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Management of Traffic Problems Using 4-Phase Modeling with Time Setting Design Using Python

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ABSTRACT : This research examines the application of a 4-phase traffic management model using Python-based simulation software to optimize traffic flow. The study focuses on the Sukomoro intersection in Magetan Regency, which currently operates under a 3-phase traffic light system. A comprehensive methodology is employed, incorporating traffic data analysis, simulation modeling, and performance evaluation. Findings reveal that with a total capacity of 1.800 pcu/hour and a vehicle flow (Qsmp) of 1.600 pcu/hour, the intersection operates at a saturation degree (DS) of 0.89, indicating it is nearing maximum capacity. The analysis further identifies a geometric delay (DG) of 6.23 seconds per vehicle and a traffic delay (DT) of 7 seconds per vehicle, resulting in a total delay of 13.23 seconds per vehicle. The implementation of adaptive signal control and intersection synchronization demonstrates the potential to enhance capacity by up to 25%. To optimize intersection performance, the study suggests an integrated traffic management approach, including adaptive signal control, inter-intersection synchronization, and dedicated scheduling for heavy vehicles.

Keywords - Traffic Management, 4-Phase Modeling, Python Simulation, Intersection Capacity, Signal Control Optimization

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1. INTRODUCTION

Managing traffic in urban areas is becoming increasingly complex, especially in developing regions experiencing rapid motorization [1]. Magetan Regency, in particular, has seen a significant rise in the number of motor vehicles in recent years, directly contributing to greater traffic challenges, such as congestion and increased accident rates [2]. Several studies have explored different aspects of traffic management in Indonesia, including traffic density analysis based on traffic light regulations at intersections in Kediri City [3], traffic management in the Central Business District (CBD) of Tegal City [4], and the enforcement of traffic safety regulations nationwide [5].

Harahap et al. [6] stated that the simulation method functions as an important foundation in the field of traffic signal timing design. This refers to extensive efforts to improve traffic conditions, especially to optimize traffic flow and minimize congestion [7], [8].

One effective approach to tackling the complexity of traffic management is the use of simulation technology [9]–[12]. Various studies have explored its application in transportation, including VANETs modeling and simulation to improve transportation management systems [13], the development of daily employee travel simulation models to optimize departure times [14], and the use of digital maps for Smart Village initiatives [15]. Additionally, simulation technology plays a key role in traffic performance analysis, such as dynamic system simulation models for assessing congestion in port areas [16], micro-simulation techniques for evaluating the impact of vehicle type restrictions on road performance [17], and load-balancing strategies for alleviating traffic congestion [18].

Simulation software, particularly Python-based modeling tools, offers significant advantages in terms of time and cost efficiency. Furthermore, it enables high-precision traffic performance analysis, as shown in studies utilizing the 1997 MKJI method and PTV Vissim Microsimulation software [19].

A major benefit of simulation technology is its ability to assess traffic management strategies without interfering with real-world traffic flow [20]. By testing various control measures in a virtual environment, transportation authorities can evaluate their effectiveness before implementation, reducing the risk of resource misallocation and inefficient decision-making.

An accurate simulation model allows the Transportation Department to analyze different traffic scenarios without physical risks [21]–[24], helping them plan infrastructure improvements, regulate traffic flow, and optimize routes more effectively [25]. This, in turn, enhances both mobility and safety.

Currently, the Magetan Regency Transportation Department is addressing traffic issues at the Sukomoro intersection on the provincial road in Magetan Regency. The intersection operates on a 3-phase traffic light system, where red and green lights simultaneously control traffic from the north and south directions. Due to heavy congestion during specific hours, a transition to a 4-phase system is being considered for improved traffic management.

2. METHODS

This study adopts a comprehensive methodological approach that integrates traffic management analysis with software development techniques. The methodology is designed to address both the theoretical foundations of traffic management and the practical implementation of a Python-based simulation system.

The first phase involves identifying and analyzing traffic management challenges across different locations. This includes assessing complex factors such as congestion patterns, pollution levels, and overall traffic efficiency. Additionally, the analysis considers the broader aspects of urban mobility and sustainable development, highlighting the critical relationship between traffic management and urban quality of life.

After identifying key issues, the methodology moves to the design and development of a 4-phase traffic management model. This phase includes detailed planning, implementation procedures, monitoring mechanisms, and evaluation methods to ensure effective traffic regulation. Figure 1 shows Sukomoro Intersection.

Figure 1 Sukomoro Intersection

The model is specifically developed to tackle the unique challenges observed at the Sukomoro intersection, taking into account both current traffic patterns and anticipated future demands. Its core technical aspect involves creating a Python-based simulation model, selected for its adaptability and capability to process complex traffic scenarios.

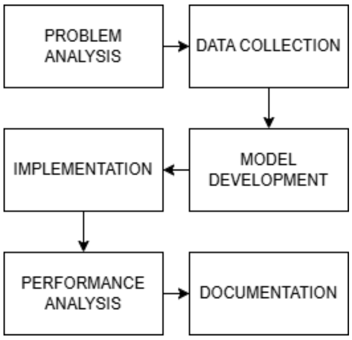

Figure 2 Methodology Diagram

Figure 2 shows methodology diagram used in this case study. Data collection and analysis play a vital role in the research methodology. This study utilizes both primary data—such as traffic volumes, vehicle classifications, and queue lengths—and secondary data, including historical traffic trends and existing signal timings. A systematic analysis of this data helps identify traffic patterns and optimize signal timing parameters.

The implementation phase focuses on translating the theoretical model into practical applications. This involves developing timing algorithms, testing different traffic scenarios, and fine-tuning the system based on real-world conditions. Additionally, the methodology includes continuous evaluation and adjustment procedures to ensure optimal system performance.

The final phase involves results analysis and evaluation. This includes comparing traffic conditions before and after implementation, assessing performance improvements, and examining the broader impact on urban mobility. The study also outlines recommendations for future enhancements and system upgrades.

Throughout the research process, a strong emphasis is placed on documentation and adherence to academic standards. This includes systematically recording experimental procedures, data analysis methods, and implementation strategies. The methodology concludes with a comprehensive assessment of the system's contributions to both theoretical insights and practical traffic management solutions.

By integrating theoretical frameworks with real-world implementation strategies, this methodological approach ensures a systematic and rigorous investigation of traffic management improvements while maintaining both scientific integrity and practical relevance.

3. RESULT AND DISCUSSION

The Python-based intersection modeling approach developed in this study introduces an innovative computational simulation framework for traffic management analysis. Utilizing the SimPy library, the model creates a dynamic simulation environment that accurately represents the complex interactions between vehicle movements and traffic signal operations.

3.1 Data Collection

Key parameters, including vehicle arrival rates, signal timing durations, and lane configurations, are integrated to generate realistic traffic flow scenarios. By employing stochastic modeling techniques, the program simulates vehicle arrivals using an exponential distribution, effectively replicating real-world traffic patterns across four intersection lanes.

At the core of the model are advanced functions for vehicle arrival, traffic flow management, and signal control, enabling researchers to monitor critical performance indicators such as wait times, queue lengths, and intersection throughput. This computational approach offers flexibility in adjusting parameters, supports scalable analysis, and lays the groundwork for developing advanced traffic management strategies.

3.2 Simulation Model Development

Notable innovations include the ability to simulate various signal timing scenarios, assess intersection capacity, and explore the potential integration of machine learning techniques for adaptive traffic control in the future.

While the current model has certain limitations—such as assuming uniform vehicle types and employing simplified geometric representations—it serves as a powerful computational tool for analyzing and optimizing urban traffic dynamics. This study highlights the potential of Python-based simulation in addressing complex transportation management challenges. Figure 3 shows two intersection simulation program.

Figure 3 Two Intersection Simulation Program

3.3 Traffic Management Parameter Calculation

The capacity analysis of the Sukomoro Intersection provided key insights into its traffic dynamics, as summarized in Table 1. With a total capacity of 1.800 smp/vehicles per hour and an actual traffic flow of 1.600 smp/vehicles per hour, the intersection operates at a Saturation Degree (DS) of 0.89, indicating it is nearing its maximum operational limit.

A DS value of 0.89 is a critical threshold in traffic management, signifying that the intersection is functioning very close to full capacity while maintaining a fragile equilibrium in traffic flow. This finding is particularly significant as it underscores the intersection’s susceptibility to congestion. Even a slight increase in vehicle volume could lead to major traffic disruptions, emphasizing the need for proactive management strategies.

Table 1 Capacity Intersection Parameter

Parameter	Value	Unit	Description
Total Capacity	1.800	vehicles/hour	Maximum capacity of intersections
Vehicle Flow	1.600	vehicles/hour	Actual traffic volume
Degree of Saturation (DS)	0.89	-	Level of approach to maximum capacity
Effective Road Width	5.5	meters	Width of effective lane

The delay analysis (Table 2) offers valuable insights into the intersection’s operational efficiency. The total delay per vehicle is recorded at 13.23 seconds, comprising 6.23 seconds of Geometric Delay (DG) and 7 seconds of Traffic Delay (DT).

A notable finding is the high proportion of heavy vehicles, which make up 70% of the total traffic volume. This significant presence of trucks and buses greatly affects traffic flow, leading to increased delays and reduced road capacity. Heavy vehicles require longer acceleration, deceleration, and maneuvering times, directly impacting overall traffic performance and contributing to congestion.

Table 2 Vehicle Delay Analysis

Delay Type	Duration	Unit	Main Contributor
Geometric Delay (DG)	6.23	seconds/vehicle	Road geometry design
Traffic Delay (DT)	7.00	seconds/vehicle	Traffic flow
Total Delay	13.23	seconds/vehicle	Geometry and traffic flow
Heavy Vehicle Proportion	0.7	-	70% trucks/buses

The queue probability analysis (Table 3) provides key insights into potential traffic congestion. Based on the MKJI 1997 methodology, there is a 75% likelihood of queue formation, indicating that three out of four signal cycles are expected to result in vehicle queues. This high probability significantly increases the risk of traffic buildup, especially during peak hours.

These findings highlight the urgent need for advanced traffic management strategies that extend beyond conventional signal timing adjustments to effectively mitigate congestion and improve traffic flow.

Table 3 Queue Probability

Parameter	Value	Description
Queue Probability	75%	Based on the MKJI 1997 curve
Signal Cycle with Queueing	3 of 4	Likelihood of queue formation

The four-phase signal timing design was developed as an innovative solution to the complex traffic management challenges at the Sukomoro Intersection. With an initial cycle time carefully set at 42 seconds, the design strategically distributes green times across different phases—14 seconds for the vertical phase and 10.5 seconds for the horizontal phase—while accounting for a total lost time of 7 seconds. This advanced approach goes beyond traditional static signal timing methods, introducing a more dynamic and adaptive traffic management strategy.

A key factor in achieving this precision was the use of Python-based modeling, which enabled researchers to optimize signal timing through comprehensive computational simulations. By leveraging advanced computational techniques, the research team was able to simulate and analyze multiple traffic scenarios, ensuring a more responsive and efficient signal timing strategy.

The carefully allocated green times and well-managed lost time reflect a data-driven approach to intersection management, aiming to reduce congestion, minimize vehicle delays, and enhance overall traffic efficiency. This methodological innovation underscores the potential of computational modeling in revolutionizing urban traffic management, offering a flexible and intelligent framework to address the complexities of intersection traffic flow.

Table 4 Signal Timing Parameters

Parameter	Vertical Phase	Horizontal Phase
Green Time	14 seconds	10.5 seconds
Flow Ratio (PRI)	0.4	0.3

The vehicle composition at the Sukomoro Intersection exhibits a distinctive pattern, with heavy vehicles (trucks and buses) accounting for 70% of the traffic flow, while light vehicles make up only 30%. This imbalance has a significant impact on traffic dynamics, posing considerable challenges to intersection efficiency.

Heavy vehicles inherently reduce road capacity, require longer stopping distances, and take more time to accelerate and maneuver, leading to slower traffic flow and a higher risk of congestion. Given their dominant presence, an adaptive traffic management approach is essential. Implementing specialized strategies that accommodate the unique movement characteristics of heavy vehicles can help minimize disruptions and enhance overall intersection performance.

Table 5 Cycle Time and Lost Time

Parameter	Value	Unit
Initial Cycle Time (Cua)	42	seconds
Total Lost Time (LTI)	7	seconds
Start Loss	3	seconds
End Gain	4	seconds

The Python-based software modeling approach has proven to be a powerful computational tool for advanced traffic management, offering unprecedented capabilities in urban transportation analysis. By enabling comprehensive virtual scenario testing, the model provides effective risk mitigation strategies, allowing transportation planners to simulate complex traffic conditions without the risks associated with real-world implementation.

3.4 Simulation Model Analysis

This data-driven decision-making framework transforms traditional traffic management by leveraging computational power to analyze intricate traffic patterns. Additionally, its adaptive signal timing strategies mark a significant technological advancement in intersection optimization. This innovative modeling technique highlights how sophisticated computational methods can revolutionize the understanding and management of urban traffic systems, offering a flexible and intelligent framework for tackling complex transportation challenges.

3.5 Analysis of 4-Phase Implementation in Handling Traffic Management Problems

This research introduces a comprehensive, multi-faceted approach to traffic management, designed to tackle the complex challenges at the Sukomoro Intersection through innovative technological strategies.

The first strategy involves adaptive signal control using Intelligent Traffic System (ITS) technologies, which can dynamically adjust to real-time traffic conditions and potentially increase intersection capacity by up to 25%. The second approach focuses on inter-intersection synchronization through Green Wave Technology, improving traffic efficiency by approximately 15% by optimizing signal coordination across multiple intersections. The third strategy addresses the significant impact of heavy vehicles by proposing dedicated scheduling and specialized lane configurations, which could reduce traffic delays by 20-25%.

These integrated solutions leverage computational modeling, intelligent traffic systems, and strategic infrastructure planning to enhance urban traffic flow and significantly improve overall intersection performance.

4. CONCLUSION

The analysis confirms that intersection capacity is significantly affected by factors such as the degree of saturation (DS), traffic delays, queue probabilities, and signal efficiency. With a total capacity of 1,800 vehicles per hour and an actual traffic flow of 1,600 vehicles per hour, the DS value of 0.89 indicates that the intersection is operating near its maximum limit, highlighting the urgent need for effective traffic management to prevent congestion.

Key findings include a total delay of 13.23 seconds per vehicle, which is particularly concerning during peak hours, and a 75% probability of queue formation, emphasizing the necessity of optimized signal control. Implementing adaptive signal systems and synchronizing traffic signals could potentially increase capacity by up to 25% and reduce waiting times.

To enhance intersection efficiency and safety as traffic volumes continue to grow, recommended improvements include investing in advanced technology and infrastructure, educating road users, conducting regular performance evaluations, fostering collaboration among stakeholders, and utilizing real-time data for informed decision-making. These measures will contribute to a more efficient and sustainable traffic management system.

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