle emissions. Furthermore, the analysis results from Transyt also provide a strong scientific basis for decision-making in long-term traffic planning and management in complex urban areas.

3. RESULT AND DISCUSSION

The road network is a unified road network consisting of a primary and secondary road network system intertwined in a hierarchical relationship. The road network in Magetan Regency is 684.92 km consisting of 15.61 km of national roads, 39.06 km of provincial roads, and 630.25 km of district roads. The condition of roads in Magetan Regency is generally in good condition with the average pavement using asphalt. However, there are several road sections that are in poor condition, especially on Regency roads located in remote areas of Magetan Regency. Road intersections include two or more roads that join or intersect, including roads and roadside facilities for traffic movement within them. All intersections in Magetan Regency are at-grade intersections. In this study, there are 21 signalized intersections and 4 unsignalized intersections shown in Fig 3. Several indicators that affect intersection performance include intersection capacity, saturation flow, cycle time, green time, degree of saturation, as well as queue length and delay length. Meanwhile, the performance indicators of signalized intersections include the degree of saturation, delay time and queue length (Sarjana & Khairunisa, 2025).

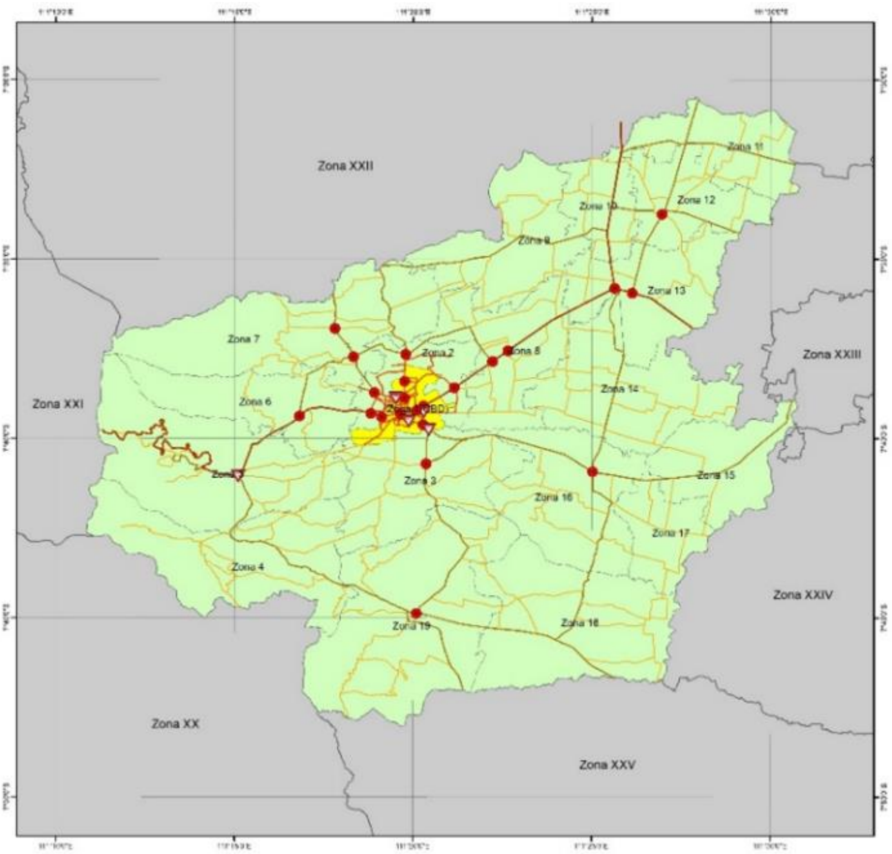

Figure 3. Map of intersection locations in Magetan regency

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The location of the two intersections used as the study area is in the center of Magetan Regency's activities or CBD area with the intersection legs being provincial roads and district roads. The two intersections used as the study area are the Stadion intersection and the RSUD intersection. The distance between the Stadion intersection and the RSUD intersection is 400 meters. The land use around the intersection is commercial, dominated by offices and government around the sections and intersections. The Stadion intersection is a type of intersection with signalized arrangements that have 3 intersection legs with the type 322 intersection, having 3 intersection legs with 2 lanes on minor flows and 2 lanes on major flows, while for the RSUD intersection has a signalized arrangement that has 3 intersection legs with the type 322 intersection, which has 3 intersection legs with 2 lanes on minor flows and 2 lanes on major flows shown in Fig 4.

Figure 4. The study locations include the Stadion intersection and the RSUD Sayyidiman intersection

The Stadion intersection is a 3-way intersection with a signalized intersection control type at each approach and has an intersection performance with a saturation degree of 0.65, a queue length of 33.41 meters and an average delay of 29.64 seconds. The Stadion intersection is located at the intersection of Pahlawan Street, Yosonegoro Street, and Governor Suryo Street with office and government land uses around it. Meanwhile, the RSUD Sayyidiman intersection is a 3-way intersection with a signalized intersection control type at all three legs of the intersection, namely east, west, and north. This intersection has an intersection performance with a saturation degree of 0.48, a queue length of 26.58 m and an average delay of 25.51 sec/pcu. The RSUD Sayyidiman intersection is located at the intersection of Pahlawan Street, S Parman Street, and Jenderal Sudirman Street with commercial land use characteristics around its land.

Table 1. Intersection performance at the Stadion intersection and the RSUD Sayyidiman intersection under existing conditions

Intersection Performance	Road Name	Approach	Saturation Level	Queue Length (m)	Delay (seconds/pcu)
Stadion	Gubernur Suryo Street	East	0.65	32.58	30.23
	Yosonegoro street	South	0.58	28.83	30.43

Intersection Performance	Road Name	Approach	Saturation Level	Queue Length (m)	Delay (seconds/pcu)
	Pahlawan street	West	0.6	33.41	28.49
RSUD Sayyidiman	Pahlawan street	East	0.48	26.58	24.55
	Jend Sudirman Street	West	0.47	16.49	25.81
	S. Parman street	North	0.47	15.09	26.5

The Stadion intersection has a total cycle time of 73 seconds with a green time of 19 seconds on the east and west legs of the intersection and 17 seconds on the south leg of the intersection. The red time is 3 seconds on each leg of the intersection and the yellow time is 3 seconds. The Stadion intersection has an average delay of 29.64 seconds/pcu. The highest degree of saturation is on the east approach with 0.65, the highest queue length is on the west approach with 33.41 meters, and the highest delay is on the south approach with 30.43 seconds/pcu. Meanwhile, the cycle time of the RSUD Sayyidiman intersection is 66 seconds. The highest queue length is on the east leg approach with a length of 26.58 meters. The RSUD Sayyidiman intersection has an average delay of 25.51 seconds/pcu. The highest degree of saturation is on the eastern approach with 0.48, the highest queue length is on the eastern approach with 26.58 meters, and the highest delay is on the northern approach with 26.50 seconds/pcu shown in Table 1. Data obtained from measuring saturation levels, queue lengths, and delays at each approach provides a comprehensive overview of traffic efficiency and critical congestion points. This is crucial for evaluating existing performance and serves as the basis for designing more effective traffic signal optimization and coordination strategies to support smooth mobility and sustainable urban development (Maulana et al., 2024).

The existing network diagrams of the Stadion intersection are based on Transyt 14.1, which explains the performance of the Stadion intersection including saturation level, queue length, and delay time. The modeling results for the Stadion intersection on the east approach for the entry direction to the intersection with a traffic flow of 427 pcu/hour and a capacity of 2504 pcu/hour, produce figures of 62% and 7.96 pcu. While the saturation degree on the east approach is 0.62 and the queue is 7.96 pcu, as well as for other approaches. Based on Fig. 5 (a), it is known that the highest saturation degree is on the east approach with 0.62, the highest queue length is on the west approach with 32.96 meters, and the highest delay is on the east approach with 27.49 seconds/pcu. Information on saturation levels, queue lengths, and delays at each approach are key indicators for identifying bottlenecks and assessing the effectiveness of current traffic signal management. Given that the eastern approach exhibits the highest levels of saturation and delays, the recommended follow-up action is to optimize signal timing and implement inter-intersection coordination policies to reduce traffic load on this approach and improve overall network efficiency. This analysis is crucial for supporting sustainable transportation planning in the context of urban development.

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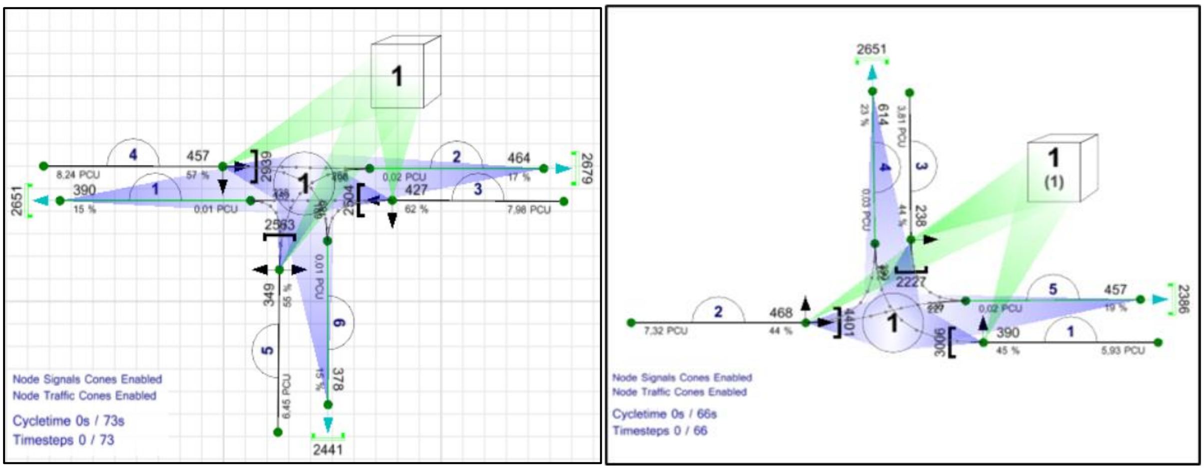

(a) (b)

Figure 5. Network diagram on existing conditions at the Stadion intersection (a) and the RSUD Sayyidiman intersection (b)

Modeling the RSUD Sayyidiman intersection on the eastern approach, with a traffic flow of 390 pcu/hour and a capacity of 3,006 pcu/hour, yielded figures of 45% and 5.93 pcu. The saturation level on the eastern approach was 0.45, and the queue length was 5.93 pcu, as was the case for the other approaches. The existing performance of the RSUD Sayyidiman intersection includes the highest saturation level on the eastern approach (0.45), the highest queue length on the eastern approach (26.36 meters), and the highest delay on the northern approach (23.82 seconds/pcu) shown in Fig 5 (b). Modeling data indicates that although saturation and queue levels have not yet reached critical levels, there is a concentration of traffic on the eastern and northern approaches that could potentially cause future congestion if not addressed immediately. Recommended follow-up actions include optimizing signal settings, both isolated and in coordination with other nearby intersections, and continuously monitoring vehicle volume growth. This analysis plays a role in supporting sustainable urban development by ensuring smooth traffic flow in strategic areas.

The feasibility analysis of the model needs to be validated to determine the alignment of existing performance data based on the model and performance obtained from survey results or direct observations in the field. The statistical test used to determine whether the resulting modeling results are acceptable or not is using the chi-square test for the degree of saturation, delay, and queue. The chi-square test is carried out on three intersection performance indicators including the degree of saturation, delay and queue at the intersection where these three indicators are output from the Transyt software. After model creation, the results of the modeling performance data are used for validation. This process is crucial to ensure that intersection planning and optimization decisions are not based on assumptions or data that deviate from reality. In other words, this validation serves as a link between the theoretical model and operational reality, while strengthening the legitimacy of the resulting technical recommendations for improving traffic efficiency and developing sustainable transportation.

Table 2. Validation results of saturation, delay, and queue length

Intersection	Approach	Road Name	Degree of Saturation		Chi-Square Test	Delay		Chi-Square Test	Queue Length		Chi-Square Test
			PKJI	Transyt		PKJI	Transyt		PKJI	Transyt	
Stadion	E	Gubernur Suryo street	0.65	0.62	0.0015	30.23	27.49	0.2731	32.58	31.92	0.0136
	S	Yosonegoro street	0.58	0.55	0.0016	30.43	27.47	0.319	28.83	28.67	0.0009
	W	Pahlawan street	0.6	0.57	0.0016	28.49	25.72	0.2983	33.41	32.96	0.0061

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RSUD Sayyidiman	E	Pahlawan street	0.48	0.45	0.002	24.55	20.93	0.6261	26.58	26.36	0.0019
	W	Jenderal Sudirman street	0.47	0.44	0.002	25.81	22.51	0.4838	16.49	16.27	0.0031
	N	S Parman street	0.47	0.44	0.002	26.5	23.82	0.3015	15.09	15.24	0.0015

Based on the calculation results presented in Table 2, it can be seen that the model is in line with the conditions in the field and can be used for intersection modeling with a chi-square value <11.07 which indicates that the model created is feasible to be applied in the field. After validation between the 2023 PKJI calculation and the transyt software on three intersection performance indicators including the degree of saturation, delay, and queue length, between the data obtained from the 2023 PKJI calculation and transyt there is a data match or the data obtained from both sources is not much different and is declared valid. For this reason, the use of the model in this study is permitted and to continue the process of the next research stage, coordinating the two intersections using this software.

Before coordinating the intersection, optimization is necessary to obtain a cycle time that is appropriate to the capacity and traffic flow at the intersection, which is done through cycle time optimization without changing the traffic signal phase settings. At the Stadion intersection, there are three road segments meeting where two road segments are major flows and one road segment is minor flows. Time optimization at the Stadion intersection with the eastern approach at Gubernur Suryo street in phase 1 has a green time of 16 seconds, all red 2 seconds, yellow 3 seconds. For the southern approach at Yosonegoro street in phase 2 has a green time of 13 seconds, all red 2 seconds, yellow 3 seconds. Meanwhile, on the western approach at Pahlawan street in phase 3 with a green time of 15 seconds, false red 2 seconds and yellow 3 seconds. The optimum cycle time of the Stadion intersection is 59 seconds, with a green time on the eastern approach of 16 seconds, the southern approach of 13 seconds, and the western approach of 15 seconds. This process is crucial to ensure that intersection planning and optimization decisions are not based on assumptions or data that deviate from reality. In other words, this validation serves as a link between theoretical models and operational reality, while also strengthening the legitimacy of the resulting technical recommendations for improving traffic efficiency and developing sustainable transportation.

Transyt 14.1 software modeling of the Stadion intersection after optimization isolated to the eastern approach with a traffic flow of 427 pcu/hour and a capacity of 2,504 pcu/hour yielded 59% and 6.36 pcu shown in Fig 6 (a). This translates to a saturation level of 0.59 on the eastern approach and a queue length of 6.36 pcu. The highest saturation level was on the eastern approach with a value of 0.59, the longest queue length was on the western approach with a value of 26.92 meters, and the highest delay was on the southern approach with a value of 23.83 seconds/pcu. Post-optimization modeling results indicate improvements in several approaches, such as reduced queues on the eastern and western approaches and reduced delays on the southern approach. These findings suggest the need for further evaluation of the overall impact of isolated optimization on broader road network coordination. This step is to determine whether improving performance at a single intersection will have a systemic positive effect on the city's road network, thereby supporting mobility efficiency and the sustainability of urban traffic as a whole.

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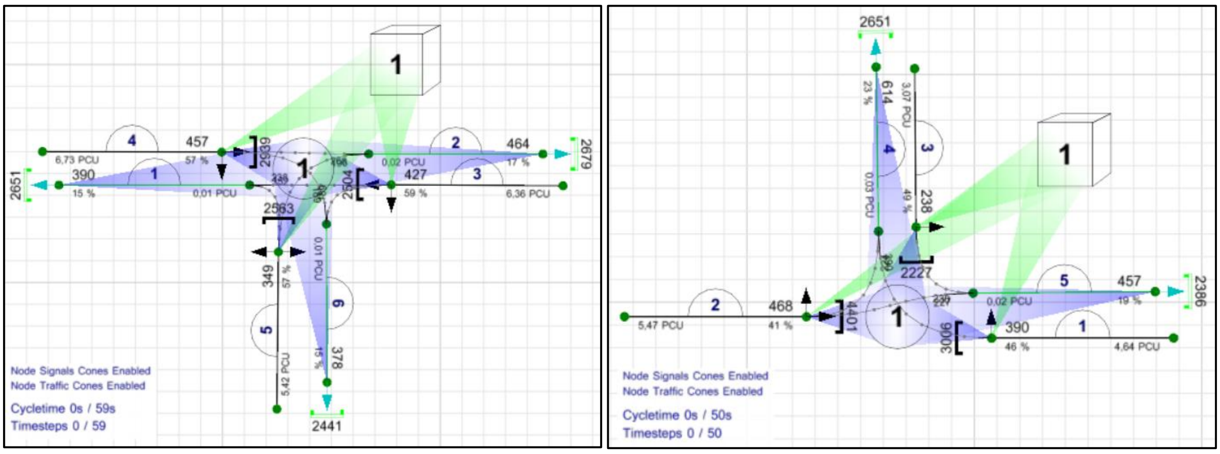


(a) (b)

Figure 6. The network diagram is the result of optimization of the Stadion intersection (a) and RSUD intersection (b)

At the RSUD Sayyidiman intersection, there are three road intersections, where two roads are major and one road is minor. On the eastern approach at Pahlawan Street in phase 1 with a green time of 13 seconds, all red 2 seconds, yellow 3 seconds. For the western approach at Jenderal Sudirman Street in phase 2 with a green time of 12 seconds, all red 2 seconds, and yellow 3 seconds. Meanwhile, on the northern approach at S Parman Street in phase 3 with a green time of 10 seconds, all red 2 seconds and yellow 3 seconds. The optimum cycle time at the RSUD Sayyidiman intersection is 50 seconds with a green time on the eastern approach of 13 seconds, the western approach of 12 seconds, and the northern approach of 10 seconds. Transyt software modeling of the RSUD Sayyidiman intersection after isolated optimization on the eastern approach with a traffic flow of 390 pcu/hour and a capacity of 3,006 pcu/hour yielded figures of 46% and 4.64 pcu, meaning the degree of saturation on the eastern approach was 0.46 and the queue was 4.64 pcu, as was the case for the other approaches. The highest degree of saturation is on the eastern approach with 0.49, the highest queue length is on the eastern approach with 20.62 meters, and the highest delay is on the northern approach with 20.50 seconds/pcu shown in Fig 6 (b). Signal phase data and modeling results indicate that optimal cycle timing improves performance on several approaches, characterized by reduced saturation and queue lengths. Further action is needed to assess the long-term effectiveness of this signal arrangement on daily traffic patterns and peak loads, and to evaluate the possibility of integrating coordination between intersections to improve network mobility efficiency. These findings support the development of a more efficient and sustainable urban transportation system through data- and technology-driven traffic management.

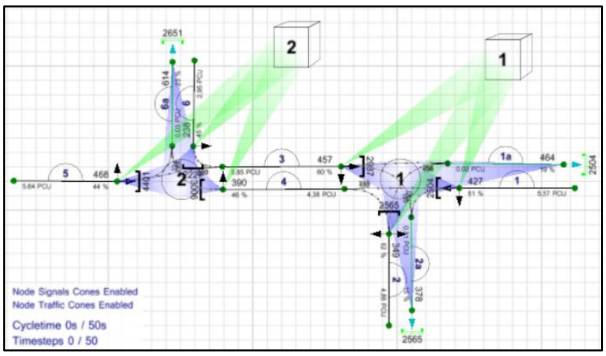


Figure 7. Optimization coordination of the Stadion intersection and RSUD Sayyidiman intersection in the network diagram.

DOI: 10.14710/pwk.v22i2.82082

Coordinated intersection modeling on the eastern approach of the Stadion intersection for the entry direction to the intersection with a traffic flow of 427 pcu/hour and a capacity of 2504 pcu/hour produces figures of 61% and 5.57 pcu which means the degree of saturation in the eastern approach is 0.61 and the queue is 5.57 pcu as well as in other approaches shown in Fig 7. The network diagram of the coordinated intersection between the Stadion intersection and the RSUD Sayyidiman intersection is made according to existing conditions where the input data includes saturation flow, traffic flow, speed, track length, phase and cycle time. This is expected to create a green wave where vehicles can pass through several intersections without stopping, thereby reducing delays, queues, and fuel consumption. Possible follow-up actions include a long-term evaluation of the performance of this coordination, including travel time between intersections, its impact on emissions, and road user satisfaction. In addition, this coordination approach can be extended to other intersections in the same corridor to form a more optimal integrated traffic network and support the development of sustainable urban transportation.

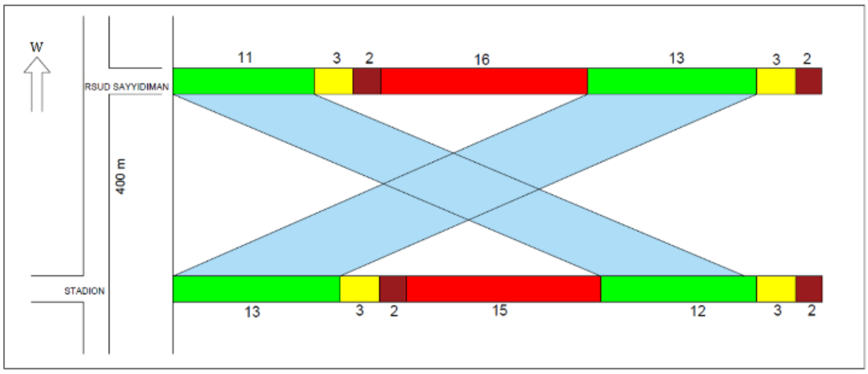
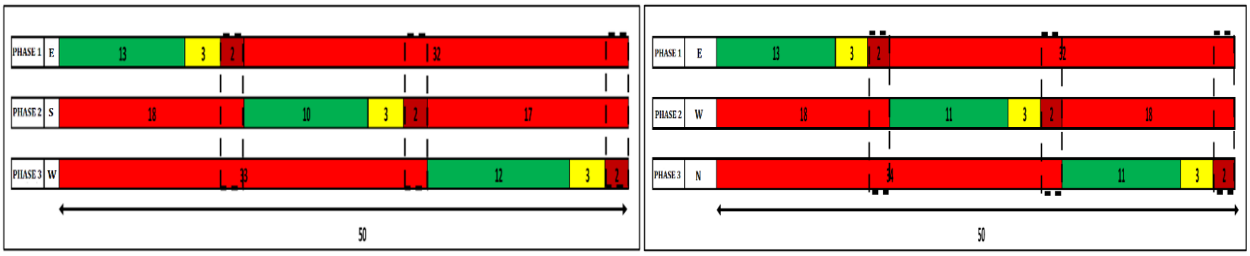


Figure 8. Coordination intersection diagram between the Stadion intersection and the RSUD Sayyidiman intersection

Fig. 8 shows the visualization of vehicle movement from west to east and from east to west. At the two intersections, it can be explained that the platoon of vehicles or convoy of vehicles that get the green phase at the first intersection, and when moving again will get the green phase at the next intersection, so that this condition can reduce the value of delays and queues of vehicles at the intersection and accelerate the speed of traffic on the coordinated road section. The offset obtained from west to east at the coordination intersection is above 33 seconds and has a bandwidth of 11 seconds. Meanwhile, the offset obtained from east to west is 32 seconds and has a bandwidth of 13 seconds. After knowing the offset and bandwidth between the Stadion intersection and the RSUD Sayyidiman intersection, the results of the intersection performance are obtained in the form of the latest coordination time management data which has a cycle time at the Stadion intersection of 50 seconds with a green time on the east approach of 13 seconds, a south approach of 10 seconds and a west approach of 12 seconds, with a green time lost of 15 seconds.

The effectiveness of intersection coordination through the platoon progression concept where vehicles passing the first intersection in the green phase will continue their journey and still get the green phase at the next intersection. This creates a smoother traffic flow, reduces delays and queue lengths, and increases the efficiency of vehicle movement. The follow-up to this narrative is to evaluate the long-term performance of the offset and bandwidth settings, as well as refine cycle time and lost green time management to further increase efficiency. In addition, these results can be used as a basis for formulating policies to widen the coordination corridor to other adjacent intersections to realize a broader integrated traffic system in supporting sustainable urban mobility.



(a) (b)

Figure 9. Cycle time diagram after coordination at the Stadion intersection (a) and RSUD Sayyidiman intersection (b)

The saturation degree value at each approach from the Stadion intersection after coordination using the transyt software can be seen that the highest saturation degree is at the southern approach with a saturation degree of 0.62, the highest delay is at the southern approach with a delay of 22.73 sec/pcu, the highest queue length is at the western approach with 23.4 meters shown in Fig 9 (a). This data is crucial for identifying critical points requiring further action, such as signal timing reconfiguration, phase changes, or increased lane capacity. Further action is needed to analyze the southern and western approaches at the Stadion intersection to identify the root causes of the high saturation, delays, and queues. The results of this analysis can then be used to design performance improvement strategies, either through micro-traffic engineering, such as adjusting green times, or physical interventions, such as lane widening or optimizing traffic management during peak hours.

Cycle time and phase time data for each approach from the RSUD Sayyidiman intersection after coordination can be seen that the latest coordination time setting data has a cycle time of 50 seconds with a green time on the east approach of 13 seconds, a west approach of 11 seconds and a north approach of 11 seconds, with a green time lost of 15 seconds shown in Fig 9 (b). The performance of the RSUD Sayyidiman intersection after coordination can be seen that the highest degree of saturation is on the east approach with 0.46, the highest queue length is on the east approach with 19.46 meters, and the highest delay is on the north approach with 18.88 sec/pcu. The data shows that despite coordination, the eastern and northern approaches still show relatively lower performance, characterized by the highest degree of saturation, the longest queues, and the greatest delays. Further analysis of the distribution of green times between approaches is needed to determine whether the current time allocation aligns with the actual traffic flow. Furthermore, additional simulations or readjustment of signal settings are needed to balance overall intersection performance and ensure that coordination between intersections optimally impacts traffic efficiency.

Table 3. Comparison of intersection performance at the Stadion and RSUD Sayyidiman intersection under existing, optimized, and coordinated conditions

Intersection	Approach	Degree of Saturation			Queue Length (meters)			Delay (seconds/pcu)		
		Existing	Optimization	Coordination	Existing	Optimization	Coordination	Existing	Optimization	Coordination
Stadion	E	0,62	0,59	0,61	31,92	25,44	20,68	27,49	21,62	19,6
	S	0,55	0,57	0,62	28,67	24,08	21,6	27,47	23,83	22,73
	W	0,57	0,57	0,6	32,96	26,92	23,4	25,72	21,58	21,25
RSUD Sayyidiman	E	0,45	0,46	0,46	26,36	20,62	19,46	20,93	16,75	16,89
	W	0,44	0,41	0,44	16,27	12,15	12,53	22,51	16,43	17,53
	N	0,44	0,49	0,45	15,24	12,28	11,8	23,82	20,5	18,88

Based on Table 3, it is known that the existing level of service at the Stadion intersection has an average delay of 26.89 seconds/pcu. After coordination, the average delay at the Stadion intersection is 21.19

seconds/pcu. The delay at the Stadion intersection decreased by 21.19%. Meanwhile, the existing level of service at the RSUD Sayyidiman intersection has an average delay of 22.42 seconds/pcu. After coordination, the average delay at the intersection is 17.76 seconds/pcu. The delay at the RSUD Sayyidiman intersection decreased by 20.79%. This data details the improvement in traffic performance after signal coordination at two major intersections, the Stadion intersection and the RSUD Sayyidiman intersection. Prior to the coordination, the Stadion Intersection had an average delay of 26.89 seconds/pcu, indicating a moderate to heavy traffic service level. After the coordination, the average delay decreased to 21.19 seconds/pcu, a 21.19% reduction, reflecting a significant increase in traffic efficiency. A similar trend occurred at the RSUD Sayyidiman intersection, where the average delay decreased from 22.42 seconds/pcu to 17.76 seconds/pcu, a 20.79% reduction. This decrease in delay indicates that the coordinated signal timings were able to create smoother traffic flow and reduce vehicle waiting times at both intersections, thereby overall improving the level of service and efficiency of vehicle movement in the coordinated corridor. The follow-up to this analysis data is the need for permanent implementation of the traffic signal coordination system at the Stadion Intersection and the RSUD Sayyidiman intersection, as well as regular monitoring to maintain the efficiency that has been achieved. The average delay reduction of 21.19% and 20.79%, respectively, indicates that signal coordination has proven effective in improving intersection performance and speeding up vehicle travel times. An important role of this data is as a basis for decision-making for the implementation of technology-based traffic management in strategic corridors, which can reduce congestion, vehicle emissions, and improve road user comfort. In addition, these results also serve as a reference in sustainable transportation planning in urban areas.

The main findings of this study indicate that intersection coordination can improve the efficiency of urban mobility by improving traffic performance in interconnected corridors. The analysis shows that after signal coordination, there was a significant decrease in delays at both intersections, indicating reduced vehicle stopping time and improved traffic flow. The implementation of the green wave concept allows vehicles to move in a platoon manner without having to stop frequently at each intersection, thereby reducing queue lengths and improving intersection service levels. This study identified critical points at certain approaches, such as the south and west approaches at the Stadion Intersection and the east and north approaches at the RSUD Sayyidiman Intersection, which still require further adjustments in signal timing or other technical interventions. In the context of sustainable urban development, these findings make an important contribution by demonstrating that intersection coordination-based optimization impacts transportation engineering (Ding et al., 2026), energy efficiency (Z. Shen et al., 2026), and environmental quality (Boontaveeyuwat & Wongwai, 2025) (Yasa et al., 2024). Reducing delays and repeated vehicle stops has direct implications for fuel consumption and exhaust emissions, thus supporting the principles of low-carbon mobility. Improved access to strategic areas such as office areas, government offices, and healthcare facilities also strengthens urban productivity and connectivity. This study confirms that intersection coordination is an effective and applicable strategy in supporting an efficient, environmentally friendly and sustainable urban transportation system.

The potential novelty generated in this study lies in the integration of the green wave-based intersection coordination concept with the approach of urban mobility efficiency and sustainable urban development within a comprehensive urban transportation analysis framework. This study is able to evaluate the technical performance of intersections through indicators of saturation degree, delay, and queue length, and demonstrates how signal coordination between interconnected intersections can improve the efficiency of vehicle movement in the urban corridor as a whole. This study's important contribution to urban mobility efficiency is seen in the ability of signal coordination to create a more continuous vehicle flow, reduce repeated stops at intersections, speed up travel times, and improve the level of service of the road network. This study is able to make a real contribution to sustainable urban development by showing that reducing delays and queues has a direct impact on energy efficiency, reduced fuel consumption, and reduced vehicle emissions, thus supporting the concept of low-carbon mobility and environmentally friendly transportation. This study strengthens previous studies by presenting empirical evidence that intersection coordination can be an effective strategy to improve the connectivity of strategic areas in urban areas such as government centers, offices, and health facilities. This study contributes as a data and technology based urban traffic management model that can improve transportation performance and support the creation of more efficient, productive, and sustainable cities.

4. CONCLUSION

The study results show that intersection coordination can improve the efficiency of urban mobility by reducing delays and queues on interconnected road corridors. Integrated signal cycle timing and phases create a more orderly vehicle movement pattern through the green wave concept, allowing vehicles to move more smoothly with fewer obstacles. The practical implications of these findings play a significant role in traffic management and urban transportation planning because intersection coordination can be an effective strategy to improve road service levels, reduce fuel consumption, suppress vehicle emissions, and support connectivity to strategic areas. In the context of sustainable development, the results of this study indicate that optimizing intersection control systems has an impact on improving transportation performance and supporting the creation of a more efficient, environmentally friendly, and sustainable urban mobility system. Further research is recommended to develop intersection coordination based on adaptive systems or intelligent transportation systems, considering long term traffic growth, and integrating emission and energy consumption analyses to obtain a more comprehensive urban transportation management model.

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