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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Assessing Signalization Effects on Mixed-Traffic Intersection Performance through Data Analysis and Microsimulation Approaches: A Case Study in East Lombok, Indonesia

Amelia Nurul Damayanti

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Transport Policy and Planning

SUPERVISOR :
Prof. dr. ir. Ansar-Ul-Haque YASAR

MENTOR :
dr. Dimitrios ZAVANTIS

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PREFACE

Throughout my Master's studies in Transportation Sciences at Hasselt University, I have had the opportunity to engage with various disciplines that expanded my understanding of transportation systems and infrastructure. These studies offered a foundation in areas such as transportation planning, road safety, human behavior analysis, technological trends, transportation approach methods, all of which raised my analytical skills and sparked my curiosity.

The efficient management of at-grade intersections is one of the most persistent problems in expanding urban and semi-urban areas, especially in areas with mixed traffic conditions like Indonesia. For example, the Masbagik intersection in East Lombok is a crucial hub for the local road system and has been known to encounter this congestion and delays, especially during rush hour. This observation sparked interest in analyzing its current operational state quantitatively and determining the possible effects of applying common traffic engineering interventions.

In this thesis, we will explore about this topic. This study conducts a thorough performance analysis of the Masbagik intersection with the assistance of my mentor, dr. Dimitrios Zavantis, and my supervisor, Prof. dr. Ansar-Ul-Haque Yasar. It compares a suggested fixed-time signalized control strategy with its existing unsignalized operational characteristics. Both well-established analytical methods, based on the Pedoman Kapasitas Jalan Indonesia (PKJI) 2023, and in-depth microsimulation using PTV VISSIM are used in this study. Locally customized driving behavior parameters are included to reflect the unique traffic composition, which includes a high motorcycle prevalence. My hope is that this study can contributes to a better understanding of intersection control in mixed-traffic environments and provides a data-driven basis for traffic management decisions in East Lombok.

I extend my sincere gratitude to Prof. dr. Ansar-Ul-Haque Yasar for his invaluable guidance and encouragement throughout this research process. My deepest thanks also go to dr. Dimitrios Zavantis for his insightful feedback and support. I am also grateful to Hasselt University for providing the academic environment and resources that made this study possible. Finally, I would like to express my deepest gratitude to my mother, my father, my partner, and my brother. Their unwavering support, encouragement, and belief have been my greatest motivation. Their support has made this achievement more meaningful.

SUMMARY

Urban intersections in developing country frequently experience poor traffic control, high vehicle congestion, and safety issues, especially in places where there is mixed traffic, including motorcycles, light vehicles, heavy vehicles, and pedestrians. The Masbagik intersection in East Lombok, Indonesia, is one of these intersections that faces these challenges. This research was conducted to evaluate whether implementing a fixed-time traffic signal could improve operational performance at this location and to examine the potential for future adoption of smart traffic systems, such as IoT-based signal control.

To achieve these goals, this study using a mixed methodology, combining data analytical techniques using the Indonesian Road Capacity Guidelines or Pedoman Kapasitas Jalan Indonesia (PKJI - 2023) in Bahasa Indonesia, with traffic simulation by PTV VISSIM. The key performance indicators like Level of Service (LoS), delay, and degree of saturation were calculated using the analytical component. The VISSIM simulation helped visualize interactions in both unsignalized and signalized (before and after) scenarios by simulating real-world traffic dynamics.

From the findings, it shows that the implementation of the proposed fixed-time traffic signal system improved traffic flow, reduced average vehicle delay, and provided safer crossing opportunities for pedestrians. Both analytical and simulation results confirmed that a structured signal plan improves overall intersection performance. The study also included a public perception survey, which revealed community support for intelligent traffic management solutions, despite limited awareness of Intelligent Traffic System (ITS), Internet of Things (IoT)-based system.

With the help of infrastructure improvements, this study offers the local government official actionable suggestions for implementing fixed-time signalization as an intervention. Additionally, promotes the use of smart traffic systems in the future, by emphasizing the value of preparing for them through data-driven planning, community involvement, and institutional coordination.

In conclusion, the proposed fixed-time signal plan offers a practical solution that can improve traffic efficiency and safety at the Masbagik intersection. Moreover, this study establishes a foundation for future integration of intelligent traffic solutions in similar mixed-traffic settings in Indonesia and other developing countries.

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INTRODUCTION

The concept of a transportation system is an interconnected set of connections between nodes, networks, and demand. They are emphasized as an important and practical part of human activity, social-economic connections, and economic growth. Movements of people, products, and information rise as societies modernize and change between various types of transportation. Although these changes positively impact economic growth, they also have several adverse effects on people and societies, including increased traffic, accidents, noise, the environment take, energy use, air pollution, and carbon dioxide (CO2) emissions. This creates major challenges for the system, making it difficult for transportation experts to maintain efficacy and efficiency.

Road Infrastructure management is a challenging problem that presents major difficulties for all governments and transportation organizations. The issue is caused by the rising need for transportation systems that are effective, safe, and sustainable, which necessitates effective management and control of road networks. However, achieving the best control and management of road infrastructure, especially at intersections, can be difficult due to a lack of resources, inadequate infrastructure, and the complexity of the transportation ecosystem. As a result, there are several issues that arise, including resource inefficiency, traffic congestion, and accidents. There are three types of transport policies: infrastructure investments, price instruments, and regulations (Berg et al., 2017). A vital part of running effective transportation networks is infrastructure. Supporting infrastructure improvements, such as constructing modal interchanges or extending the metro network, can improve the experience of users of public transportation while lowering operational costs for businesses (Vasallo & Bueno, 2019).

In many parts of Indonesia, including provincial and regency-level urban centers like in East Lombok, West Nusa Tenggara, intersections often evolve from simple uncontrolled crossings to points requiring more structured management as traffic volumes increase. The transition from an unsignalized state to a signalized one is a common intervention aimed at mitigating operational inefficiencies and enhancing safety. However, the effectiveness of such intervention depends on a realistic assessment of its possible effects, meticulous design of the signalization plan based on established engineering principles, and a deep comprehension of the traffic conditions that currently exist.

This thesis research study will focus on precisely such an assessment. It investigates the Masbagik intersection, a key junction in East Lombok, which currently operates as an unsignalized intersection and faces the operational difficulties brought on by mixed traffic and rising demand. The main goal of this study is to measure the intersection's current performance before carefully assessing the possible operational effects of installing a traffic signalization system.

To achieve this, the study employs a dual methodological approach. Firstly, we will evaluate the performance of the current unsignalized state and suggest a signalized design using well-established Indonesian Road Capacity Guidelines, namely the Pedoman Kapasitas Jalan Indonesia (PKJI) 2023. Second, we make model the intersection's operations more dynamically by using PTV VISSIM, a microsimulation program. Adapting driving behavior parameters to local Indonesian conditions, with a focus on the high motorcycle traffic, is an essential part of the simulation modelling process. This study attempts to give a thorough understanding of the possible advantages and difficulties related to signalizing the Masbagik intersection by examining the result from these analytical and simulation approaches. The findings are meant to offer data-driven insights that can help guide local traffic management choices and add to the broader knowledge about intersection control in comparable mixed-traffic environments.

Table 1. Key Challenges

Challenges	Potential Instruments
Infrastructure	• Inability to meet the increasing demands of growing traffic volumes. • Deterioration of roads and related structures beyond their intended lifespan.
Maintenance practices	• Financial constraints prevent prompt restoration. • Insufficient resources for regular inspection and maintenance activities.
Monitoring	• Limited availability and quality of data on road conditions and performance. • Lack of comprehensive systems for continuous monitoring and evaluation of road infrastructure. • Inconsistent data collection methodologies across regions or authorities.
Environment	• Increased vulnerability of road infrastructure to extreme weather.
Safety concern	• Inefficient traffic management systems. • Inadequate road signage, markings, lighting, etc. • Insufficient cyclist and pedestrian infrastructure.
Technological advancement	• Limited integration of data analytics, Internet of Things (IoT), and artificial intelligence (AI) for efficient predictive maintenance. • Slow adoption of emerging technologies for monitoring and infrastructure management.
Lack of coordination	• Limited coordination between government, local authorities, and private agencies. • Challenges in aligning priorities and policies for effective development.

Background

Traffic management involves organizing the flow of vehicles and pedestrians within the transportation system of a specific area or region. The main objective is to promote smooth, safe, and efficient travel on roads. Roads are vital in transportation sector as they facilitate daily access and movement. When more people travel to the exact location at the same time, issues such as congestion, pollution, accidents, and elevated transportation costs will arise, representing frequent challenges in daily transportation.

Current Road Infrastructure in East Lombok Regency

The road network in East Lombok Regency is categorized based on its status into national roads, provincial roads, and regency roads, and by function into primary arterial roads, primary collector roads, and primary and secondary local roads. Most roads in East Lombok, whether national, provincial, or regency roads, have a 2/2 UD (two lanes, two ways, undivided) configuration. Some provincial roads feature a 4/2 UD (four lanes, two ways, undivided) configuration, and others operate as one-way roads (2/1). Intersection control in the region includes signalized intersections, priority intersections, and uncontrolled intersections (Kusumajati, 2023).

Road Traffic Accidents in East Lombok Regency

The high number of traffic accidents in East Lombok Regency is influenced by several factors, such as human behavior, inadequate infrastructure and lack of traffic control systems, which pose a threat to public safety and mobility. Based on official data from the Traffic Unit of the East Lombok Police Department (Satlantas Polres Kabupaten Lombok Timur), the region continues to experience a high number of road traffic accidents. Over the past five years (2018 - 2022), traffic accidents have resulted in numerous fatalities, serious injuries, and minor injuries.

Table 2. Road Traffic Accident in East Lombok Regency (Year 2018 – 2022)

Year	Number of Accident	Severity Level		
		Fatalities	Serious Injuries	Minor Injuries
2018	388	115	3	458
2019	384	114	3	397
2020	241	86	3	232
2021	281	79	11	292
2022	260	63	2	280
Total	1554	457	22	1659

Source: Traffic Unit of the East Lombok Police Department

Over the five-year period from 2018 to 2022, there were a total of 1.554 recorded traffic accidents in East Lombok. The year 2018 recorded the highest number of accidents, with 388 accidents, followed closely by 2019 with 384 accidents. In these periods, there was the highest number of fatalities, with 115 deaths in 2018 and 114 deaths in 2019. In total, the five-year period accounted for 457 deaths, 22 serious injuries, and 1.659 minor injuries. Notably, while the total number of accidents slightly decreased in the later years, the material losses did not show a consistent downward trend.

Table 3. Monthly Traffic Accident Data in East Lombok (Year 2018 – 2022)

Month	2018	2019	2020	2021	2022	Total
January	41	46	23	14	27	151
February	20	36	22	15	21	114
March	21	41	31	27	22	142
April	32	37	18	28	22	137
May	41	37	24	28	38	168
June	31	37	27	20	23	138
July	43	31	18	27	33	152
August	30	33	13	26	43	145
September	35	23	15	20	28	121
October	28	24	18	30	3	103
November	29	24	17	23	0	93
December	37	15	15	23	0	90
Total	388	384	241	281	260	1554

Source: Traffic Unit of the East Lombok Police Department

When analyzing the distribution of accidents by month, it becomes clear that certain periods are more accident-prone than others. Between 2018 and 2022, the month with the highest combined accident total was May, followed by January and July. This suggests that early and mid-year months coincide with high travel activity, possibly due to holidays, school schedules, or agricultural and market cycles in East Lombok.

Table 4. Accident Data by the Time of Day in East Lombok (Year 2018 – 2022)

Time	2018	2019	2020	2021	2022	Total
00.00 - 06.00	17	17	8	28	32	102
06.01 - 12.00	109	123	75	103	91	501
12.01 - 18.00	141	147	88	102	88	566
18.01 - 23.59	121	97	70	48	49	385
Total	388	384	241	281	260	1554

Source: Traffic Unit of the East Lombok Police Department

The time-of day analysis provides further insight into when accidents are most likely to occur. From 2018 to 2022, the most dangerous time period was between 12:00 and 18:00, which accounted for the highest number of accident (576 cases). This was followed by the morning period between 06:00 and 12:00, which recorded 501 cases. The evening hours (18:00 – 23:59) has fewer accidents, while the lowest accident rate occurred during the early morning (00:00 – 06:00).

Table 5. Traffic Accidents by Age Group in East Lombok (Year 2018 – 2022)

Year	Age 0 - 9	Age 10 - 15	Age 16 - 30	Age 31 - 40	Age 41 - 50	Age 51+
2018	39	72	235	66	67	99
2019	46	44	180	78	73	93
2020	22	32	115	44	43	65
2021	24	38	135	57	50	78
2022	20	37	127	44	50	67
Total	151	223	792	289	283	402

Source: Traffic Unit of the East Lombok Police Department

Accident data from East Lombok from 2018 to 2022 also show a clear pattern in terms of the age groups most frequently involved in traffic accidents. The most common age group is 16 to 30, which had the highest number of traffic accident cases across all five years, with a total of 792 incidents. In comparison, older age groups (31 – 40 and 41 – 50) had significantly fewer cases (280 and 253, respectively). Several factors contribute to this trend. Individuals aged 16 to 30 are the most active users, whether commuting to school, work, or social activities, and are more likely to drive motorcycles or private vehicles.

Problem Statement

In this research, we will focus on the Masbagik Intersection in East Lombok, Indonesia. The Masbagik region serves as a key transit hub connecting various regions, including Central Lombok, West Lombok, and North Lombok. This national road facilities significant socio-economic activities, with commercial zones, religious landmark, and public services contributing to heavy traffic volumes. This area's strategic importance is reflected in its role as a gateway for goods and people, which is amplified by its geographic location and economic vitality. However, the road infrastructure in Masbagik area faces multiple challenges, including traffic congestion, road safety issues, and insufficient monitoring and maintenance systems. In addition, around the Masbagik Commercial Area, there is also an unsignalized intersection, with significant traffic conflicts and considerable delays for minor road users attempting to merge or cross. The high density of motorcycles, often showing flexible and assertive maneuvering, further complicates interactions and challenges conventional traffic flow assumptions.

Existing problems such as on-street parking, side friction due to commercial activities, and unregulated intersections disrupt traffic flow and create safety risks, particularly during peak hours. Current traffic management measures are reactive rather than proactive, leading to inefficiencies and lack of timely interventions. Addressing these operational and safety deficiencies is important for improving the local transportation system's effectiveness and supporting sustainable regional development. While advanced traffic management systems offer future potential, a foundational step often involves evaluating the impact of established control measures, such as fixed-time signalization, to bring order and improve safety at such critical junctions. In this study, we will address the problem of evaluating the transition from an unsignalized to a signalized state at a typical Indonesian mixed-traffic intersection.

In this specific area, we gathered the problem identification which will be mentioned below:

1. Traffic Congestion
   High traffic volumes in the Masbagik area are worsened by on-street parking near shops and mosques, which reduces the road capacity and disrupts the flow of vehicles. The lack of dedicated parking spaces worsens the congestion during peak hours.
2. Safety Concerns
   Safety risks are amplified at the Masbagik intersection, an uncontrolled four-way crossing. This intersection serves arterial, collector, and local roads and meets significant delays during peak hours. High side friction caused by mixed traffic (e.g., motorcycles, cars, and pedestrians) and inadequate traffic control measures increases the risk of accidents, particularly during peak hours.
3. Lack of Basic Traffic Control and Future Preparedness
   The Masbagik intersection currently lacks of even basic traffic signal control, resulting to inefficient traffic flow and safety concern. Furthermore, the absence of any advanced traffic management or monitoring systems means the intersection cannot adapt to changing traffic conditions or provide data for proactive management. While this study focuses on the foundational impact of fixed-time signalization, it also acknowledges the broader context where intelligent systems like IoT-based traffic control represent potential future improvements for optimizing performance beyond what fixed-time control can offer.

Objectives

The primary aim of this research is to evaluate and compare the operational performance of the Masbagik intersection in East Lombok under its current unsignalized condition versus a proposed signalized control strategy. This evaluation utilizes both established Indonesian analytical methods (using Indonesian Road Capacity Guidelines 2023 as we called it in short PKJI 2023) and detailed microsimulation. The objectives presented below seek to outline the specific aims of the research, which include the assessment of current practices, the investigation of potential applications, and the proposal of strategic recommendations for the effective adoption in enhancing road infrastructure resilience and sustainability.

1. Analyze the existing operational performance of the current unsignalized Masbagik intersection using PKJI 2023 (Chapter 6) methodology.

2. Develop and calibrate a PTV VISSIM microsimulation base model (scenario 1) that represents the existing traffic conditions at the unsignalized Masbagik intersections and using PKJI 2023 analytical results as calibration benchmarks.
3. Design a fixed-time traffic signal control plan for the Masbagik intersection in accordance with PKJI 2023 (Chapter 5) guidelines.
4. To evaluate and compare the operational performance of the Masbagik intersection in East Lombok under its current unsignalized condition versus a proposed signalized control strategy, with both analytical methods (PKJI 2023) and microsimulation (PTV VISSIM).
5. Identify the potential suitable application of IoT technologies for traffic management system.

Research Questions

To thoroughly evaluate the impact of implementing the proposed signalization system at the Masbagik intersection using both analytical and simulation approaches, the following main research question and several sub-questions intended to methodically break down the issue serve as the study's direction:

The main question:

1. What is the impact of implementing a fixed-time traffic signalization system at the currently unsignalized Masbagik intersection in East Lombok, considering local traffic conditions and driver behaviors when evaluated using Indonesian standard analytical methods and microsimulation methods?

The sub-questions:

2. How does the VISSIM microsimulation performance of the proposed signalized intersection compare to its analytically predicted performance in terms of delays and queue lengths?
3. What are the key differences in operational performance between the existing unsignalized Masbagik intersection and the proposed signalized traffic control system?
4. Based on the evaluation of the fixed-time signalization and findings from surveys, what are the practical recommendations for improving traffic management at the Masbagik intersection, and what is the perceived local readiness or potential for future consideration of more advanced traffic control systems like IoT-based solutions?

Research Method

This research describes the methods and systematic approach used to accomplish the research goals from previous section. The research aims to evaluate the impact of signalization on the performance of the Masbagik intersection in East Lombok, comparing its current state with a proposed signalized control strategy. Data collection through surveys, standardized Indonesian analytical techniques for evaluating intersection capacity and performance, and in-depth microsimulation modelling with PTV VISSIM were all part of the multifaceted strategy that was used.

Initially, the study will collect quantitative data from various governmental and public sources. This secondary data includes traffic flow statistics, accident data, road network map, and road and intersection performance, which will establish a baseline understanding of the current state of the road infrastructure. Analyzing these figures with Microsoft Excel will help us to organize and pre-process the necessary information from the data before feeding it into the simulation model. However, it is important to note that the reliability and accuracy of the results are determined by the quality of the collected data and the suitability of the statistical techniques used in the analysis (Wang et al., 2022).

Alongside quantitative analysis, we will conduct qualitative research by distributing questionnaires to a diverse group of Indonesian residents. These questionnaires aim to gather public perceptions of mixed traffic, road safety issues, and knowledge and acceptance of potential future implementations of IoT-based smart traffic light systems. The qualitative data from these surveys is important as it reflects the community's perspective.

The data collection process is divided into two types: primary data and secondary data, both of which are used to analyze and solve problems related to the existing road network. The following are the data collection techniques applied:

- ***Primary Data***: This data collected through conducting surveys and spread the questionnaires to a diverse Indonesian society.
- ***Secondary Data***: This refers to data obtained from relevant agencies and university for East Lombok Regency in 2022. This data used to understand the traffic conditions in the road network of the Masbagik Commercial Area in East Lombok Regency. The data obtained is traffic data such as traffic volume and pedestrian volume data.

A thorough analysis will be performed on both the quantitative and qualitative data. Quantitative data will be statistically analyzed to find trends and patterns leading to potential improvement areas of concern. Thematic analysis will be performed on the survey's qualitative data using the necessary tools to find the important narratives that represent public opinion and expectations regarding IoT technologies. The methods of analysis used in this study are as follows:

- ***Road Segment Performance Analysis***

  To analyze road segment performance, the Volume to Capacity (V/C) ratio is first determined. The road capacity is calculated using data from road inventory surveys, which include parameters such as road width, shoulder width, road type, population density, and traffic distribution factors. These elements help establish the capacity of each road segment. The traffic volume, measured as the peak traffic flow in passenger car units per hour (pcu/hour), is obtained through a traffic counting survey. By dividing the observed traffic volume by the road capacity, the V/C ratio is derived, indicating the level of congestion on the road.

  In addition to the V/C ratio, the average speed for each road segment is analyzed. The average speed is calculated by dividing the length of a road segment by the time it takes for vehicles to travel that distance. This metric provides insights into the efficiency of vehicle movement along the segment. Furthermore, the density of each road segment is assessed by dividing the traffic volume by the length of the road segment. The density value reflects the concentration of vehicles within a specific area, highlighting levels of congestion and road performance.

- ***Intersection Performance Analysis***

  For intersections, the analysis focuses on evaluating the degree of saturation, queue lengths, and vehicle delays. The degree of saturation is determined by dividing the traffic volume at the intersection by its capacity. The intersection volume used in this calculation corresponds to the highest observed traffic flow in pcu/hour. To estimate the capacity, data on entry lane width, median width, surrounding land use, city size, and the percentage of vehicles turning to each road-sides are collected. This can provide an understanding of how efficiently the intersection handles traffic flow and identifies its saturation levels.

- ***Pedestrian Activity and Facility Analysis***
  Although the focus on this study is on vehicle operations at the Masbagik intersection, pedestrian activity plays an important role in influencing traffic flow and safety, especially in mixed-traffic environments. From data obtained observations revealed frequent pedestrian movements across all approaches at the specific time, particularly near commercial areas and mosques. Most pedestrians cross without designated crosswalks, often weaving between vehicles due to the lack of proper facilities. This factor contributes to side friction, delays, and safety risks. Some existing pedestrian infrastructure around the intersection is minimal and no visible signage or pedestrian signals around. A dedicated pedestrian phase will be included in the proposed traffic signal design.

- ***Analytical Performance Evaluation and Design***
  With using standardized Indonesian methodologies outlined in the PKJI 2023, this section will provide analysis of performance of existing unsignalized intersection (scenario 1) by calculating the overall intersection capacity based on geometric data and traffic flow compositions. The next step is to design the proposed signalized intersection (scenario 2) and analyzed the performance prediction for the proposed plan. For scenario 1 and scenario 2, we will also calculate for their overall Degree of Saturation and average vehicle delay, including breakdowns for major road approaches and minor road approaches.

- ***Microsimulation Modelling***
  PTV VISSIM (Student Version), a behavior-based microsimulation software, was used to model the Masbagik intersection in detail and evaluate the performance of both the scenarios conditions. The first step is model development (e.g., network coding, traffic inputs, and traffic routings) and the next step is a calibration of the base model, to ensure its outputs reasonably matched the performance benchmarks derived from PKJI 2023 Chapter 6 analysis. Once the base model was calibrated, the proposed signalized intersection model will be made. Lastly, we will run a simulation and evaluate the performance from the data collection.

- ***Survey Analysis***
  Data from the survey regarding the local perceptions will be analyzed using descriptive statistics (e.g., frequencies, percentages) and thematic analysis for any open-ended responses. The aim was to identify common viewpoints, perceived benefits, potential concern, and overall readiness for such advanced technologies in the East Lombok Regency.

The comparison between analytical and simulation results for Scenario 2 was used to understand the potential real-world performance of the proposed signal plan under dynamic conditions with detailed behavioral modelling. Furthermore, the VISSIM results for scenario 1 (calibrated base case) were compared against scenario 2 (proposed signalized) to quantify the impact of implementing signalization. By taking this approach, the study aims to produce useful insights to improve road infrastructure management in Indonesia, specifically in East Lombok area. It will also discuss the broader impact of our findings on IoT intelligent transportation systems and outline potential future work.

LITERATURE REVIEW

Introduction

In urban and regional transportation planning, management traffic at intersections is essential because it has a direct effect on road safety and network efficiency. In developing country like Indonesia, where urbanization continues to grow and vehicle ownership is increasing, the current road infrastructure is frequently under an immense stress. Initially intended for lower traffic volumes or functioning without formal control, many intersections have the potential to develop into major congestion spots that increase traffic, delays, and raise the risk of accidents. The distinct traffic patterns found in many urban and semi-urban areas in Indonesia, where a high percentage of motorcycle coexist with cars, buses, and non-motorized transportation in the mixed traffic streams on the road, making it more complicated.

To overcome these obstacles, traffic management must be done carefully. Fixed-time traffic signalization is a widely adopted fundamental measure to introduce order, allocate right-of-way, improve safety, and handle conflicting traffic streams at busy intersections. And beyond analytical methods, microsimulation has become as a powerful tool for evaluating traffic operations in detail. It allows for the modelling of individual vehicle behaviors, interactions within mixed traffic, as well as the traffic control system's dynamic performance in different demand scenarios.

While fixed-time signalization provides a foundational level of control, the evolution of Intelligent Transportation Systems (ITS) has introduced more advanced solutions. Among these, IoT-based smart traffic light systems have the potential to provide real-time adaptive control, which aims to optimize signal timings based on current traffic conditions, thereby further increasing safety and efficiency. The arrival of Internet of Things (IoT) technologies provides a transformative opportunity to address these persistent issues. IoT-based systems use interconnected sensors, real-time data analytics, and cloud computing to monitor road conditions, traffic flow, and environmental factors, allowing for proactive interventions. These technologies optimize traffic signals enabling a dynamic traffic management which can resulting in less congestion and increasing road safety. Despite of these advancements, the adoption of IoT technologies remains low, especially in developing countries such as Indonesia. Intelligent mobility solutions are frequently limited to urban centers, leaving vast rural and semi-urban areas neglected. This uneven distribution highlights the importance of scalable, cost-effective, and specific IoT applications that cater to a wide range of geographic and socioeconomic environments. Addressing these challenges not only aligns with the goals of sustainable urban development, but also points out IoT technologies potential for transforming road infrastructure management around the world.

Finally, the review will discuss the development and use of IoT technologies in smart traffic light systems, including comparative studies. This will give the theoretical foundation for this study, which assesses a fundamental signalization step and taking into account potential future technological developments for the Masbagik intersection.

The History of Traffic Light Systems

Traffic lights have been an important development in managing urban transportation and ensuring road safety. Before the introduction of traffic lights, early methods of traffic control were manual, relying on police officers and physical barriers. However, there approaches were inefficient due to prone of human error and struggled to address the growing traffic caused by the rise of motorized vehicles in the late 19th century (Michel, 2014). The need for more systematic solution became needed as ever as urban areas experienced increasing congestion and safety risks.

The first major step toward automation came in 1868, when J.P. Knight introduced a gas-lit traffic signal in London, which police officers previously manually operated. It was innovative for its time, but this system still lacking the reliability for widespread use. The discovery and adoption of electricity in the early 20th century revolutionized traffic management. In 1914, the first electric traffic light was installed in Cleveland, Ohio. It used red and green lights, with a buzzing sound to warn drivers of an impending light change since a yellow phase had not been implemented (Ahmadin, 2023). Although it improved upon previous methods, these early electric lights still required manual intervention.

A significant breakthrough occurred with the development of the three-color-traffic signal, which introduced the yellow light. Unlike the previous existing traffic light devices that only featured red and green lights, the addition of the yellow sign provided a transition period, signaling caution to drivers before the lights changed to red or green. This innovation significantly improved traffic safety and reduced uncertainty at intersections (Eom et al., 2020). Over time, the three-color system became the global standard due to its simplicity and effectiveness. Efforts to standardize traffic signals gained momentum in 1968 during the Vienna Convention on Road Signs and Signals, which officially established the universal meanings for red (stop), green (go), and yellow (caution). This global agreement ensured uniformity, making traffic signals easier to understand and reducing the risk of misinterpretation among drivers across different countries (Eom et al., 2020). However, these systems have some limitations such as rely on pre-programmed timing plans or fixed signal cycles, which are developed based on factors like traffic volume, pedestrian movement, and intersection geometry (Eom et al., 2020). While this approach ensures consistency, it lacks the flexibility to adapt to real-time changes in traffic conditions or accommodate non-standard patterns, such as during special events or irregular congestion (Mohamed & Radwan, 2022). Despite of their limitations, traditional traffic lights significantly impact urban mobility with some of advantages like familiarity, standardization, and low maintenance.

As technology advanced, traffic light systems evolved to become smarter and more efficient. In the late 20th century, the introduction of digital controllers and vehicle-actuated signals allowed traffic lights to adapt to real-time conditions, rather than relying on fixed cycles. With further developments, Intelligent Transportation Systems (ITS) integrated tools like vehicle detection sensors, traffic cameras, centralized control systems, and many more tools that enables traffic engineers to manage signals in real-time.

In recent years, technologies such as Artificial Intelligence (AI) and machine learning have taken traffic light management to the next level. AI-powered algorithms analyze vast amounts of real-time traffic data to optimize signal timings, predict congestion patterns, and detect anomalies. Machine learning allows traffic light systems to adapt dynamically to changing traffic condition (Alharbi et al. 2021).

Although advanced smart traffic light systems can not entirely erase all problems like traffic congestion, accidents, and violations, they serve as a far more effective solution compared to traditional methods. These systems play an important role in improving urban mobility, reducing delays, and ensuring safer roads. As cities continue to grow, advancements in technology will drive the development of more adaptive, flexible, and intelligent traffic control systems to make more sustainable transportation networks.

Impact of Traffic Lights on Crashes Reduction

As mentioned in the previous content, traffic lights are fundamental components of road safety infrastructure, designed to regulate the flow of vehicles and pedestrians at intersections, thereby reducing conflict points and minimizing accident risks. Studies have consistently shown their effectiveness in preventing accidents, especially at high-risk intersections and pedestrian crossings. For instance, research highlights that traffic lights at intersections reduce the number of crashes by providing clear and predictable signals to drivers and pedestrians. This enhanced the safety interactions for all road users.

Traffic lights significantly reduce accidents by addressing key conflict points in road networks. A comprehensive analysis found that signalized intersections experienced a 29% reduction in total crashes compared to their non-signalized counterparts, with left-turn phases and pedestrian-specific signals playing an important role in reducing risks associated with turning movements and pedestrian crossings (Kononenko et al., 2024). These reductions stem from the structured control provided by traffic lights, which ensures that vehicles and pedestrians move in an organized and predictable manner.

Further evidence of the good impact of traffic light comes from case studies involving red-light cameras, an enforcement mechanism often integrated into traditional systems. These cameras enhance compliance by deterring drivers from running red lights, a major cause of right-angle crashes. Research from intersections equipped with red-light cameras highlights a 24% reduction in right-angle crashes and a 20% drop in injury-related collisions. However, slight increases in rear-end crashes due to abrupt braking by drivers attempting to avoid violations highlight the importance of balancing enforcement and signal design (Tae-Young & Byung-Ho, 2010). Similarly, in the United States, intersections with enhanced lighting and properly calibrated signals experienced significant safety improvements. These interventions reduced crash rates, especially at locations with high traffic volumes, where visibility was a critical factor (CIE, 2022).

Additionally, comprehensive studies of signalized intersections globally reveal broader safety impacts. In South Korea, a longitudinal study of intersections with red-light cameras showed a sustained reduction in crashes over three years, with crashes rates declining by up to 39.31% in the third year after installation (Tae-Young et al., 2012). In Ukraine, traffic signals combined with enhanced road lighting reduced night-time crashes by as much as 75%, emphasizing the importance of visibility and proper signal placement in achieving optimal results (CIE, 2022).

While traffic lights have been shown to improve safety, there are still various challenges. Poor signal timing, improper placement, and a lack of visibility can reduce their effectiveness. Furthermore, static timing systems may struggle to adapt to changing traffic patterns, resulting in traffic jams and more rear-end crashes. Nevertheless, these issues can be addressed through regular evaluations and maintenance to ensure optimal transportation networks performance.

Fixed-Time Traffic Signal Control Principles

In urban and semi-urban intersections, fixed-time signalization is a fundamental traffic control technique that is usually used, especially in developing countries. Based on preset traffic volumes and patterns, it works by allocating specific green, yellow, and red intervals to each traffic movement. Unlike adaptive systems, fixed-time signals follow a predetermined cycle rather than reacting to changes in traffic in real-time. Despite its drawbacks, this approach is still useful because of its simplicity, reasonably priced, and has the potential to increase intersection safety and efficiency in environments with limited technological resources.

In Indonesia, numerous intersections still operate without signal control. This adds to congestion, delays, and reckless crossing behavior. These problems can be reduced by implementing a fixed-time signal system, which controls vehicle movements in a way that minimizes conflict. Pedoman Kapasitas Jalan Indonesia (PKJI) 2023, or we can also call it Indonesia Road Capacity Manual in English, offers a national standard for the development and assessment of such systems. PKJI 2023 is designed to accommodate Indonesian traffic conditions, taking into consideration regional issues like the prevalence of motorcycles and roadside friction (such as on-street parking and vendors on the street), and irregular driving behavior.

The advantages of fixed-time control are emphasized in numerous studies. When an unsignalized intersection was converted to fixed-time signal control, in German, it still be preferable, such as highly predictable traffic patterns or budget constraints (Thunig et al., 2019). The installation of a fixed-time signal has also resulted in better turning movement regulation and decreased crash risk in similar Southeast Asian environment (Jatoth et al., 2020). In high-conflict intersections, installing traffic signals can lower crash rates by 20% to 50%, according to the U.S. Federal Highway Administration (2015). This is relevant in cases where pedestrian and vehicle interactions are not adequately controlled.

Intersection capacity calculations are modified to account for local conditions in the updated PKJI 2023 model. These include adjustments for side friction, vehicle mix, land width, and surface conditions, which are essential components of capacity planning. According to a study comparing PKJI 2023 with the earlier MKJI 1997, PKJI 2023 produced more accurate estimates of saturation and delay, particularly in settings with high level of motorcycle traffic and informal pedestrian movement (Dewantara et al., 2024).

Fixed-time signal control also offers a scalable solution. They offer a realistic and doable step toward modern intersection control for local governments in developing areas like East Lombok. As highlighted by Yusuf et al. (2021), once digital readiness increases, fixed-time signals can be used as a basis for future integration with adaptive or Internet of Things-based smart traffic systems. The importance of benchmarking intersection models to improve urban traffic management is also mentioned in Ba and Tordeux (2023) study, for allowing more exploration for future research to further optimize intersection performance.

Nonetheless, it is vital to recognize the limitations of fixed-time signal control. Its inability to adjust to real-time traffic conditions can lead to inefficiencies during off-peak hours or when responding to unforeseen traffic disruptions like road construction or local events. Additionally, in mixed-traffic environments with high motorcycle usage and informal behaviors, fixed-time signal plans need to be carefully planned and reviewed on a regular basis.

In this study, fixed-time control signalization is proposed as a first-stage intervention to enhance performance in the absence of traffic control. A signal plan was developed for peak-hour operation using PKJI 2023 Indonesian standards, and microsimulation will be use to further assess it. This strategy helps not only address the current operational issues but also supports for future development.

Microsimulation in Intersection Analysis

Microsimulation has grown as an important tool for assessing traffic performance, especially in complex, heterogeneous traffic situations that are challenging to simulate with conventional analytical methods. Microsimulation tools like VISSIM simulate the movement of individual vehicles based on behavior rules, such as lane-changing, and car-following dynamics, in opposition to macroscopic models that generalize vehicle flow using aggregated equations (Barceló, 2010). This enables for a more thorough and accurate evaluation of intersection performance under different traffic patterns and conditions.

VISSIM has been used to model intersections in city like Makassar in Indonesia, where motorcycles predominate in urban and semi-urban corridors. Model accuracy for Indonesian conditions was shown to be improved by modifying behavioral parameters for lateral movements and decreased headways (Sulaeman et al., 2023). The necessity of calibrating microsimulation models to take into consideration varied traffic conditions was emphasized by Mohan et al. (2021). In a case study in Bangalore, India, Mohan et al. (2021) used VISSIM to model a congested traffic network with heterogeneous traffic flow. They emphasized the need to precisely calibrate VISSIM parameters to reflect local traffic conditions. The study's increased simulation accuracy, which was obtained by using a Genetic Algorithm for calibration, showed how VISSIM can be used to model complex traffic situations in evolving urban settings. Their research showed that adding local traffic characteristics to the calibration process can improved the model's ability to predict outcomes, especially in mixed-traffic situations that are common in developing countries.

The process of calibrating and validating parameters to make the model reflect the actual conditions is vital to achieve accurate microsimulation. VISSIM offers flexibility by letting users define vehicle headways, reaction times, and lane-changing behaviors using models like Wiedemann 74 (urban) and Wiedemann 99 (highway). Because it more accurately illustrates urban stop-and-go behavior, Wiedemann 74 was chosen for this study. The parameters were changed in accordance with delays developed from the PKJI-2023.

The study from Killi and Vedagiri (2014) highlights the role of driver behavior in intersection. Factors such as critical gap acceptance, reaction time, and speed variation can highly influence intersection performance. By testing various intersection layouts and traffic management models, users can improve safety and efficiency by optimizing signal timing and geometric configurations using microsimulation models. Additionally, to proactively evaluate intersection safety, microsimulation presents Surrogate Safety Measures (SSMs), like Post Enroachment Time (PET). By measuring the interval between conflicting vehicle movements, PET helps to detect dangerous situations before they result in crashes (Killi and Vedagiri, 2014).

El-Hansali et al. (2021) demonstrated the benefits of combining analytical design with simulation for evaluating smart signal systems. They found that while analytical methods offered baseline feasibility, simulation highlighted hidden issues like spillback, conflicting pedestrian flows, and saturation behavior. A more detail understanding of how fixed-time signalization would function in actual conditions at the study case area is provided in this study by combining VISSIM microsimulation with PKJI analytical outputs.

Advanced Traffic Management Systems: IoT and Smart Traffic Lights

The integration of Internet of Things (IoT) technologies into urban infrastructure management has emerged as a transformative solution for addressing the complexities of modern road networks. Rapid urbanization, increasing volumes, and aging infrastructure have intensified the demand for innovative approaches to optimize traffic management and ensure the sustainability of transport systems (Qasim et al. 2024). As cities grow, IoT systems can include additional sensors, data points, and computational capabilities without requiring significant infrastructure modifications, making them a cost-efficient and sustainable investment in urban traffic control. For instance, advanced systems that integrate ultrasonic and LiDAR sensors allow for precise vehicle counting and adaptive signal control (Paul et al., 2024). These innovations prioritize emergency vehicles, enhancing public safety while reducing delays. The cloud-based predictive analytics further optimize traffic flow, as demonstrated in Mumbai and Bangalore case studies (Paul et al., 2024). Furthermore, the IoT systems facilitates interconnected systems, where data from traffic sensors and vehicle tracking is analyzed in real-time. This can improve urban mobility and reduces environmental impacts such as emissions (Abdelati, 2024).

One of the key advantages of IoT smart traffic lights is their ability to prioritize emergency vehicles and public transportation. Smart traffic lights have demonstrated significant improvements in urban traffic management. These systems integrate multiple technologies, including IoT, Artificial Intelligence (AI), and various optimization algorithms, to dynamically adjust traffic signals based on real-time situations. For example, RFID-based systems and video processing algorithms optimize traffic flow and prioritize emergency vehicles (Alharbi et al., 2021). By detecting the approach of ambulances or a public transportation, these systems can modify signal patterns to grant them priority, reducing response times, and improving service efficiency. In addition, the smart traffic lights can contribute to pedestrian safety by integrating with crosswalk systems and dynamically adjusting crossing times based on pedestrian density. Real-world implementation of smart traffic lights, such as those employing video processing techniques, have demonstrated significant reductions in congestion and waiting times at busy intersections (Razavi et al., 2019). In 2023, other studies by Hongbo et al., the case in Minnesota has revealed that adaptive systems reduced the frequency of red-light running, which is a leading cause of intersection accidents. These systems dynamically adjust signal timings based on traffic flow, reducing congestion, and accident rates while improving the overall traffic flow efficiency (Hongbo et al., 2023).

In addition to optimizing traffic flow, smart traffic systems can prevent crashes at complex intersections. Matsuzaki et al. (2008) proposed an intelligent traffic light system aimed at reducing pedestrian-vehicle accidents at blind intersections. This system uses advanced pedestrian detection and vehicle proximity sensors to assess collision risks in real-time. When an accident is approaching, the system sends a warning signal to nearby vehicles, which then apply brakes autonomously according to a predetermined deceleration curve to ensure a smooth and safe stop. Experiments validated the system's effectiveness, demonstrating that vehicles could successfully stop before hitting each other. This not only improves pedestrian safety, but also lowers the risk of injuries to vehicle occupants caused by sudden braking, demonstrating the practical application of IoT technologies in improving intersection safety.

To further optimize traffic light systems, optimization algorithms play a critical role in enhancing efficiency. These algorithms use various variables such as traffic volume, congestion patterns, road infrastructure, and technology to determine the most effective signal timing strategies. Below are the key approaches and techniques used for optimizing smart traffic light systems:

1. ***Traffic Simulation Models*** – Traffic simulation tools such as VISSIM are frequently used to simulate real-world traffic conditions based on variables like traffic volume, road shape, and time of day. These models help in designing and evaluating both fixed-time and adaptive traffic control systems, enabling traffic engineers to identify the most effective signal schemes (Garg, 2023).
2. ***Traffic Flow Models*** – Models like the Cell Transmission Model (CTM) and Light Hill Whitham Richards (LWR), provide a theoretical understanding of traffic flow and congestion dynamics. When combined with optimization techniques, these models contribute to the development of traffic control strategies that take real-time congestion into account and resolve it (Nugrahani, 2005).
3. ***Reinforcement Learning*** – Reinforcement learning, a type of machine learning, is gaining popularity in traffic signal optimization. Traffic systems equipped with reinforcement learning agents can dynamically adjust signal timings based on real-time traffic feedback, allowing them to adapt to changing conditions and reduce congestion (Coskun, 2019).
4. ***IoT Integration with Optimization Techniques*** – A comprehensive traffic light system that equipped with ultrasonic and LiDAR sensors provides accurate vehicle counts, enabling precise signal adjustments (Paul et al., 2024). In a similar case, recent implementations have demonstrated the cost-effectiveness of transitioning traditional traffic lights into dynamic systems using IoT technologies (Yusuf et al., 2021).
5. ***Genetic Algorithms*** – Genetic algorithms, inspired by the principles of natural selection, optimize traffic signal timings by simulating the evolution of solutions. These algorithms are highly effective in complex, nonlinear urban transportation networks because they can explore large solution spaces efficiently (Garg, 2023).

Furthermore, a study about smart traffic lights by El-Hansali et al. (2021), introduces a Smart Dynamic Traffic Monitoring and Enforcement System, focusing on the use of Variable Speed Limit (VSL) controls as an intelligent transportation system (ITS) strategy. The study emphasizes how VSL systems adjust speed limits dynamically based on real-time traffic data gathered through connected vehicle (CV) technology and IoT sensors. Using simulation tools such as VISSIM, the research demonstrated that VSL control strategies significantly improve traffic performance and safety by reducing vehicle stops, improving average vehicle speed, lowering travel times, and decreasing average stopped delay per vehicle. The system has been particularly effective in managing congestion and enhancing safety in areas below highway capacity limits, providing a blueprint for integrating similar technologies into other urban and highway systems. The results reinforce the importance of combining IoT with dynamic traffic controls to address congestion and ensure smoother traffic flow in real-world scenarios.

The integration of IoT technologies with advanced optimization methods offers a powerful solution for traffic signal optimization. These systems enable adaptive responses to real-time traffic conditions, improving efficiency, reducing delays, and enhancing safety. As cities grow and traffic demands increase, the adoption of IoT and smart traffic light systems provides scalable, sustainable, and effective approach to managing modern transportation networks.

Comparative Study Analysis of IoT Applications

This section presents a comparative analysis of studies focusing on smart traffic lights across different countries, to examine the unique problems addressed, the innovative solutions proposed, and the outcomes achieved. By highlighting key contributions, this study aims to identify effective strategies and provide insights into scalable, cost-efficient, and adaptable approaches to traffic signal management.

The following table summarize findings from selected research associated with smart traffic light systems, which these technologies were implemented.

Table 6.Literature Review Comparative Study

Reference	Country	Problem	Solution	Result
Paul et al. (2024)	India	High congestion and delays, especially during peak hours, causing environmental pollution and inefficiencies.	IoT smart traffic signal system using ultrasonic sensors, LiDAR, and cloud-based predictive algorithms to adjust signal timings and prioritize emergency vehicles.	Significant improvement in traffic flow and emergency vehicle prioritization. Reduced travel delays and emissions.
Alharbi et al. (2021)	Saudi Arabia	Static signal systems cause delays and fail to adapt to heavy traffic or peak hours.	Fog computing-based dynamic smart traffic lights integrated with image processing to calculate vehicle density and reallocate green signals in real time.	Reduced waiting times and traffic congestion. Efficient signal adjustment at busy intersections using vehicle density analysis.
Oliveira et al. (2021)	Brazil	High installation and maintenance costs for wired traffic systems in urban centers. Inefficiencies in handling traffic failures and emergency events.	Wireless communication-based smart traffic light system for real-time remote operation. Integrated safety routines to detect faults and provide immediate alerts to manage centers.	Cost-efficient, easy-to-install solution that reduced congestion and enabled faster response time for emergency events.
Yusuf et al. (2021)	Indonesia	Fixed-time traffic lights increase congestion, inefficiencies, and fuel consumption.	Adaptive smart traffic lights to adjust signal timings based on traffic density, emergency vehicles, and pedestrian needs using IoT and sensors.	Reduces traffic congestion, improved emergency response times, and enhanced pedestrian safety.
Abdelati (2024)	Egypt	Rising urbanization and increased traffic accidents due to poor	IoT-based adaptive traffic management that integrated with big data and AI to predict traffic	Reduced emissions, congestion, and accidents. Improved safety and

		infrastructure and lack of adaptive traffic systems.	patterns and optimize light timings for better urban mobility.	sustainability through predictive capabilities and IoT integration.
Li et al. (2023).	USA	High frequency of red-light running (RLR) incidents leading to traffic crashes.	Adaptive signal control systems that optimize signal timing based on vehicle arrival during yellow lights and traffic flow conditions/	Reduced RLR-related crashes while maintaining traffic efficiency. Improved safety across various traffic conditions.

Literature Review Conclusion

Fixed-time signalization is proving to be a workable, widely adopted, and still a good option to increase intersection safety, decrease delays, and improve traffic flow especially in developing countries. Although less flexible than adaptive systems, fixed-time signal control offers a cost-effective solution. Research shows that fixed-time control signals can solve a number of operational issues that unsignalized intersections face when they are designed according to specific standards like PKJI 2023.

It has been demonstrated that microsimulation tools like PTV VISSIM can successfully simulating the mixed traffic conditions found on Indonesian roads. Compared to analytical models, VISSIM microsimulation offers a thorough, behaviorally realistic evaluation of intersection performance that takes into consideration side friction effects, high motorcycle volumes, and driving patterns.

IoT technologies are proving to be game changers in managing road infrastructure and traffic systems, especially as cities grow and traffic increases. This review shows how these technologies are helping solve issues like congestion, road safety, and maintenance. Some exciting examples about using smart traffic lights in different countries with its benefits and innovations as stated in previous sections, does not mean there are no hurdles to overcome. Installing these systems can be expensive and many concerns need to be addressed. Additionally, governments and organizations must work together to create consistent policies and frameworks.

Overall, combining analytical methods, microsimulation, and exploration of smart technologies in the future can forms a solid foundation for evaluating and improving intersection performance, aligning well with the objectives of this study at the Masbagik intersection, East Lombok, Indonesia.

DATA ANALYSIS

Study Area: Masbagik Intersection, East Lombok, Indonesia

The study area for this research is the Masbagik Commercial Area in East Lombok Regency, which is consists of arterial roads Kopang-Masbagik road and Masbagik-Rempung road.

- ***The Kopang-Masbagik road,*** serves as a primary arterial route, connecting to Masbagik-Rempung road and Masbagik-Pancor road. This road experiences heavy traffic congestion especially during peak hours in the morning and in the afternoon. The area is dominated by commercial zones, resulting in high side friction caused by on-street parking and activities along the road.
- ***The Masbagik-Pancor road,*** it functions as a key connector between the national road network and the East Lombok Regency capital. However, this segment usually faces reduced road capacity to

public transport vehicles stopping on the roadway to wait for passengers. This practice leads to significant traffic congested in the area.

The road network in East Lombok Regency characteristics have been mentioned in the previous background section.

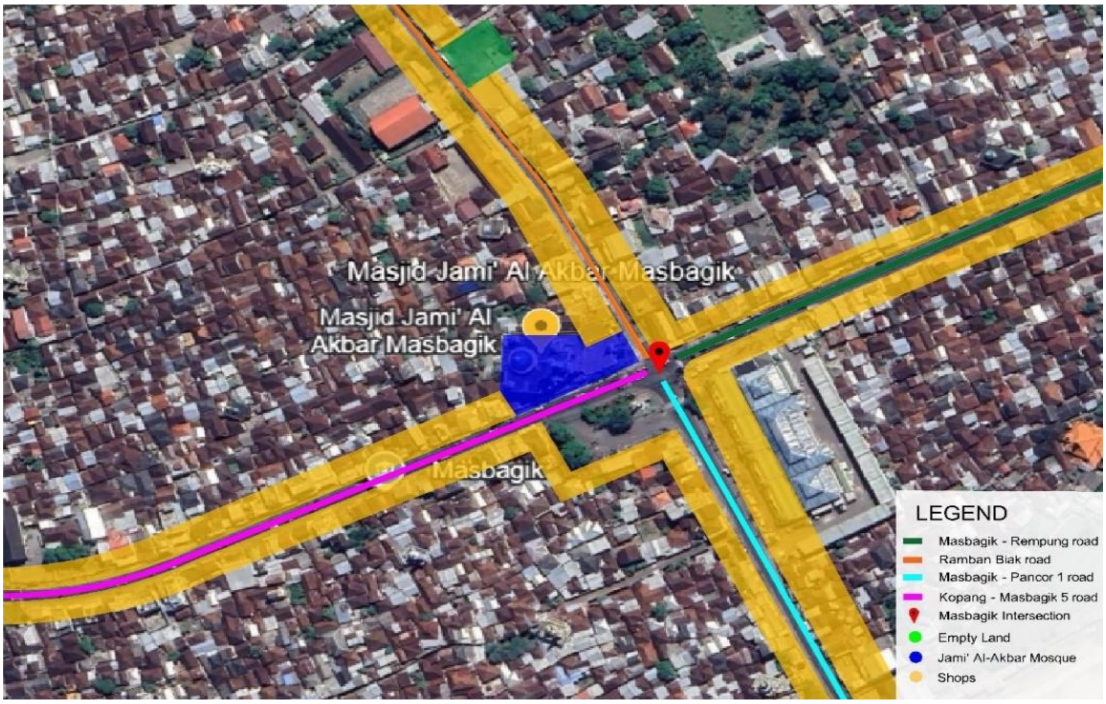

Figure 1. Study Area: Masbagik Commercial Area, East Lombok Regency

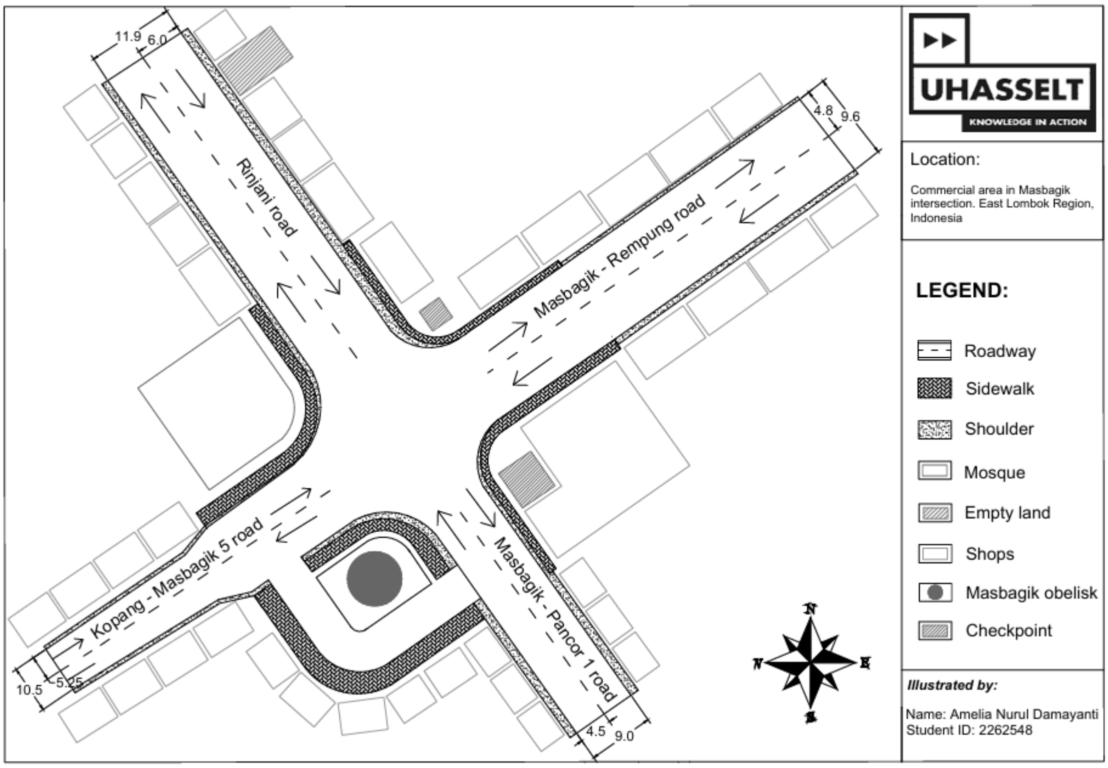

Figure 2. Cross-section of Masbagik Commercial Area

Figure 3. Masbagik Intersection

Road Segment Performance Analysis

The Masbagik Commercial Area is one of the key commercial zones in East Lombok Regency. This area is strategically located along Kopang-Masbagik 5 road and Masbagik-Rempung road, which are part of the national road network connecting West Lombok and serving as an exit route from East Lombok Regency. Additionally, the area includes routes leading to the city center, continuing through the Masbagik intersection toward Masbagik-Pancor 1 road. To analyze the performance of road segments in this area, several surveys were conducted to collect the required data. These surveys include road inventory survey, traffic volume classification survey, and speed survey.

Road Inventory Survey

The road inventory survey was conducted to gather data on the geometric characteristics of the roads and their capacity to accommodate vehicle traffic. The study covers key road segments located within the Masbagik Commercial Area. This survey provides essential information about road widths, lane configurations, and other geometric details that determine the capacity of the roads to handle traffic flow. The detailed road inventory data for the Masbagik commercial area will be presented in the table below.

Table 7. Road Inventory

Segment	Function	Road Status	Length (m)	Road Type	Lane Width (m)
Kopang-Masbagik 5 road	Arterial	National	2145	2/2 UD	5.25
Masbagik-Rempung road	Arterial	Provincial	2503	2/2 UD	4.8
Masbagik-Pancor 1 road	Collector	Provincial	3147	2/2 UD	4.5
Rinjani road	Local	Regency	4636	2/2 UD	6

Source: Road Infrastructure Survey, East Lombok 2022

From the table, we can see that the roads within Masbagik commercial area consists of four road segments with several roads category. These roads serve as key routes for residents traveling to and from the city center and surrounding regions. In addition, these roads experience medium side friction, largely due to commercial activities, parking, and pedestrian movement, which impacts their performance.

Road Segment Capacity

Road Capacity refers to the maximum number of vehicles a road segment can accommodate. It is influenced by factors such as lane width and median, population density, road geometry, and side friction. The road capacity analysis is calculated by using the formula in Indonesian Road Capacity Guidelines, 2023 (Pedoman Kapasitas Jalan Indonesia, PKJI). On the table below are the calculated capacities of the surveyed road segments based on these factors.

Table 8. Road Capacity Adjustment

Road Name	Base Capacity	Lane Width Factor	Side Friction	Capacity (pcu/h)
Kopang-Masbagik 5 road	2900	0.86	0.86	2169.78
Masbagik-Rempung road	2900	0.86	0.86	2169.78
Masbagik-Pancor 1 road	2900	0.86	0.86	2494,00
Rinjani road	2900	0.86	0.86	2169,78

Source: Road Infrastructure Survey, East Lombok 2022

The capacity calculation has adjustments for factors such as lane width (a narrower lane reduces capacity), directional flow, side friction (caused by parking, pedestrians, and commercial activity), and city size, which accounts for urban area dynamics. In this case, Masbagik-Pancor 1 road shows a higher adjusted capacity due to a city size factor of 0.86, reflecting better optimization under observed conditions. While Rinjani road and other arterial roads maintain similar capacities, primarily impacted by side friction and lane width.

Road Traffic Volume

The traffic volume data was obtained through classified traffic counting surveys. The result of the survey conducted in 2022 were used to measure vehicle flow on key road segments in the Masbagik Commercial Area. The table below displays traffic volume across the surveyed road segments. Masbagik-Pancor 1 road has the highest total volume, reflecting higher vehicle flow in the area compared to others. Meanwhile, Rinjani road shows the lowest total volume and has lighter traffic conditions.

Table 9. Traffic Volume

Segment	Total Volume (vehicle/hour)	Total Volume (pcu/hour)	Capacity (pcu/hour)
Kopang-Masbagik 5 road	2567	1444.70	2169.78
Masbagik-Rempung road	2051	1352.80	2169.78
Masbagik-Pancor 1 road	2913	1258.40	2494.00
Rinjani road	1671	641.80	2169.78

Source: Road Infrastructure Survey, East Lombok 2022

Speed Analysis

Speed is a key indicator for assessing the performance of road segments in the Masbagik Commercial Area. The lowest average speed was recorded on Kopang-Masbagik 5 road at 31.66 km/hour, indicating congestion or other challenges affecting smooth traffic flow. On the other hand, Rinjani road has the highest average speed of 37.08 km/hour, suggesting relatively smoother traffic conditions.

Table 10. Speed

Segment	Speed (km/hour)
Kopang-Masbagik 5 road	31.66
Masbagik-Rempung road	33.71
Masbagik-Pancor 1 road	35.14
Rinjani road	37.08

Source: Road Infrastructure Survey, East Lombok 2022

Traffic Density

The traffic density is calculated by dividing the traffic volume by the average speed, which is displayed in passenger car units per kilometer (pcu/km). This indicator is used to assess the level of congestion on the road segments. The findings of the traffic density analysis are shown below:

Table 11. Traffic Density

Segment	Total Volume (pcu/hour)	Speed (km/hour)	Density (pcu/km)	V/C Ratio
Kopang-Masbagik 5 road	1108	31.66	45.63	0.67
Masbagik-Rempung road	697	33.71	40.13	0.62
Masbagik-Pancor 1 road	627	35.14	35.81	0.56
Rinjani road	553	37.08	17.30	0.31

Source: Road Infrastructure Survey, East Lombok 2022

The highest density was observed on Kopang-Masbagik 5 road at 45.63 pcu/km, indicating severe congestion and low vehicle speeds. Masbagik-Pancor 1 road also shows significant congestion with a V/C ratio of 0.61, nearing the road's capacity limit. The lowest density occurs on Rinjani road, with a value of 14.90 pcu/km, reflecting lighter and smother flow.

Level of Service (LoS)

Level of service is a qualitative measure used to describe the operational conditions of a road or intersection. It reflects the level of comfort and convenience experienced by drivers and is determined based on the Volume-to-Capacity (V/C) ratio. The V/C ratio compares the current volume of traffic on a road segment to its designed capacity. This ratio is essential for evaluating how efficiently a road segment operates and whether improvements are needed to accommodate traffic demand. The V/C ratio is calculated by dividing the traffic volume (pcu/h) by the road capacity (pcu/h).

In the Masbagik commercial area, four main road segments were analyzed based on data collected in 2022, including their traffic volume and adjusted capacity. As shown in the Table 12, the LoS analysis provides information on the current performance of key roads in the Masbagik area. Two of the four roads are in near-unstable conditions (LoS D), indicating a need for proactive traffic management strategies. These findings support the implementation of intelligent traffic systems and infrastructure upgrades to maintain mobility and safety as traffic demand grows.

Table 12. Level of Service

Segment	V/C	Level of Service
Kopang-Masbagik 5 road	0.67	D (Approaching unstable flow)
Masbagik-Rempung road	0.62	D (Approaching unstable flow)
Masbagik-Pancor 1 road	0.56	C (Stable flow, limited freedom)
Rinjani road	0.31	B (Reasonably free flow)

Intersection Performance Analysis

The performance analysis of an intersection is critical for determining its efficiency and impact on traffic flow. A field survey was carried out at Masbagik Intersection, an unsignalized four-leg intersection (Type 422) with two lances on both the main and minor roads.

Intersection Inventory

The Masbagik Intersection is in a commercial area and does not have traffic signals, making it important to assess how traffic flows through the intersection. Further additional geometric details about the Masbagik Intersection, such as sidewalks, lane configurations, and approach width, are outlined in Table below.

Table 13. Inventory of Masbagik Intersection

Direction	North	South	East	West
Road Section	Rinjani road	Masbagik-Pancor1 road	Masbagik-Rempung road	Kopang-Masbagik road
Total Pavement Width (m)	11.9	9	9.6	10.5
Median Width (m)	-	-	-	-
Left Shoulder Width (m)	0.6	0.6	0.8	0.7
Effective Approach Width (m)	11.9	9	9.6	10.5
Effective Left Turn Lane Width (m)	6	4.5	4.8	5.25
Effecitve Right Turn Lane Width (m)	-	-	-	-
Number of Lanes	2	2	2	2
Road Marking Condition	Poor	Poor	Poor	Poor

Source: Transportation Department Service of East Lombok Regency 2022

It shows that approach widths vary across the intersection. Rinjani Road has the widest effective lane width (11.9 m), whereas Masbagik-Pancor 1 Road has the narrowest (9 m). Sidewalks are present on some approaches, and the widths vary, affecting pedestrian movement and safety. Additionally, the absence of medians may contribute to vehicle conflicts at the intersection.

Traffic Condition and Side Friction

Side friction is a significant factor influencing the performance of the Masbagik Intersection, which is classified as **medium**. This side friction is primarily caused by commercial activity, roadside parking, pedestrian crossings, and informal stalls near the intersection. It has several effects on traffic performance:

- Increased travel time and delays
- Increased interactions between pedestrians and vehicles
- Disruptions to traffic flow due to parked vehicles and loading/unloading activities.

Given the high level of side friction, measures such as parking restrictions, pedestrian crossing improvements, and potential signalization strategies should be considered to improve intersection performance.

Pedestrian Activity and Facility Analysis at Masbagik Intersection

Pedestrians serve as crucial road users, especially in thriving commercial districts like Masbagik area. Ensuring their safety, comfort, and efficient movement is important in urban transportation planning and intersection design. The Masbagik intersection, in its current unsignalized state, poses risks to pedestrians due to potential conflicts with vehicular traffic and a lack of formal, priority crossing facilities. This sub-chapter aims to:

- Analyze existing pedestrian activity levels along the approach roads and crossing movements at the Masbagik Intersection, based on survey data.
- Determine the requirements for adequate pedestrian infrastructure, specifically sidewalk widths.
- Provide recommendations for pedestrian crossing facilities.
- To align these recommendations with established principles of pedestrian-inclusive design and relevant to Indonesian guidelines, such as the Pedoman Kapasitas Jalan Indonesia (PKJI) 2023, for best practices in pedestrian facility design within signalized intersection.

Pedestrian Flow Data Overview

To understand pedestrian dynamics at the Masbagik Intersection, dedicated pedestrian surveys were conducted.

Table 14. Pedestrian Data for Masbagik Commercial Area

Segment	Time	Number of Pedestrians Walking along the roadside		Number of Pedestrians Crossing
		Left	Right	
Kopang-Masbagik 5 road	08:00 – 10:00	161	167	90
	12:00 – 14:00	303	314	124
	16:00 – 18:00	123	155	63
Masbagik-Rempung road	08:00 – 10:00	183	154	74
	12:00 – 14:00	291	368	156
	16:00 – 18:00	144	120	59
Masbagik-Pancor 1 road	08:00 – 10:00	158	150	94
	12:00 – 14:00	240	252	128
	16:00 – 18:00	123	125	60
Rinjani road	08:00 – 10:00	145	139	136
	12:00 – 14:00	275	292	155
	16:00 – 18:00	145	107	86

Source: Transportation Department Service of East Lombok Regency 2022

As detailed in the Table 14, these surveys captured pedestrian volumes during three distinct periods of the day: 08:00 – 10:00, 12:00 – 14:00, and 16:00 – 18:00. These periods were selected to represent typical morning, midday, and late afternoon activity levels. The recorded data reflect pedestrian activity along the roadside (longitudinal movement) and crossing movement (lateral movement) for both directions.

Analysis of Pedestrian Volumes and Patterns

The survey data reveals considerable pedestrian activity around the Masbagik Intersection, varying by time of day and specific approach road.

Pedestrian Flow Along Road Segments (Longitudinal Demand)

From table 14, we will summarize the peak 2-hour pedestrian volumes walking along each road segment and the average peak hourly flow. This combined flow provides an indication of the total demand for sidewalk space along each corridor.

- Kopang-Masbagik 5 road (West Approach): Total of 617 pedestrians (303 left and 314 right) during 12:00 – 14:00. This indicates to an average peak hourly flow of approximately 309 pedestrians/hour.
- Masbagik-Rempung road (East Approach): Total 659 pedestrians (291 left and 368 rights) during 12:00 – 14:00. This indicates to an average peak hourly flow of approximately 330 pedestrians/hour. This approach reveals the highest longitudinal pedestrian flow.
- Masbagik-Pancor 1 road (South Approach): Total of 492 pedestrians (240 left and 252 right) during 12:00 – 14:00. The average peak hourly flow is approximately 246 pedestrians/hour.
- Rinjani road (North Approach): Total of 567 pedestrians (275 left and 292 right) during the afternoon period. This translates to an average peak hourly flow of approximately 284 pedestrians/hour.

These volumes clearly indicate a consistent and high demand for pedestrian pathways along all approaches to the intersection. The East (Masbagik-Rempung road) and West (Kopang-Masbagik 5 road) approaches, being arterial roads, show high longitudinal pedestrian traffic. The data also shows that all approaches have considerable crossing demand, with the East (Masbagik-Rempung) and North (Rinjani) approaches experiencing the highest crossing volumes during their respective peak periods for this movement. These levels of unprotected crossings in a busy commercial area with significant vehicular traffic (as analyzed in previous sections) pose a high safety risk. This indicates a substantial and continuous demand for adequate walking space.

Pedestrian Crossing Volumes at Intersection Approaches

The volume of pedestrians crossing the roads at the intersection is an important safety parameter. On the table below, it summarizes the peak 2-hour crossing volumes and the equivalent average peak hourly rates.

Table 15.Peak Pedestrian Crossing Volumes at Masbagik Intersection Approaches

Segment	Peak Survey Period (for Crossing Flow)	Peak Pedestrians Crossing (people/2-hours)	Average Peak Hourly Crossing Flow (people/hour)
Kopang-Masbagik 5 road	12:00 – 14:00	124	62.0
Masbagik-Rempung road	12:00 – 14:00	156	78.0
Masbagik-Pancor 1 road	12:00 – 14:00	128	64.0
Rinjani road	12:00 – 14:00	155	77.5

From the table above, all four approaches experience pedestrian crossing demand, with peak hourly rates ranging from 62 to 78 pedestrians. The Rinjani (North) and Masbagik-Rempung (East) approaches show the highest crossing volumes. These figures, especially in the absence of signalized control, indicate a high potential for pedestrian-vehicle conflicts and highlight an urgent need for protected crossing facilities.

Recommendations of Required Facilities

Based on the analyzed pedestrian volumes, specific recommendations for pedestrian infrastructure can be seen in the next content below.

Required Sidewalk Width

Adequate sidewalk width is vital for pedestrian comfort and safety. While PKJI 2023 primarily addresses vehicular and intersection capacity, detailed geometric design standards for sidewalks, including width calculations based on pedestrian flow rates (e.g., pedestrians per minute per meter of width, aiming for a certain Level of Service), are typically found in broader Indonesian road and urban infrastructure design guidelines, such as those issued by the Ministry of Public Works (e.g., Peraturan Menteri PU, related to technical road requirements or specific pedestrian facility design manuals).

Considering the peak longitudinal flows observed (e.g., up to 330 pedestrians/hour on one approach, meaning potentially 150 – 180 pedestrians/hour on the busier side if flow is unevenly distributed). The recommendation for this case is:

- Sidewalks on all approaches to the Masbagik Intersection be designed with a minimum clear effective width of 2.0 meters.
- For approaches with higher combined flows like Masbagik-Rempung and Kopang-Masbagik 5, and potentially higher concentrations on one side due to commercial activity, a width of 2.5 to 3.0 meters would be more appropriate to achieve a comfortable pedestrian Level of Service.
- The detailed design should refer to specific Indonesian standards which may link pedestrian flow per unit width (e.g., pedestrians/minute/meter) to desired LoS categories (e.g., LoS C or better for urban commercial sidewalks).

Widths below 1.5 to 2.0 meters can lead to congestion on sidewalks, forcing pedestrians onto the carriageway, especially when accommodating bi-directional flow or diverse user groups (e.g., individuals, groups, people with shopping bags). The commercial nature of Masbagik, with potential for window shopping and entry/exit from stores, further supports the need for generous sidewalk widths for pedestrians to walk side-by-side and accessibility for users with mobility aids or strollers.

Recommendation for Pedestrian Crossing Facilities

The analysis of pedestrian crossing volumes and the subsequent warrant analysis (PV^2) from the Table 16, indicate an urgent need for formal, controlled pedestrian crossing facilities at the Masbagik intersection. Relying on unsignalized Zebra crossings that are not contributes evenly in each approach in a busy commercial area with substantial vehicular and pedestrian traffic, as currently exists, face safety risks and contributes to inefficient traffic operations for all road users. From these findings, we strongly suggest for Pelican or signalized pedestrian crossings on all four approaches to the Masbagik intersection. This recommendation is based on a PV^2 analysis, which is a widely accepted method for warranting traffic control devices at pedestrian crossings by considering the interaction between pedestrian (P) and vehicular (V) volumes.

From all approaches, high conflict potential (PV^2 values) in the table is significant, ranging from 1.E+08 to 3.E+08. Typically, PV^2 values exceeding national or international thresholds (often in the range of 10^8 to 2×10^8) indicate that an uncontrolled zebra crossing is no longer adequate. At such levels, the frequency of interactions between pedestrians and vehicles is high, leading to increased risk of accidents and unacceptable delays for pedestrians trying to find safe gaps in traffic. In mixed traffic environments common in Indonesia, with a high proportion of motorcycles and varying driver discipline, relying solely on driver yielding is often insufficient to guarantee pedestrian safety. That is why it is necessary to upgrade to Pelican (signalized) crossings.

Table 16. Recommendations for Crossing Facilities

Segment	Peak Avg. Pedestrian Rate (P) (people/hour)	Peak Avg. Vehicle Rate (V) (vehicle/hour)	Peak PV^2 Rate	Recommended Crossing Facility
Kopang-Masbagik 5	53.5	2227.5	3.E+08	Pelican
Masbagik-Rempung	57.5	2135.25	3.E+08	Pelican
Masbagik-Pancor 1	55.5	2386.25	3.E+08	Pelican
Rinjani	67.75	1343.25	1.E+08	Pelican

The peak average vehicle rates (V) are consistently high across all approaches (1343 to 2386 vehicles/hour). At these volumes, continuous traffic flow makes it difficult for pedestrians to cross safely at an unsignalized zebra crossings. Drivers are less likely to yield, and pedestrian assertiveness can lead to risky maneuvers.

While the peak average pedestrian rates (P) (53 to 68 people/hour) might seem moderate in isolation, their interaction with the high vehicular volumes creates an unsafe situation. Furthermore, these are average hourly rates, short-term peaks within the hour may be higher, particularly in a commercial area with frequent arrivals and departures from shops, mosque, or transportation stops.

Descriptive and Comparative Analysis

The following section provides a descriptive and comparative analysis of traffic conditions in selected segments of the Masbagik commercial area. The analysis examines vehicle composition, daily fluctuations, traffic volume trends, and segment-level performance using field data collected via Classified Turning Movement Counts (CTMCs). While the initial research plan included regression analysis, data limitations, particularly the availability of only average speed per segment and a small sample of road segments, made statistical modeling unsuitable. Instead, this chapter provides useful information by comparing observed traffic patterns, segment-specific delays, and daily volume profiles. These findings contribute to the development of simulation scenarios and inform recommendations for IoT-based traffic management.

Traffic Volume and Composition Overview

Based on the field survey data, this section outlines the fundamental traffic characteristics observed at the Masbagik intersection. The total volume was converted to passenger car units (pcu) using the Indonesian Road Capacity Guidelines (Pedoman Kapasitas Jalan Indonesia, PKJI-2023) conversion factors. Understanding these baseline conditions, including traffic volume levels, daily patterns, and the mix of vehicle types, is essential for examining the existing issues and evaluating potential improvements.

Traffic volume at the intersection varies significantly throughout the day, as illustrated in the Figure 4. Distinct peak periods occur during the specific hour in the morning commute and again in the late afternoon. These peaks imply the times of greatest demand on the intersection, likely corresponding to periods of increased congestion and delay. For context in the figure below, the Masbagik-Pancor 1 road is located to the south, Kopang-Masbagik 5 road is to the east, Rinjani road is to the north, and Masbagik-Rempung road is to the west.

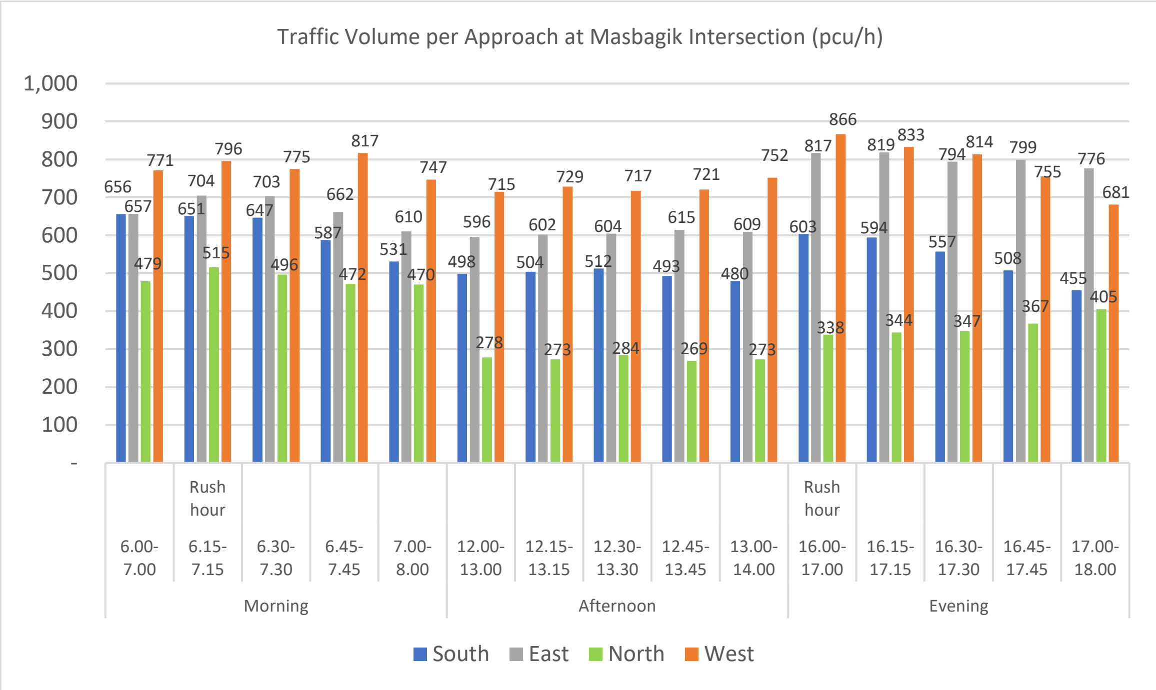

Figure 4. Traffic Volume per Approach at Masbagik intersection (pcu/h)

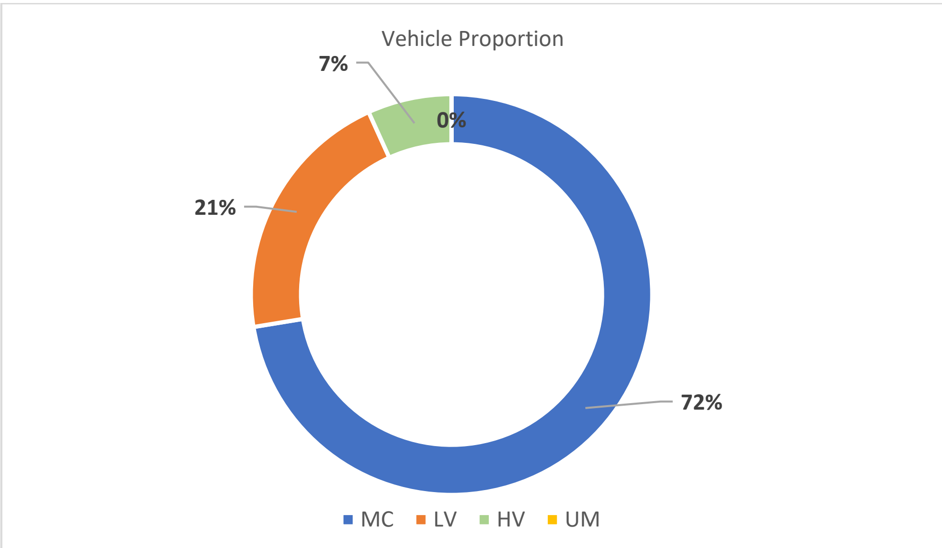

Figure 5. Vehicle Proportion

The composition of traffic is also an important factor, with motorcycles (MC) making the vast majority of vehicles passing through the intersection. Light vehicles (LV – including cars, pickups, etc.) form the second largest group, while heavy vehicles (HV – including larger buses and trucks) and unmotorized (UM) traffic represent much smaller proportions. This high prevalence of motorcycles influences the intersection's operational characteristics and must be considered in any capacity analysis or simulation modelling.

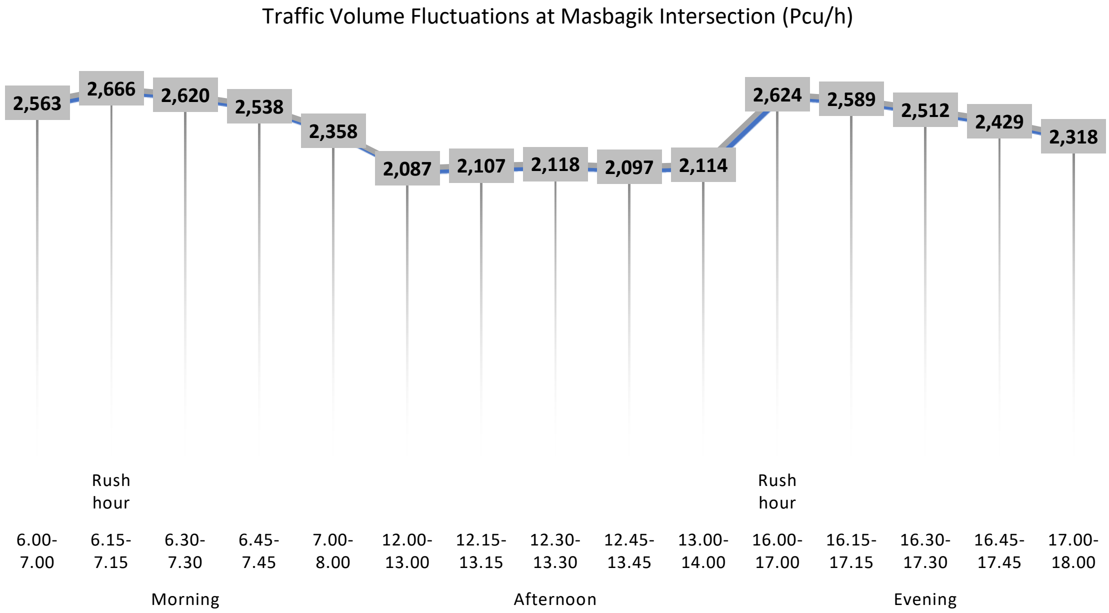

Figure 6. Traffic Volume Fluctuations at Masbagik Intersecion (Pcu/h)

The Figure 6 displays the total combined traffic volume entering the entire Masbagik intersection from all four approaches added together. It uses a single line to show the overall rise and fall of traffic throughout the day, making it easy to spot the peak times for the intersection as a whole.

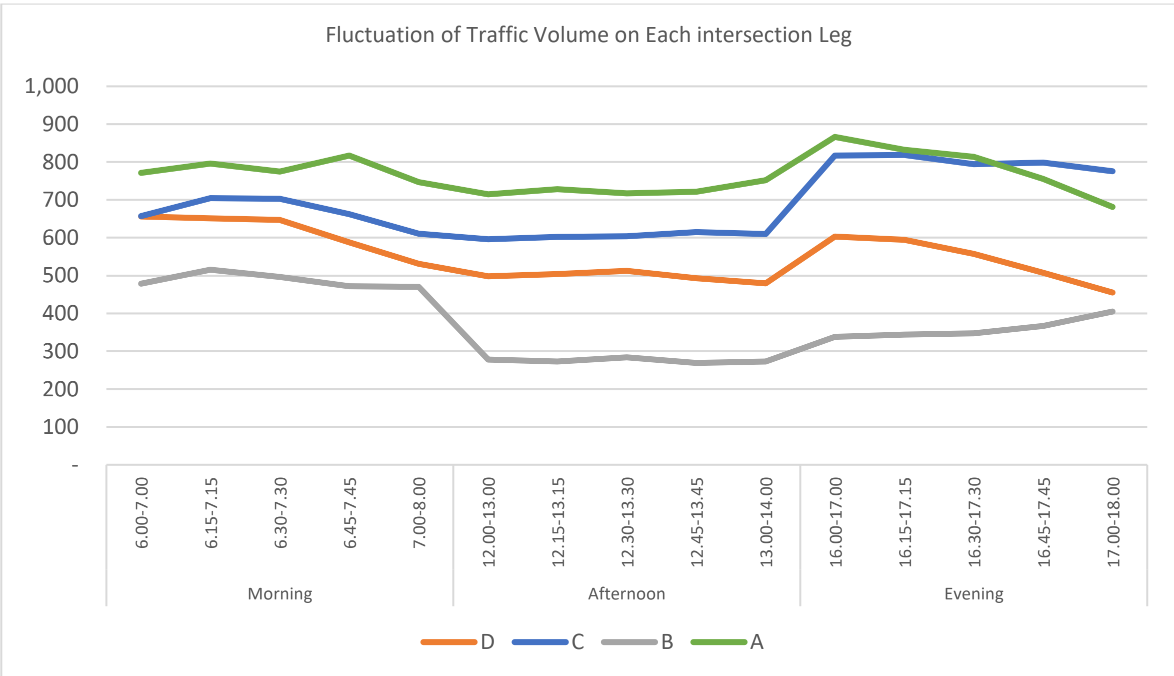

Figure 7. Fluctuation of Traffic Volume on Each Intersection Leg

The Figure 7 breaks down the total volume. It displays separate lines for each individual approach. Each line shows how the traffic volume fluctuates over time for only on that specific leg. This allows us to compare the volume patterns of the different approaches. To see which ones are busiest at different times, and understand how each approach contributes to the overall intersection peaks. For instance, you can see that approaches A and C generally have higher volumes than B and D. For context, A (west) is the Kopang-Masbagik 5 road, B (north) is the Rinjani road, C (east) is the Masbagik-Rempung road, and D (south) is the Masbagik-Pancor 1 road.

To understand how vehicles move through intersections in the study area, Classified Turning Movement Count (CTMC) surveys were conducted. These surveys aimed to measure the proportion of vehicles that turning left, turning right, or proceeding straight from each intersection approach. This turning movement proportion data is important as it depicts the circulation patterns of vehicles traveling through the intersection. Also, it helps us to understand how traffic moves through each leg of an intersection, especially to predict congestion points, designing dedicated lanes, and configuring signal phases properly. This information serves as a key data input for building and calibrating the traffic simulation model. The measured turning proportions can be seen in the Figure below.

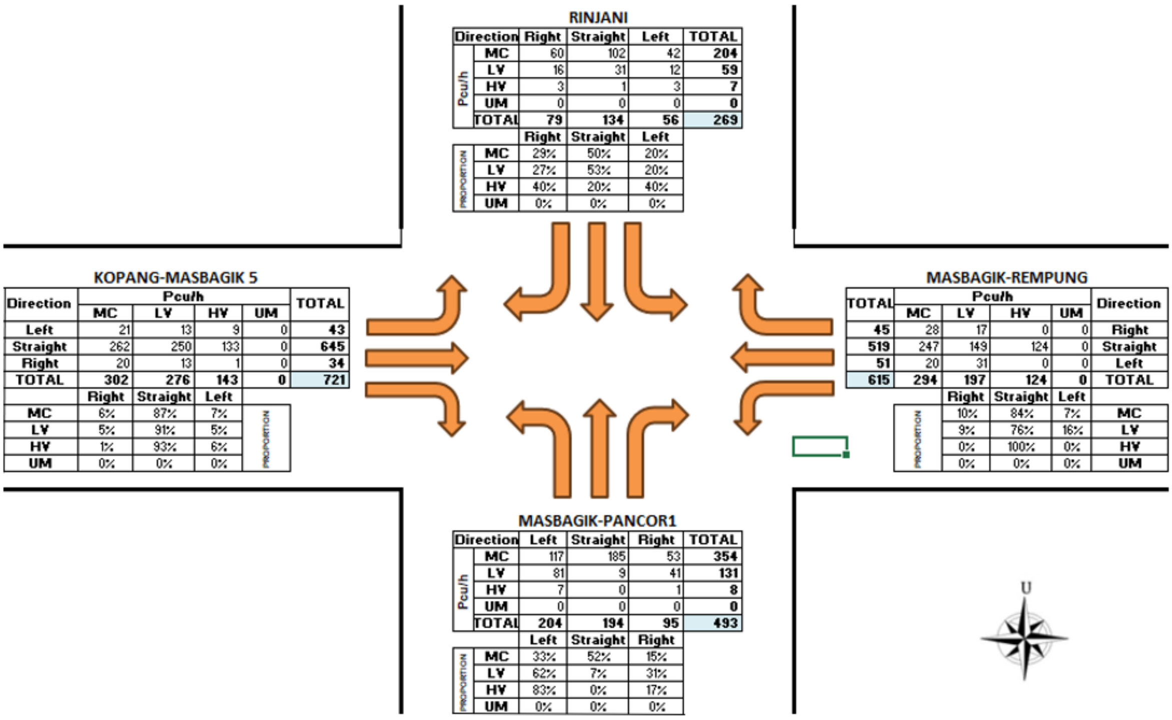

Figure 8. Classified Turning Movement Count (CTMC) Survey Result

Let's try to calculate the turning movement percentage distribution for the Masbagik – Rempung road approach using the data from the Figure 8. This calculation shows the percentage of traffic coming from the Masbagik – Rempung road (East) approach that turns left, goes straight, and turns right during the survey time.

- Total left turn volume = 43 vehicles (pcu/h)
- Total straight volume = 420 vehicles (pcu/h)
- Total right turn volume = 34 vehicles (pcu/h)
- Overall total volume = 497 vehicles (pcu/h)

Example calculation (Left turn):

Percentage (%) = (Volume of specific movement / Overall total approach volume)*100

- Percentage left = (43/497)*100
- Percentage left = 0.0865*100
- Percentage left = 8.7%

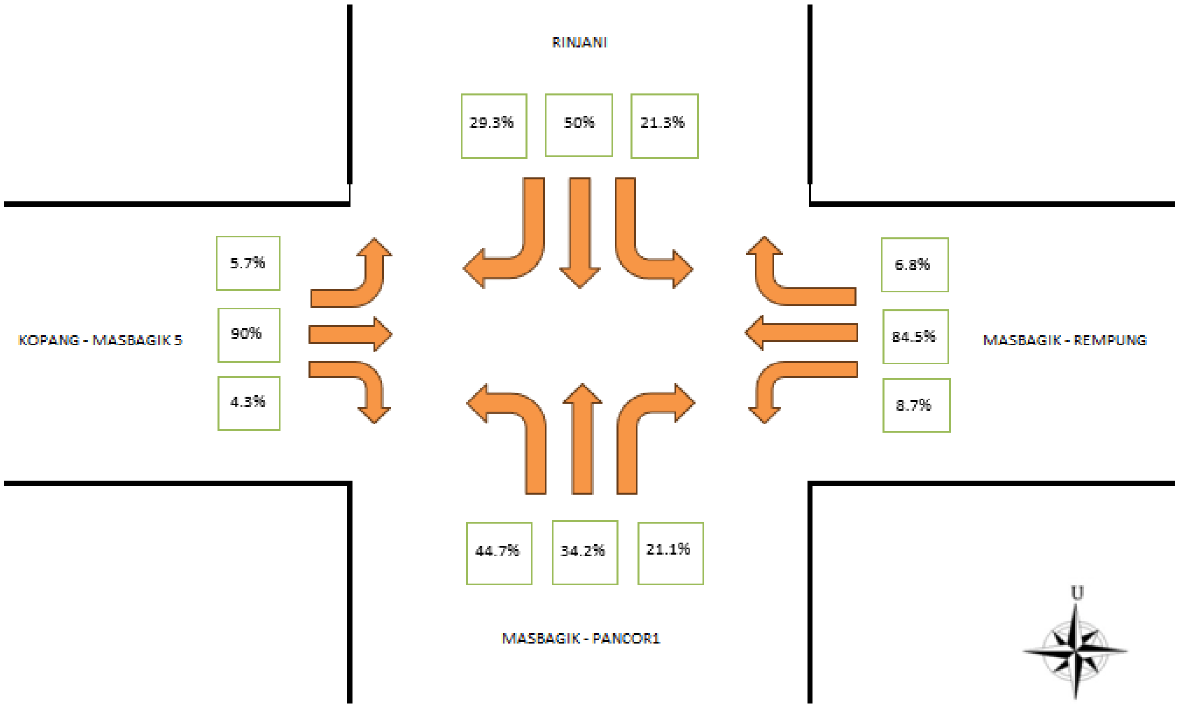

Figure 9. Percentage Distribution of Turning Flows by Approach at Masbagik Intersection

Segment Delay Comparison

Traffic delay is defined as the extra time a vehicle takes to travel a given distance compared to the ideal time it would take under free-flow conditions. Delay is a commonly used measure in traffic studies because it directly reflects the level of service and efficiency experienced by road users. It is calculated using the following formula:

$$Delay\ (sec) = D\left(\frac{1}{V_{obs}} - \frac{1}{V_{ff}}\right) \times 3.6$$

Where:

- D = segment length (km)
- V_{obs} = observed speed (km/h)
- V_{ff} = assumed free-flow speed (50 km/h)

According to Indonesian Road Capacity Guidelines, 2023 (Pedoman Kapasitas Jalan Indonesia, PKJI) the standard free-flow speed for urban arterial 2/2 UD roads is generally 40 – 50 km/h for mixed traffic in moderately dense urban areas. For our case (semi-urban commercial area with moderate congestion, we will use 50 km/h as a reasonable assumption. For readability, we will convert the delay in hours to seconds.

From Table 17 shows that these delay values show that even under moderate congestion, vehicles in this area experience approximately between 87 to 116 seconds of additional travel time per segment. Furthermore, while Rinjani road has the highest average speed, its long distance contributes to the longest delay, suggesting consistent flow despite higher volume. The variation in delay across segments emphasizes the influence of segment geometry and vehicle interaction beyond traffic volume alone.

Table 17. Traffic Delay Data

Segment	Length (m)	Observed Speed (km)	Free-flow Speed (km/h)	Estimated Delay (sec)
Kopang-Masbagik 5 road	2145	31.66	50	89.46
Masbagik-Rempung road	2503	33.71	50	87.09
Masbagik-Pancor 1 road	3147	35.14	50	95.85
Rinjani road	4636	37.08	50	116.31

Rush Hour Volume Clustering Analysis

Following from the previous analysis, this sub-section introduces a clustering approach to categorize traffic intensity throughout the day. While the previous section identified general peak hours based on visual trends, this clustering analysis provides a more systematic method to detect rush hour patterns and group time intervals with similar traffic conditions. The purpose of this analysis is to identify distinct clusters of traffic volume levels over time using classification rather than relying solely on observation. By doing so, the study can pinpoint specific high-volume windows that represent true rush hours, differentiate them from moderate or low-flow periods, and help assist in the design of IoT-based interventions like smart signal prioritization that are only activated during critical periods. This is especially important in semi-urban areas like Masbagik intersection area, where traffic conditions vary significantly throughout the day due to school hours, market activities, and regional commuting patterns.

The data used in this analysis consists of overlapping 1-hour time windows, recorded in 15-minute increments (e.g., 12:00 – 13:00, 12:15 – 13:15, and so on). The reason for using overlapping time windows is to see changes in traffic patterns more accurately. Traffic conditions do not always change exactly on the hour. For instance, a rush hour may start at 06:45, but if we only use full hour blocks (e.g., 06:00 – 07:00), we might miss when the traffic actually starts increasing. By checking traffic every 15 minutes, the analysis becomes more sensitive to real-world shifts and can detect the beginning and the end of congestion periods more accurately. Furthermore, each interval includes the total traffic volume (converted to pcu), and a cluster label (Volume_Cluster) representing its traffic intensity level.

A clustering algorithm (e.g., K-means) was applied to group time intervals into volume-based categories. Each interval is assigned a label that reflects which cluster it belongs to. The clustering analysis revealed a clear separation of traffic demand throughout the day, with time intervals grouped into three distinct volume categories: high, medium, and low. These categories align with observed traffic behavior and help define the temporal structure of congestion at the Masbagik intersection.

From the Table 18 we can see the high-volume cluster, representing rush hour conditions, includes time intervals from 06:00 to 07:45 in the morning and from 16:00 to 17:00 in the evening. These periods show strong and consistent spikes in traffic volume, likely due to school and work-related travel in the morning and return trips. These intervals are the most critical for traffic optimization, making them ideal candidates for smart traffic light strategies or longer green phases to accommodate the surge in demand.

Table 18. Rush Hour Volume Clustering

Hour	Total Volume	Volume_Cluster
12:00 – 13:00	2087	0
12:15 – 13:15	2107	0
12:30 – 13:30	2118	0
12:45 – 13:45	2097	0
13:00 – 14:00	2114	0
06:00 – 07:00	2563	1
06:15 – 07:15	2666	1
06:30 – 07:30	2620	1
06:45 – 07:45	2538	1
16:00 – 17:00	2624	1
16:15 – 17:15	2589	1
16:30 – 17:30	2512	1
07:00 – 08:00	2358	2
16:45 – 17:45	2429	2
17:00 – 18:00	2318	2

The low-volume cluster, on the other hand, occurs during the middle of the day from 12:00 to 14:00. These hours correspond to an ease in traffic activity, when most commuters are either stationary or off the road. Traffic flow is light and stable at these times, implying that standard fixed-time signal settings are likely sufficient without adaptive intervention. The medium-volume cluster covers transitional periods such as from 07:00 to 08:00 in the morning and from 16:45 to 18:00 in the evening. These hours occur as traffic begins to build up toward or taper off from peak levels. While not as intense as rush hours, these intervals still present moderate congestion and may require adaptive signal control if traffic volume increases.

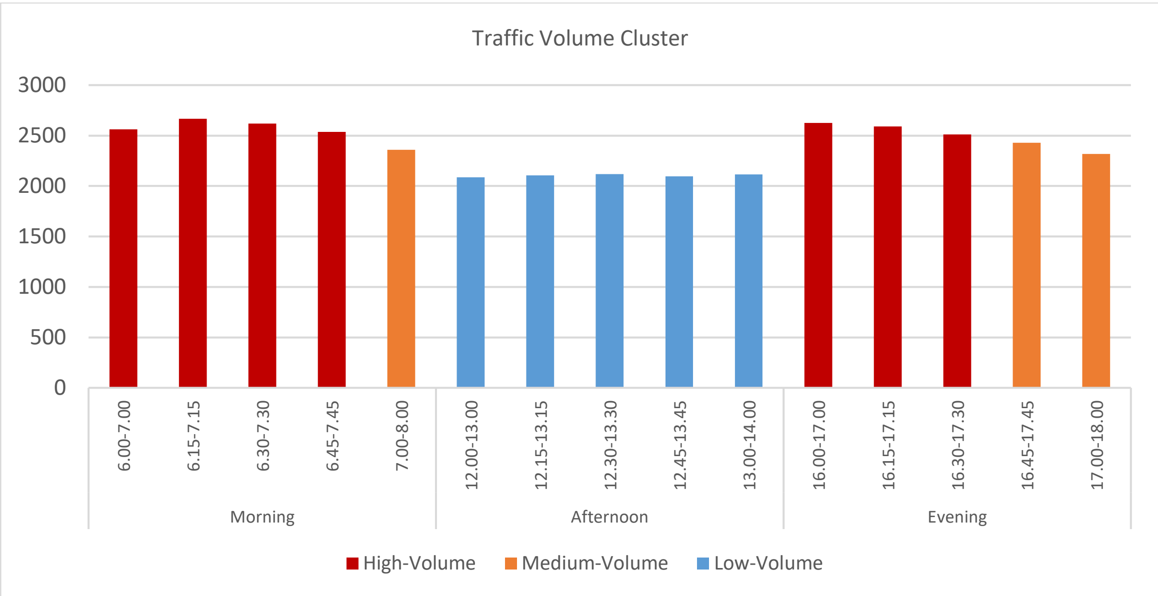

Figure 10. Traffic Volume Cluster

Overall, this clustering analysis deepens the descriptive traffic understanding by quantifying when traffic conditions transition from normal to congested. It also can improve the connection between field data and simulation by selecting clustered rush hours intervals, simulation input can more accurately reflect real-world congestion. This is important for evaluating the potential impact of smart traffic systems in peak versus off-peak settings.

Hourly Vehicle Volume by Type

Understanding how different vehicle types contribute to overall traffic volume throughout the day is essential for evaluating congestion dynamics and designing targeted interventions. This section presents an analysis of hourly traffic volume disaggregated by vehicle type, including motorcycles (MC), light vehicles (LV), and heavy vehicles (HV), based on classified traffic count data. While total traffic volume provides a broad picture of flow intensity, separated information reveals more complex patterns. Motorcycles, for example, usually dominate urban traffic in Indonesia, but their operation differs significantly from light and heavy vehicles. Motorcycles can weave through traffic, but heavy vehicles take longer to accelerate, take up more space, and frequently cause localized congestion. As a result, separating vehicle types helps identify what kind of traffic dominates at certain times, and how each type contributes to peak congestion.

From the figure below, we can see that motorcycles (MC) dominate traffic across all observed periods, with the highest volume occurring in the morning hours between 06:00 and 07:15. After this morning peak, motorcycle volume shows a gradual decline during the midday period between 13:00 and 14:00. In addition, smaller rise is observed in the late afternoon, particularly during the 16:15 – 17:15 interval. Light vehicle (LV) volume remains relatively stable throughout the day, fluctuating within a narrower range compared to motorcycles. The volume of light vehicles is highest during the evening period, especially from 16:15 to 17:30, which may correspond with commuter travel and school pick-ups. Heavy vehicles (HV) show their peak during the midday hours, from 12:45 to 13:45, a pattern likely associated with deliveries and local goods movement. These observations indicate that different vehicle types has different operational cycles, which must be considered when evaluating intersection performance and planning control strategies. All traffic counts were converted to passenger car units (pcu) using PKJI-2023 with the standard conversion factors: MC = 0.5, LV = 1.0, HV = 1.3.

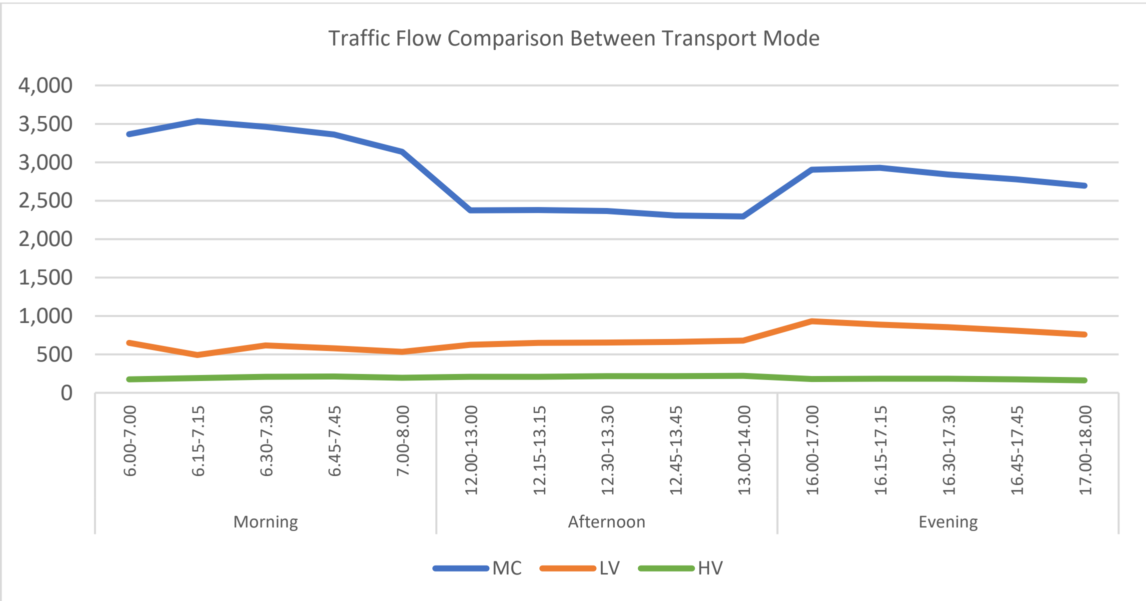

Figure 11. Traffic Flow Comparison Between Transport Mode

These insights are important for designing more targeted and efficient traffic solutions. Understanding not just how much traffic moves through an area, but what type of vehicles dominate at different times, adds depth to congestion diagnosis and supports more responsive traffic management strategies, especially when testing smart traffic light systems or vehicle-prioritized IoT-based interventions.

Analyzing Peak Congestion and Heavy Vehicle Patterns to Strengthen the Case for Smart Traffic Light Implementation

This section takes what we have learned from previous “Rush Hour Volume Clustering Analysis” and “Hourly Vehicle Volume by Type” analysis, and puts it all together. By examining when the intersection is busiest and how heavy vehicle move through it, we can clearly show how smart traffic solutions can address the current traffic jams and safety issues discussed in the problem statement.

Analysis from the Rush Hour Volume Clustering Analysis section showed us when traffic hits its peak: in the morning (06:00 – 07:00) and again in the late afternoon (16:00 – 17:00). These are times when people are going to school and work. In the Segment Performance Analysis section pointed out, during these busy times, roads like Kopang-Masbagik 5 and Masbagik-Rempung are struggling, operating at what we call a Level of Service (LoS) in D level. In plain terms, this means drivers face a lot of stop-and-go traffic and everything slows down. This supports the congestion issues highlighted in the Problem Statement section. The Masbagik intersection’s using unsignalized configuration (a type 422 four-leg configuration) is inadequate to manage these surges, leading to increased longer queues and intersection saturation.

At the same time, from the “Hourly Vehicle Volume by Type” analysis, it shows something interesting about heavy vehicles, their busiest time is around midday. Even though it is not during the main rush hours, these large vehicles create their own set of challenges. Because their big shapes and slow to get going, they can really affect the flow of other traffic. The observed midday inefficiencies caused by heavy vehicles, despite moderate total volumes, mirror findings by Prasetijo et al. (2011), who emphasized the frictional effects of large vehicles on unsignalized intersection performance under mixed traffic. Their research confirms that vehicle type, not just volume, significantly influences capacity under uncontrolled conditions, reinforcing the need for time and vehicle-sensitive traffic control systems. This is especially true at an intersection like Masbagik, which already has medium levels of side friction. In addition, lanes leading to the intersection vary in width and there are no dividers in the middle, making it more difficult when large HVs are trying to get through. This can make the existing problems of infrastructure wear and safety concerns even worse. When we look at these specific traffic patterns, the intense rush hour jams and the impact of heavy vehicles, it becomes clear that the way Masbagik intersection is currently managed is not working well enough. It does not have any kind of Advanced Traffic Control System (ATCS). This is where smart traffic lights come in.

- ***Managing Heavy Vehicle Impact and Enhancing Safety***
  Smart systems can also help with the challenges caused by heavy vehicles. They could potentially identify these larger vehicles using sensors or cameras, and adjust the signal timings to help them pass through more easily and safely. This would cause less disruption to other traffic. It is a much more proactive way to manage things than what is happening now, and it would make the intersection safer for everyone. This is important as mentioned in the survey

results showed, safety is a big concern, with issues like reckless driving and drivers not obeying signals, being key causes of accidents.

- ***Aligning with Public Expectation and Improving Overall Efficiency***
  From the survey analysis, it shows strong public support for implementing smart traffic light systems, reflecting a perception that such technology can reduce delays and improve safety. The detailed traffic patterns analyzed in this study provide the technical reasons for the improvement. The transition from an unsignalized, uncontrolled intersection to an effectively managed one is expected to significantly enhance the overall operational efficiency and safety of the Masbagik road network. This directly addresses the core research question of how IoT can optimize traffic flow and improve safety.

In conclusion, when the specific temporal patterns of congestion and the distinct behavior of different vehicle classes are assessed against the Masbagik intersection, it shows a clear picture. Improving the intersection from unsignalized to signalized intersection is not just a small improvement; it is a vital step for creating a safer and more reliable traffic system in East Lombok.

Analytical Performance Assessment for Masbagik Unsignalized Intersection

This sub-section is specifically will assess the Masbagik unsignalized intersection as a base case for the later use on the research. The analysis will focus on evaluating its capacity, degree of saturation, and vehicle delays under current traffic loads. The following details an analytical performance assessment of the exiting unsignalized Masbagik Intersection using the methodologies outlined in the PKJI 2023, specifically Chapter 6 about Unsignalized Intersection Capacity.

In the PKJI 2023, it provides a standardized framework for analyzing unsignalized intersections in Indonesia. The following steps detail the calculation of Capacity (C), Degree of Saturation (DJ), and average vehicle delay (T) for the Masbagik Intersection based on its existing geometry and surveyed traffic volumes.

Input Data

a. Intersection Type and Geometry

The Masbagik intersection is a 4-leg intersection, all approaches have 2 lanes. This corresponds to intersection type 422 as per PKJI 2023 Table 6-2. Effective approach widths (L_E) from table 14 are:

- North (Rinjani, Minor): $L_{E,North}$ = 11.9 m
- South (Masbagik – Pancor 1, Minor): $L_{E,South}$ = 9 m
- East (Masbagik – Rempung, Mayor): $L_{E,East}$ = 9.6 m
- West (Kopang – Masbagik , Mayor: $L_{E,West}$ = 10.5 m
- Median: No median is present on any approach (PKJI Table 6-3, F_M = 1.0)

Based on this hierarchy (Arterial > Collector > Local), for the Masbagik intersection, the mayor roads are the West and East, since both of the roads are Arterial roads. The North and South approaches, being Local and Collector roads respectively, are designated as the minor roads.

b. Traffic Volumes (q)

The Traffic volumes are sourced from the Figure 8 (“Classified Turning Movement Count (CTMC) Survey Result”). These volumes are stated to be already converted to pcu/h.

- $q_{North,total}$ = 270 pcu/h

- $q_{East,total}$ = 616 pcu/h
- $q_{South,total}$ = 494 pcu/h
- $q_{West,total}$= 722 pcu/h

Total intersection inflow (q_{KB}) = 722 + 270 + 616 + 494 = 2102 pcu/h

c. ***Environmental and Other Conditions***

The population of East Lombok is 1.350.650 inhabitants, categorizing as a big city. According to PKJI 2023, Table 6-4, for a city population between 1.0 – 3.0 million, the city size correction factor (F_{UK}) is 1.0.

- Side Friction (F_{HS}):
  The Road Environment type is in a commercial area. The side friction class is classified as "medium" for all approaches. In addition, since from the Figure 8 the Unmotorized (UM) indicates zero vehicles, the ratio of non-Motorized vehicles (R_{KTB}) is 0. From PKJI 2023, Table 6-7, for environment type commercial, side friction class medium, and R_{KTB} is 0, the F_{HS} = 0.94

- Turning Ratios (Overall Intersection):
  - Total Left Turns ($Q_{T,BKi}$): (43 (W) + 57 (N) + 51 (E) + 205 (S)) = 356 pcu/h
  - Total Right Turns ($Q_{T,BKa}$): (34 (W) + 79 (N) + 45 (E) + 95 (S)) = 253 pcu/h
  - Left-Turn Ratio (R_{BKi}): $Q_{T,BKi}/q_{KB}$ = 356/2102 = 0.169
  - Total Left Turns (R_{BKa}): $Q_{T,BKa}/q_{KB}$ = 253/2102 = 0.120
  - Total Turning Ratios (R_B) for geometric delay calculation = R_{BKi} + R_{BKa} = 0.289

- Ratio of Minor Road Flow (R_{mi}):
  - Flow from Minor Roads (q_{mi}): $q_{North,total}$ + $q_{South,total}$ = 764 pcu/h
  - R_{mi}: q_{mi}/q_{KB} = 764/2102 = 0.363

Calculation of Intersection Capacity (C)

The capacity of the unsignalized intersection is calculated using PKJI 2023 Equation 6-2, by applying various correction factors to the basic capacity.

a. ***Average Approach Width (LRP)***

- Average Approach Width for Major Roads (LRP_major): ((9.6 m/2) + (10.5 m/2))/2 = 5.025 m
- Average Approach Width for Minor Roads (LRP_minor): ((11.9 m/2) + (9 m/2))/2 = 5.225 m
- Overall Average Approach Width (LRP_avg): (5.025 + 5.225)/2 = 5.125 m

b. ***Basic Capacity (C0)***

From PKJI 2023, Table 6-1, for intersection type 422, C0 = 2900 pcu/h

c. ***Correction Factor for Average Approach Width (F_{LP})***

- Using PKJI 2023 Equation 6-3 (for type 422):
- F_{LP} = 0.70 + 0.0866 x LRP_avg (5.125) = 1.144

d. ***Correction Factor for Median (F_M)*** = 1.0 (no median)

e. ***Correction Factor for City Size (F_{UK})*** = 1.0

f. ***Correction Factor for Side Friction (F_{HS})*** = 0.94

g. ***Correction Factor for Left-Turning Flow (F_{BKi}):***

R_{BKi} = 0.169. Using PKJI 2023 Equation 6-8: F_{BKi}: 0.84 +1.61 x 0.169 = 1.112

h. *Correction Factor for Right-Turning Flow (F_{BKa}):*
For a 4-leg intersection (type 422), PKJI 2023 Equation 6-9 states: F_{BKa}: 1.0

i. *Correction Factor for Minor Road Flow Ratio (FR_{mi}):*
R_{mi}: 0.363. For type 422, from PKJI 2023 Table 6-8, FR_{mi} = 1.19 x R_{mi}^2 – 1.19 x R_{mi} + 1.19 = 0.915

j. *Calculate Overall intersection Capacity (C):*
- Using PKJI 2023 Equation 6-2, C = C0 x F_{LP} x F_M x F_{UK} x F_{HS} x F_{BKi} x F_{BKa} x FR_{mi}
- C = 2900 x 1.144 x 1 x 1 x 0.94 x 1.112 x 1 x 0.915 = 3173.7 pcu/h
- The Capacity (C) is 3173.7 pcu/h

Determination of Intersectino performance (Reflecting PKJI Form S-II)

a. *Calculate Degree of Saturation (DJ)*
- Using PKJI 2023 Equation 6-11, DJ = q_{KB}/C
- DJ = 2102 / 3174 = 0.662

b. *Calculate Average Intersection Delay (T)*
- Traffic Delay (T_{LL}): since DJ > 0.6, using Equation 6-14:
  $T_{LL} = \frac{1.0504}{(0.2742-0.2042 \times DJ)} - (1-DJ)^2$ = 7.44 seconds/pcu

- Geometric Delay (T_G): with Total Turning Ratio R_B = 0.289, PKJI 2023 Equation 6-18 (for DJ < 1):
  $T_G = (1-DJ) \times \{6 \times R_B + 3 \times (1-R_B)\} + 4 \times \mathrm{DJ}$ = 3.96 seconds/pcu

- Total Average Intersection Delay (T): Using PKJI Equation 6-12:
  T = $T_{LL} + T_G$ = 7.44 + 3.96 = 11.40 seconds/pcu

- Delay on Major vs. Minor Roads:
  - Traffic Delay on Major Road (T_{LLma}), using PKJI 2023 Equation 6-16:
    T_{LLma} = 5.59 seconds/pcu
  - Traffic Flow from Major Roads (q_{ma}) = 1338 pcu/h
  - Traffic Flow from Major Roads (q_{mi}) = 764 pcu/h
  - Traffic Delay on Minor Road T_{LLmi}, using PKJI 2023 Equation 6-17:
    T_{LLmi} = 10.68 seconds/pcu

  - Total Average Delay for Minor Approaches (T_minor):
    T_minor: T_{LLmi} + T_G = 14.64 seconds/pcu
  - Total Average Delay for Major Approaches (T_mayor):
    T_minor: T_{LLma} + T_G = 9.55 seconds/pcu

Summary of Calculated Analytical metrics for the Existing Unsignalized Masbagik Intersection

This analytical assessment of the Masbagik unsignalized intersection, utilizing the PKJI 2023, provides quantitative insights into its current operational characteristics. The overall Degree of Saturation of approximately 0.662 indicates that the intersection operates below its theoretical capacity during the analyzed design hour, utilizing about 66% of its available capacity. While a DJ value below 0.85 is generally considered acceptable within PKJI guidelines, this overall figure can cover up a lot of differences in performance across approaches.

The average delay for all vehicles crossing the intersection estimated to be approximately 11.40 seconds. However, a more significant finding is the difference in delay between vehicles on major and minor road approaches. Vehicles on the minor road approaches (North and South) are expected to have an average delay of 14.64 seconds. Vehicles on the major road approaches (East and West) have a shorter average delay of about 9.55 seconds.

This difference is typical of unsignalized intersections where minor road traffic must yield to major road traffic, which frequently results in longer wait times to find safe gaps, especially as traffic volumes on the major road increase. These calculated average delay values, particularly the separate figures for major and minor approaches, serve as critical quantitative benchmarks. They will be the primary targets for the calibration of the VISSIM base model representing the existing unsignalized conditions. Key Summary:

- Overall Intersection Capacity (C): 3174 pcu/h.
- Overall Intersection Degree of Saturation (DJ): 0.662.
- Overall Average Intersection Delay (T): 11.4 seconds/vehicle.
- Average Delay on Major Approaches (T_mayor): 9.55 seconds/vehicle.
- Average Delay on Minor Approaches (T_minor) 14.64 seconds/vehicle.

Proposed Design for Signalized Masbagik Intersection with Integrated Pedestrian Facilities

Overall Design Objectives and Principles

The main objective for redesigning the Masbagik intersection is to transition it from its current unsignalized state to an efficiently managed, signalized intersection that improves safety and mobility for all road users. The proposed design is grounded in the following principles:

- ***Safety First***: Prioritizing the reduction of conflict points and providing protected movements for both vehicles and pedestrians.
- ***Efficiency:*** Optimizing traffic flow to reduce delays and queue lengths, especially during peak periods.
- ***Accessibility:*** Making sure the intersection is easily and safely navigable for all pedestrians, including those with mobility challenges.
- ***Compliance with Indonesian Standards****:* Following the guidelines set forth in the Indonesian Road Capacity Guidelines, 2023 (Pedoman Kapasitas Jalan Indonesia, PKJI) for traffic light system design and relevant Ministry of Public Works regulations for pedestrian facilities.
- ***IoT Integration Potential:*** Designing a signal system that is compatible with future integration of IoT-based smart traffic management features for adaptive control and real-time monitoring.

Proposed Vehicular Traffic Signalization

Based on the traffic volume analysis and the procedures outlined in PKJI 2023 (in Chapter 5: Traffic Light Intersection Capacity), a signalized control has been developed. The design incorporates the latest city population data for East Lombok (1.350.650 inhabitants, leading to F_UK = 1.00) and detailed calculations in the following chapter.

Design Hour Traffic Volume (q) and Design Parameters

The design of the traffic light system for the Masbagik intersection requires precise design hour traffic volumes expressed in Passenger Car Units (pcu). These volumes come from a Classified Turning Movement Count (CTMC) survey conducted at the intersection.

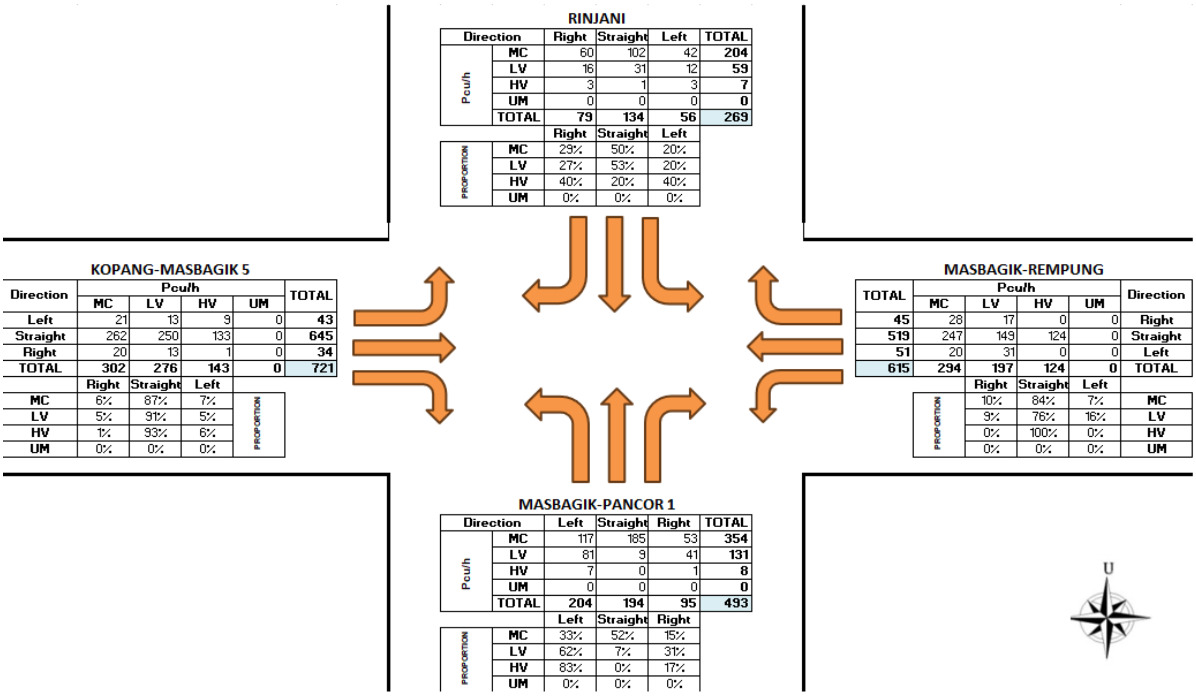

Figure 12. Design Hour Volumes for Traffic Light System Design at Masbagik Intersection

- *North Approach (Rinjani):*
  Total q_N = 270 pcu/h (Left:57, Straight: 134, Right: 79)
- *East Approach (Masbagik-Rempung):*
  Total q_E = 616 pcu/h (Left: 51, Straight: 520, Right: 45)
- *South Approach (Masbagik-Pancor 1):*
  Total q_S = 494 pcu/h (Left: 205, Straight: 194, Right: 95)
- *West Approach (Kopang-Masbagik 5):*
  Total q_W = 722 pcu/h (Left: 43, Straight: 645, Right: 34)

The PCU values presented in Figure 12 are calculated for the purpose of designing the traffic light system and evaluating its operational performance under signalized conditions. From Table 5-2 of PKJI 2023, it specifies the equivalents for Passenger Car Units (PCU). The following PCUs were applied to the assumed vehicle movements in the proposed phasing plan; for Motorcycle (MC) it is 0.15, for Light Vehicle (LV) it is 1.0, and for Heavy Vehicles (HV) it is 1.30. It is important to note that these PCU values are specific to the analysis of signalized intersections as per PKJI 2023. They reflect the discharge characteristics of different vehicle types from a queue at a traffic signal.

At previous section, readers may recall Figure 8. Classified Turning Movement Count (CTMC) Survey Result, where general traffic volumes for the Masbagik area were presented using a different set of PCU values, notably an PCU of 0.5 for motorcycles. That earlier conversion was appropriate for general traffic stream analysis or for evaluating the capacity and Level of Service of unsignalized segments or intersections based on different sections of road capacity manuals (such as those for urban road segments where motorcycle behavior in continuous flow might differ).

However, for the detailed of the traffic signal timings, saturation flows, and signalized intersection capacity presented in this current section, the PKJI 2023 guidelines for traffic light address the use of the specific PCUs from Table 5-2. This ensures that the traffic light design is based on the most relevant and accurate representation of how mixed traffic operates under signalized control. The use of these traffic light-specific PCUs (MC = 0.15) results in different total PCU volumes for traffic light design compared to general capacity analysis figures previously presented. The volume in Figure 12 above are the definitive inputs for all subsequent traffic light calculations in this chapter. Next, the key PKJI 2023 Correction Factors applied:

a. City Size Factor (F_UK): 1.00 (Population: 1.345.650 for East Lombok, categorized as large city).
b. Side Friction Factor (F_HS): N = 0.94, E = 0.94, S = 0.94, W = 0.94 (based on commercial environment, medium side friction, and Non-Motorized Vehicle Ratio (R_KTB) = 0 as UM = 0).
c. Gradient Factor (FG): Assumed 1.0 (flat approaches).
d. Parking Factor (FP): Assumed 1.0 (no immediate parking impact at stop line affecting saturation flow).
e. Left/Right Turn Ratio (RBKi/RBKa), with formula: RBKi = q_left/q_total, RBKa = q_right/q_total.
    - North: RBKi_N = 0.211, RBKa_N = 0.293
    - East: RBKi_E = 0.083, RBKa_E = 0.073
    - South: RBKi_S = 0.415, RBKa_S = 0.192
    - West: RBKi_W = 0.060, RBKa_W = 0.047
f. Left/Right Correction Turn Factors (FBKi/FBKa): Calculated for each approach based on turning ratios and PKJI formulas (Eq. 5-27, 5-28) for protected movements:
    - North: FBKi_N = 0.966, FBKa_N = 1.076
    - East: FBKi_E = 0.987, FBKa_E = 1.019
    - South: FBKi_S = 0.934, FBKa_S = 1.050
    - West: FBKi_W = 0.990, FBKa_W = 1.012

Proposed Vehicular Phasing Plan

A vehicular plan is proposed as the foundational structure for signal operation:

- Vehicular Phase 1 (VP1): North Movements. Permits all traffic movement (Left, Through/Straight, Right) from the North (Rinjani road) approach. Traffic from East, South, and West will have a red signal.
- Vehicular Phase 2 (VP2): East Movements. Permits all traffic movements (Left, Through/Straight, Right) from the East (Masbagik-Rempung road) approach. Traffic from North, West, and South will have a red signal.
- Vehicular Phase 3 (VP3): South Movements. Permits all traffic movement (Left, Through/Straight, Right) from South (Masbagik-Pacor 1 road) approach. Traffic from the other approaches will have a red signal.
- Vehicular Phase 4 (VP4): West Movements. Permits all traffic movements (Left, Through/Straight, Right) from West (Kopang-Masbagik 5 road) approach. Traffic from the other approaches will have a red signal.

Saturation Flow (J) and Critical Flow Ratios (y)

Basic Saturation Flow (J0) for each approach is calculated using PKJI Equation 5-6 (J0 = 600*LE (Effective Approach Width). Adjusted Saturation Flows (J) for each approach, using approach widths from Table 13 Intersection Inventory: N = 11.9 m, E = 9.6 m, S = 9 m, W = 10.5 m) and integrate all relevant PKJI 2023 correction factors (with F_HS = 0.94 for all). J = J0 * F_HS * F_UK * FG * FP * FBKi * FBKa

- J_N = 6978.2 pcu/h
- J_E = 5444.2 pcu/hv

- J_S = 4975.9 pcu/h
- J_W = 5937.4 pcu/h

The Flow Ratio (y_i = q_approach/J_approach) for each approach indicates the proportion of saturated green time required by that approach. The Critical Flow Ratio for each phase is the highest ‘y’ value among the approaches operating in that phase:

a. Vehicular Phase 1 (VP1: North Approach)
    - y_N = q_N/J_N = 0.0387
b. Vehicular Phase 2 (VP2: East Approach)
    - y_E = q_E/J_E = 0.1131
c. Vehicular Phase 3 (VP3: South Approach)
    - y_S = q_S/J_S = 0.0993
d. Vehicular Phase 4 (VP4: West Approach
    - y_W = q_W/J_W = 0.1216

The total of Critical Vehicular Flow Ratios (Y_vehicle), also known as Intersection Flow Ratio (RAS) in PKJI, is the sum of the flow ratios for all vehicular phases. The total of the Y_vehicle is 0.3727.

This Y_vehicle value of approximately 0.3727 is relatively low (well below typical design thresholds of 0.85 – 0.90 mentioned in PKJI 2023), means that the current vehicular demand represents only about 37.3% of the intersection’s theoretical capacity if all four-approaches were given green time proportional to their demand and were fully saturated during those times. In addition, this provides flexibilitiy in designing the signal cycle, especially for setting adequate time for pedestrian movements without imposing undue delays on vehicles. The primary constraint on cycle length will most likely be the need to accommodate all five phases (four vehicular and one pedestrian) with practical minimum green times, rather than extremely high vehicular congestion. The following sections will go over the integration of pedestrian facilities and the final decision of the operational cycle length and green time allocations for all users.

Proposed Pedestrian Facilities and Signal Integration

The plan to transform of the Masbagik intersection into a signalized junction represents an opportunity to improve pedestrian safety and mobility. The existing unsignalized environment, combined with the high pedestrian activity captured in this research, as shown in Table 14 about “Pedestrian Data for Masbagik Commercial Area” and Table 15 about “Peak Pedestrian Crossing Volumes at Masbagik Intersection Approaches”, the Masbagik commercial area experiences substantial pedestrian traffic. This includes longitudinal flows along all approach roadsides (with peak hourly demands up to approximately 330 pedestrians/hour on the Masbagik-Rempung approach), and considerable crossing volume at the intersection (peak hourly rates ranging from 62 to 78 pedestrians per approach).

Furthermore, my analysis of these volumes against established criteria (refer to sub-section “Recommendation for Pedestrian Crossing Facilities, e.g., Table 16”, concluded that Pelican (signalized pedestrian) crossings are warranted for all four approaches to the Masbagik intersection, based on a PV^2 analysis that indicated high conflict potential under existing conditions. This sub-chapter now outlines the specific design recommendations for integrating these pedestrian facilities into the traffic signal system.

Recommended Sidewalk Infrastructure

The installation of continuous and adequately sized sidewalks is vital to pedestrian safety, as it creates a dedicated pathway physically separated from vehicular traffic. Building upon previous research discussion (section “Required Sidewalk Width”, pages 44-45), which considered the observed longitudinal pedestrian flows and relevant Indonesian standards (e.g., Ministry of Public Works Regulation No. 3/2014 regarding technical road requirements), the following sidewalk installation are reaffirmed and included into this design:

- ***Minimum Sidewalk Width:*** It is strongly recommended that all approaches be equipped with accessible sidewalks with a minimum clear effective width of 2 meters.
- ***Improved Width for High-Demand Corridors*****:** Specifically for the arterial road segments of Masbagik-Rempung (east) and Kopang-Masbagik 5 (west), which identified as having the highest pedestrian through-flows and which are characterized by significant commercial frontage, a sidewalk width of 2.5 to 3 meters is recommended where physically feasible.

Justification for Recommended Widths:

- ***Accomodating Observed Demand and Ensuring Comfort:*** the 2 meters of minimum width is important to comfortably accommodate bi-directional pedestrian flow without requiring individuals to step aside frequently or resort to walking on the carriageway, especially during peak pedestrian periods. The wider 2.5 to 3 meters provision on busier commercial entrances allows for a higher Pedestrian Level of Service, which better accommodates other activities like window shopping, entry/exit from places, and small group movement without causing sidewalk congestion.
- ***Enhancing Safety:*** Wider sidewalks provide a more substantial physical and psychological buffer from nearby vehicular traffic, which is important on arterial roads with high vehicle speeds and volumes. This improves pedestrians actual and perceived safety.
- ***Promoting Accessibility:*** These recommended widths are more user-friendly for all demographics, including those who use strollers, wheelchairs, or other mobility aids, aligning with universal design principles and guaranteeing equal access to the commercial area.
- ***Standard Compliance and Best Practice:*** The 2 meters minimum is consistent with the intent of the national guidelines mentioned in the research, which seek to provide an acceptable level of pedestrian infrastructure in urbanized commercial settings.
- ***Emphasis on “Clear Effective Width”:*** This specified width represents the unobstructed pathway. The design, future implementation, and ongoing maintenance must make sure that these sidewalks are kept free of permanent impediments such as poorly sited utility poles, vendor stalls, parked vehicles, or any surface irregularities that would otherwise reduce their functional width and utility.

The establishment and maintenance of this standard of sidewalk infrastructure is a prerequisite for creating a safe and functional environment for pedestrians approaching, departing, and circulating the newly signalized Masbagik intersection.

Proposed Pedestrian Signal Phasing Strategy and Timing

A dedicated pedestrian signal phase should be included in the traffic signal system operational plan on all approaches. This is an important step toward protecting pedestrians from vehicular conflicts and formalizing their right-of-way, transforming the intersection into a truly multi-modal space. The recommended phasing strategy is Exclusive Pedestrian Phase (PedP). This strategy involves a separate stage withing the overall signal cycle in which all vehicular traffic from all four approaches comes to a complete stop (i.e., all vehicle signals display red). During this exclusive interval, pedestrians are granted the right-of-way to cross all legs of the intersection simultaneously, free from any conflicting vehicular movements.

Justification for an Exclusive Pedestrian Phase:

- ***Direct Response to Safety Imperative:*** The PV^2 analysis in the research (Table 16) provides strong quantitative justification for high pedestrian protection. An exclusive phase is the most solid implementation of signalized pedestrian control, directly mitigating the high conflict potential identified from the analysis and carrying out the “Pelican” crossing recommendation.
- ***Maximizing Pedestrian Safety:*** By completely separating pedestrian and vehicular movements in time, this strategy eliminates all potential vehicle-pedestrian conflicts during the crossing. This is essential since the Masbagik commercial area attracts a diverse pedestrian population, including more vulnerable users (such as children, the elderly, and people with disabilities) who benefit the most from a simple and fully protected crossing environment.
- ***Accommodation of Multi-Directional Crossing Needs****:* Pedestrian desire lines in bustling commercial districts are frequently complex and multi-directional, with people wanting to get to any of the four corners of an intersection. An exclusive phase naturally supports these movements with greater ease and safety.
- ***Clarity and Lower Cognitive Load for Pedestrians:*** A clear “WALK” signal during an exclusive phase is unambiguous to pedestrians. They are not required to assess gaps in potentially conflicting turning vehicular traffic, which simplifies the crossing task, reduces hesitation, and reduces the risk of misjudgment, especially in a mixed traffic environment with a large number of motorcycles, where driver behavior can be unpredictable.

For the Exclusive Pedestrian Phase, it is designed and timed to give pedestrian enough time to perceive, initiate, and safely complete the crossing. The calculations are based on standard engineering parameters for pedestrian movement and the Masbagik intersection’s unique geometric characteristics.

a. “WALK” Interval**:** A duration of 7 seconds is proposed. This period is generally accepted in traffic signal design practice as adequate for pedestrians waiting at the curb to recognize the “WALK” signal indication, assess the environment as safe (confirming that all vehicles have stopped), and confidently step into the crosswalk.

b. Pedestrian Clearance Interval*:* This interval ensures that pedestrians who entered the crosswalk during the “WALK” interval have enough time to get to the safety of the opposite curb before conflicting vehicular traffic is released. The calculation follows the standard formula; Pedestrian Clearance Time = Crossing Distance (LPK) / Assumed pedestrian Walking Speed (vPK). For the Crossing Distance (LPK), the “Total Pavement Width” for each approach, as detailed in the Table 13 (“Inventory of Masbagik Intersection”), is used as the effective crossing distance for pedestrians. With LPK_N = 11.9 meters; LPK_E = 9.6 meters; LPK_S = 9 meters; LPK_W = 10.5 meters.

The Assumed Pedestrian Walking Speed (vPK) has an assumed design walking speed of 1 m/s. This is a conservative value that often preferred for urban commercial areas with a diverse pedestrian population, to ensure that clearance time is enough for nearly all users. While PKJI 2023 uses 1.2 m/s in some general contexts (e.g., for all-red calculations in Eq. 5-9), using 1 m/s when designing pedestrian phase clearance times improves safety margins and inclusivity. So, the calculated clearance times for each approach is: Clearance_North = 11.9 seconds; Clearance_East = 9.6 seconds; Clearance_South = 9 seconds; and Clearance_West = 10.5 seconds.

c. ***Regulating Clearance Time for the Exclusive Phase:*** Since all pedestrian crossings will operate at the same time during the exlusive phase, the overall clearance interval must be long enough to accommodate the longest individual crossing. As a result, the overall pedestrian clearance is 11.9 seconds (determined by the widest road crossing, which is North/Rinjani road).'

d. ***Total Displayed Pedestrian Phase Time (g_ped_display):*** This sums the "WALK" interval with the regulating clearance interval: 7 seconds (WALK) plus 11.9 seconds (Clearance), with a total of 18.9 seconds. For practical implementation in traffic signal controllers and to provide a small operational buffer, this will be rounded up to 19 seconds. This 19-second period represents the total time pedestrians have the obvious and solid right-of-way to use the designated crosswalks on all approaches.

The specific timings calculated here will be used into the final integrated traffic light system design and operational timings presented in the following section.

Table 19. Pedestrian Phase Timing

Parameter	Duration (sec)	Description
"WALK" interval	7	Time for pedestrians to recognize the "WALK" signal and enter the crosswalk
Clearance_North	11.9	Time for pedestrians to cross the North approach
Clearance_East	9.6	Time for pedestrians to cross the East approach
Clearance_South	9	Time for pedestrians to cross the South approach
Clearance_West	10.5	Time for pedestrians to cross the West approach
Regulating Clearance Time	11.9	Longest individual crossing time, used for the exclusive phase
Total Displayed Pedestrian Phase Time	19	"WALK" interval + Regulating Clearance Time (rounded up)

Final Integrated Traffic Light Design and Operational Timings

This section combines the vehicular signalization design with the requirements of the exclusive pedestrian phase to calculate the final operational signal timings for the Masbagik intersection. The system will operate as a five-stage controller: four dedicated vehicular phases (one for each approach: North, East, South, West) and one exclusive all-way pedestrian crossing phase.

The sequence of phases will be: Vehicle Phase 1 (VP1): North approach green, Vehicle Phase 2 (VP2): East approach green, Vehicle Phase 3 (VP3): South approach green, Vehicle Phase 4 (VP4): West approach green, Pedestrian Phase (PedP): Exclusive all-way pedestrian crossing green. Then, this sequence repeats.

a. Intergreen Times (wAH) and Total Lost Time

The intergreen time is the period between the end of a green signal for one phase and the beginning of the green signal for the next conflicting phase. It comprises a yellow clearance interval (wK) and an all-red clearance interval (wMS).

- Standard yellow clearance interval (wK): 3 seconds.
- Standard all-red clearance interval (wMS) for vehicle-to-vehicle and vehicle-to-pedestrian transitions: 2 seconds.
- Total lost time for these transitions: wK + wMS = 3s + 2s = 5 seconds.
- For the transition from the Pedestrian Phase (PedP) back to a vehicular phase (VP1), pedestrians do not have a yellow interval. A vehicular all-red buffer is used: wMS = 2 seconds.

For the 5-phase cycle (VP1 → VP2 → VP3 → VP4 → PedP → VP1):

- Transition VP1 → VP2 (North to East): 5 seconds.
- Transition VP2 → VP3 (East to South): 5 seconds.
- Transition VP3 → VP4 (South to West): 5 seconds.
- Transition VP4 → VP1 (West to North): 5 seconds.
- Transition PedP → VP1: 2 seconds.

Total lost time per cycle (wHH_final), the sum of these necessary non-green periods = (5s x 4) + 2s = 22 seconds.

b. Final Cycle Length (C_final or s)

The choice of cycle length (C_final) must accommodate all five phases, the total lost time, and the required pedestrian phase time, while aiming for efficiency. With the total lost time (wHH_final) is 22 seconds and the sum of vehicular flow ratios (Y_vehicle) is 0.3727, the optimal cycle length (C_opt_vehicle) for the vehicular components (ignoring pedestrian fixed time for this initial estimation, Webster's Formula – PKJI Eq. 5-11) is:

- C_opt_vehicle = (1.5 * wHH_vehicle_only + 5) / (1 – Y_vehicle)
- C_opt_vehicle = (1.5 * 22s + 5s) / (1 – 0.3727) = (33s + 5s) / 0.6273 = 60.57 seconds ≈ 61 seconds.

A cycle length of approximately 61 seconds is suggested by Webster's formula based on purely vehicular flows and associated lost times. However, this cycle must also accommodate the 19-second pedestrian phase. A practical cycle length must be chosen. Given Y_vehicle value (0.3727), the intersection is not heavily saturated from a vehicular perspective. A common range for multi-phase signals is 60 to 120 seconds. Let's adopt a 120-second cycle length for this design. This provides a reasonable balance, allowing enough time for all five phases including the substantial pedestrian phase, without being excessively long which could increase delays.

c. Green Time Allocation

- Total Effective Green Time available within the 120s cycle:
  G_eff_total = C_final – wHH_final) = 120s - 22s = 98 seconds

- Pedestrian Phase (PedP) Green Display Time (g_ped_display):
  This is fixed based on pedestrian crossing requirements and is set to 19 seconds.
- Remaining Effective Green Time for Vehicular Phases:
  G_eff_total - g_ped_display = 98s - 19s = 79 seconds.
- Adjusted Green Time Allocation for Vehicular Phases
  This 79-seconds is now distributed proportionally among North, East, South, and West approaches to their calculated flow ratios (yN, yE, yS, yW). Sum of flow ratios these approaches: $Y_{critical}$ = 0.1131 + 0.0993 + 0.1216 = 0.3727.

  Flow Ratior (yi = qi/Ji) using previously established qi and Ji values:
  - Vehicular Phase 1 (VP1 – North) (y_N) = (270/6978.2) = 0.0387
  - Vehicular Phase 2 (VP2 - East) (y_E) = (616/5444.2) = 0.1131
  - Vehicule Phase 3 (VP3 - South) (y_S) = (494/4975.9.2) = 0.0993
  - Vehicule Phase 4 (VP4 – West) (y_W) = (722/5937.4) = 0.1216

  The formula for green time for each vehicular phase as per PKJI 2023 (Eq. 5-12 principles) is:

$$g_i = \left(\frac{y_i}{Y_{ESW}}\right) \times G_{eff\_vehicle}$$

  - Vehicular Phase 2 (VP2 - East): Green (g_E) = (0.0387/0.3727) x 79s = 8.20s ≈ 8s
  - Vehicular Phase 2 (VP2 - East): Green (g_E) = (0.1131/0.3727) x 79s = 23.98s ≈ 24s
  - Vehicule Phase 3 (VP3 - South): Green (g_S) = (0.0993/0.3727) x 79s = 21.05s ≈ 21s
  - Vehicule Phase 4 (VP4 - West): Green (g_W) = (0.1216/0.3727) x 79s = 25.78s ≈ 26s

  The sum of allocated vehicular green times is 79 seconds with all vehicular green times are above the practical minimum 7 seconds.

Expected performance of Final Integrated Design

With the final integrated signal timings and the definitive corrected traffic volumes, the Degrees of Saturation (DJ) for the vehicular approaches are calculated to assess the operational efficiency. The Degrees of Saturation for the vehicular approaches are calculates as: $DJ = qi/Ci$ With Green Time Ratio (RH_i)as (g/C) and ratios (s = 120s). The proportion of turning vehicles value are from the result of classified turning movement count.

Table 20. Vehicular Phase Performance – Degree of Saturation (DJ)

Vehicular Phase and Approach	Green Time (g)	Green Time Ratio (RH)	Saturation Flow (J) (pcu/h)	Capacity (C) (Ji/RHi)	Degree of Saturation (DJ) (pcu/h)	Proportion of Turning Vehicles (PBi)
VP1 - North	8	0.0667	6978.2	465.2	0.580	0.504
VP2 - East	24	0.2000	5444.2	1088.8	0.566	0.156
VP3 - South	21	0.1750	4975.9	870.8	0.567	0.607
VP4 - West	26	0.2167	5937.4	1286.4	0.561	0.107

Example calculation:

- VP1 (North), RH_N : 8/120 = 0.0667
  C_N = 6978.2 x (8/120) = 465.2

DJ_N = 270/465.2 = 0.580
PB_N = (57 + 79)/270 = 0.504 pcu/h

With this adjustment, the highest DJ value being 0.580 (< 0.60) is still below the desirable maximum threshold of 0.85, which is often used as a benchmark for acceptable Level of Service in PKJI 2023 and general traffic engineering practice.

This strong performance suggests that the proposed 120-second, 5-phase signal plan, which thoughtfully includes a substantial 19-second exclusive pedestrian phase, will operate with great efficiency. Under current design hour volumes, there will be a significant surplus of vehicular traffic capacity. As a result, vehicular queues and associated delays are expected to be minimal, contributing to improved traffic flow through the Masbagik intersection.

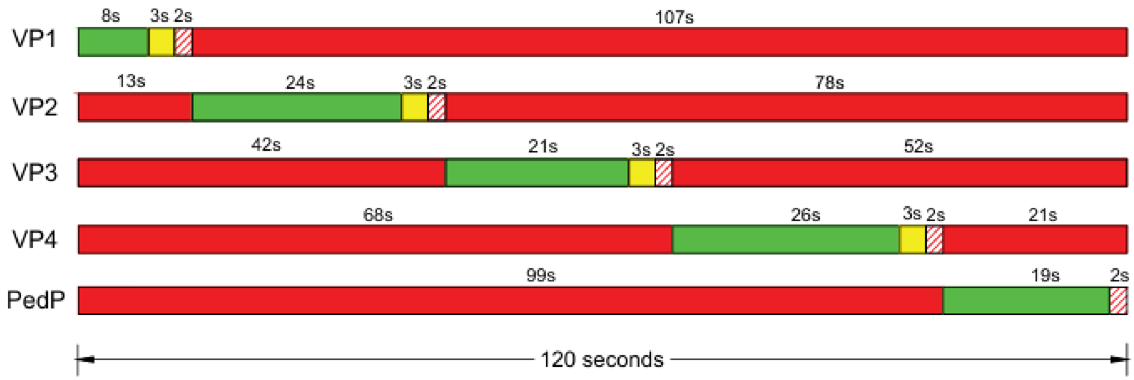

Figure 13. Signal Timing Allocation for Vehicular and Pedestrian Phases at Masbagik Intersection

Figure 13 presents the proposed 5-phase traffic signal timing plan for the Masbagik intersection, designed to operate on a total cycle time of 120 seconds. The diagram visually breaks down the duration of green, yellow, and red signal indications for each operational phase. The hatched red and white segments in the diagram denote 'all-red' times, which are essential for ensuring the intersection is clear before a conflicting phase begins.

Estimated Queue Lengths and Overall Delay

This sub-section provides an analytical estimation of vehicular queue lengths to quantitatively support the proposed signal timing plan's expectation of minimal congestion. Queue length is an important performance indicator that directly reflects vehicular accumulation during red signal intervals, affecting intersection efficiency and driver experience since long queues can cause upstream blockages and increased delays.

Given that all approaches at the Masbagik intersection operate under undersaturated conditions with the proposed design, this estimation will follow the methodology outlined in the PKJI 2023. The analysis aims to validate the anticipated minimal queue formation resulting from the new signalization plan. According to PKJI 2023, section 5.4.3 [5-15] about queue lengths, the average number of queued vehicles (N_q, in pcu) at the beginning of the green signal is calculated as in the formula shown below:

$$N_q = N_{q1} + N_{q2}$$

Where:

- N_{q1} = Sum of vehicles remaining from the previous cycle's green phase
- N_{q2} = The number of vehicles arriving and stopping during the red phase.

PKJI 2023 clarifies the calculation of N_{q1} based on the Degree of Saturation (DJ). When DJ is below 0.5, then $N_{q1} = 0$, which is not the case. And since our degree of saturation for all approaches is greater than 0.5, N_{q1} should be calculated from the following formula (PKJI 2023, section 5.4.3 [5-16]):

$$N_{q1} = 0.25 \times s \times \{(DJ - 1) + \sqrt{(DJ-1)^2 + \frac{8 \times (DJ - 0.5)}{s}}\}$$

The number of vehicles arriving and queueing during the red phase (N_{q2}) is calculated as:

$$N_{q2} = s \times \frac{(1 - RH)}{(1 - RH \times DJ)} \times \frac{q}{3600}$$

Where:

- s = Cycle length (seconds)
- RH = Green ratio for the approach (wH/s, where wH is effective green time) (g/s)
- q = Traffic flow rate for the approach (pcu/h)

The physical queue length (P_A, in meters) is obtained by [5-18]:

$$P_A = N_q \times \frac{20}{LM}$$

Where:

- N_q = Average number of queued vehicles (pcu)
- LM = Entry width of the approach (meter)
- 20 = Average area occupied by one passenger car unit (m^2/pcu), as per PKJI 2023

Calculate the Traffic Delay ($T_{LL,i}$, in second/vehicle) is obtained by [5-22]:

$$T_{LL,i} = s \times \frac{0.5 \times (1 - RH_i)^2}{(1 - RH_i \times DJ_i)} + \frac{Nq_{1,i} \times 3600}{C_i}$$

Using the input data above, the estimated average number of queued vehicles (N_q) and physical queue lengths for each approach are calculated as follows:

Table 21. Results of Queue Length Estimation for Masbagik Intersection (PKJI 2023 Method)

Approach	Phase	N_{q1}	N_{q2}	Total N_q	P_A
North	VP1	0.19 pcu	8.70 pcu	8.89 pcu	14.94 meters
East	VP2	0.15 pcu	18.45 pcu	18.60 pcu	38.75 meters
South	VP3	0.20 pcu	15.10 pcu	15.30 pcu	34 meters
West	VP4	0.14 pcu	21.38 pcu	21.52 pcu	40.99 meters

From the results, a calculated physical queue lengths now range from approximately 14.94 meters for the North approach to about 41 meters for the West approach, followed closely by the East approach at about 39 meters. While the Degrees of Saturation are lower (meaning less risk of cycle failure and overflow), the red times are longer, allowing more vehicles to accumulate in the queue during each cycle. However, the key benefit of lower Degree of Saturation values with the 120s cycle is that these queues are expected to be more stable and less prone to excessive buildup.

The PKJI method for calculating physical queue length is important to understand here. Instead of assuming vehicles form a single long line, this formula considers the entry width of the road approach

(LM). The '20/LM' part determines the length each queued vehicle contributes when spread across the available approach width. This is why the resulting physical lengths are compact, as they represent the length of the multi-lane area occupied by the queued vehicles, rather than a single-fine line where each vehicle might take up, for example, 7 meters.

From here we can calculate ratio of stopped vehicle ($R_{KH,i}$) for each approach before we can calculate geometric delay ($T_{G,i}$) and total average delay per approach (T_i).

$$R_{KH,i} = 0.9 \times \frac{Nq_{1,i} \times 3600}{q_i \times s}$$

$$T_{G,i} = \left(1 - R_{KH,i}\right) \times P_{B,i} \times 6 + (R_{KH,i} \times 4)$$

$$T_i = T_{LL,i} + T_{G,i}$$

Where:

- $P_{B,i}$ = Proportion of vehicles turning ($P_{B,i}$)

And the last step is to calculate the overall average intersection delay (TI) using PKJI 2023 [5-32]:

$$TI = \frac{\Sigma(q_i \times T_i)}{q_{total}}$$

Table 22. Summary of Calculated Delays and Performance Metrics for the Proposed Signalized Masbagik Intersection (PKJI 2023 Method, 120-second Cycle)

Approach	(g)	(RH)	(C)	(DJ)	(T_{LLi}) (s/pcu)	$R_{KH,i}$	$T_{G,i}$ (s/pcu)	T_i (s/pcu)	TI (s/pcu)
North (VP1)	8s	0.0667	465.2	0.580	55.847	0.889	3.89	59.73	48.98
East (VP2)	24s	0.2000	1088.8	0.566	43.80	0.816	3.44	47.24	
South (VP3)	21s	0.1750	870.8	0.567	46.17	0.838	3.94	50.11	
West (VP4)	26s	0.2167	1286.4	0.561	42.32	0.805	3.35	45.67	

The calculated overall average intersection delay (TI) for the proposed 120-second, 5-phase signalized design at Masbagik Intersection is approximately 48.98 second/pcu. This value is calculated using the detailed delay calculation methodology for signalized intersections described in PKJI 2023, Chapter 5. This calculation process involved several steps for each approach:

a. ***Overflow Queue ($Nq_{1,i}$):*** This was determined based on the Degree of Saturation for each approach. For each approaches overflow queues were calculated, which means that some vehicles might not clear within one cycle due to random traffic arrivals.
b. ***Traffic Delay (T_{LLi}):*** This component account for uniform delay (due to stopping for the red light) and random overflow delay. It is sensitive to the green ratio, degree of saturation, cycle length, and the overflow queue.
c. ***Geometric Delay ($T_{G,i}$):*** This accounts for time lost due to acceleration/deceleration, particularly for turning vehicles, and is influenced by the proportion of vehicles stopping ($R_{KH,i}$) and the proportion of vehicles turning ($P_{B,i}$).
d. ***Total Average Delay per Approach (T_i):*** The average delay for vehicle on each specific approach is ranging from 45.67 (West) seconds to 59.73 seconds (North).

e. Overall Average Intersection Delay (TI): This metric was calculated as an average of the individual approach delays, weighted by their traffic volumes.

The overall average delay result of 48.98 second/pcu for the proposed signalized system is higher than the 11.40 second/pcu calculated for the existing unsignalized intersection (using PKJI Chapter 6). This is a common outcome when signalizing an intersection that was previously unsignalized but not severely oversaturated. Moreover, while these analytical calculations offer an initial assessment, a traffic simulation study on the following section will provide more detailed insights into queue behavior.

Traffic Simulation

Traffic simulation is widely used tool in transportation engineering and planning, allowing for the assessment of traffic operations and the evaluation of proposed interventions in a control, virtual environment before costly real-world implementation. Microsimulation servers as a platform for modeling complex traffic behaviors, vehicle interactions, and the dynamic performance of the proposed signalization strategy in the Masbagik intersection study, which aims to address existing congestion and safety concerns using an IoT-based smart traffic light system. The findings of such a simulation would provide valuable data-driven support for the feasibility and efficacy of the proposed improvements.

For this research, the PTV VISSIM microsimulation software package was selected to model the Masbagik intersection in East Lombok. It is important to note that PTV VISSIM Student Version was used for this study. This version has certain limitations, most notably a maximum simulation period of 600 seconds (10 minutes) per run. While this restricts the ability to simulate extended peak hour periods (typically 3600 seconds), the methodology used involves multiple simulation runs and analysis of stable periods within these shorter durations. Other limitations might include restrictions on the network size or the number of objects, though these were not found to be constraining for the single intersection model developed in this research. The results and conclusion drawn from the simulation are therefore interpreted within these constraints.

Simulation Objectives

The main objectives of conducting a traffic simulation study for the Masbagik intersection are as follows:

- To develop and calibrate a microsimulation model, that accurately represents the existing geometric, traffic, and control conditions of the unsignalized Masbagik intersection (base case scenario).
- To evaluate the operational performance of the current unsignalized intersection, by quantifying the key performance indicators such as average vehicle delay, Level of Service (LoS), and queue lengths.
- To model the proposed signalized intersection (scenario 2), incorporating the designed 5-phase (4 vehicular, 1 exclusive pedestrian), 120-second cycle signal timing plan developed analytically using PKJI 2023 guidelines.
- To assess the potential effectiveness of the proposed signalized intersection control in mitigating existing traffic issues by comparing its performance against the base case scenario.

- To provide quantitative evidence to support the operational benefits and feasibility of implementing the designed intelligent traffic signal system at Masbagik intersection as means to improve traffic management and safety in East Lombok.

Model Setup

The development of a reliable microsimulation model is a foundational step in evaluating traffic operations and proposed interventions. This study used PTV VISIM (Student Version) to construct a detailed model of the Masbagik intersection and its approaches. The proves involved several steps for the different scenarios evaluated.

Figure 14. Masbagik Intersection Network in VISSIM

The following outlines the setup for the VISSIM model of the Masbagik intersection:

1. ***Network Geometry and Coding:***
   The simulation model will replicate the physical layout of the Masbagik Intersection and its four approaches: Rinjani road (North), Masbagik-Rempung (East), Masbagik-Pancor 1 (South), and Kopang-Masbagik 5 (West).
   - Links and Connectors: The road network will be coded using links representing road segments and connectors for turning movements at intersection. The geometric details will be based on the intersection inventory data (Table 13).
   - Conflict Areas: For the unsignalized scenarios, conflict areas will be defined within VISSIM at the points where vehicle paths cross or merge, with priority rules assigned based on standard traffic regulations or observed behavior if the intersection is fully uncontrolled.
   - Pedestrian Facilities: Sidewalks and pedestrian crosswalks will be coded as per the existing conditions for the base case and as per the proposed design (e.g., minimum 2 - 2.5m wide sidewalk) for the proposed scenario.

2. ***Traffic Input Data:***
   The model will be filled with traffic data collected from field surveys, as described in the Data Analysis section of this research.

- Traffic Volumes: Peak hour traffic volumes and turning movement counts for all approaches will serve as the main inputs. The data from Figure 12 (“Design Hour Volumes for Traffic Light System Design at Masbagik Intersection”) and the identified rush hour periods (from Table 18, “Rush Hour Volume Clustering Analysis”) will be used to calculate traffic demand.
- Vehicle Composition: The model will include a realistic vehicle mix, including motorcycles (MC), light vehicles (LV), and heavy vehicles (HV), based on the proportions shown in Figure 5 (“Vehicle Proportion”) and Figure 11 (“Traffic Flow Comparison Between Transport Mode”). Specific VISSIM vehicle types and models will be defined based on their operational characteristics.
- Vehicle Routing: Static vehicle routes will be defined based on observed turning movement (left, straight, right) percentages to ensure that vehicles are distributed realistically across the intersection.

The essential phases of defining traffic control (for both unsignalized and unsignalized scenarios) and model calibration were preceded by the development of this base network model. In order to guarantee that the VISSIM model accurately represents actual conditions at Masbagik, the calibration and validation procedure will also be taking into account when doing the simulation. This typically involves comparing the simulation outputs, such as average vehicle delays and queue behavior, against analytical benchmarks or field data, and adjusting by comparing simulation outputs (Dowling et al., 2004).

3. ***Traffic Control Conditions:***
   - Scenario 1: Base Case (Unsignalized): The existing Masbagik intersection, described as “uncontrolled four-way crossing” or “unsignalized four-leg intersection (Type 422)”, will be modeled. Priority will be assigned to major road approaches (e.g., East-West arterial roads) over minor ones if applicable, or modeled with minimal control to reflect “uncontrolled” behavior by carefully setting conflict marker priorities.
   - Scenario 2: Proposed Traffic Light System + Pedestrian scenario: The proposed 5-phase, 120-second cycle signal plan, as detailed in the “Final Integrated Traffic Light Design and Operational Timings” section, will be implemented using VISSIM’s fixed-time signal controller. This includes the specific green, yellow, and all-red times for each vehicular phase and the exclusive pedestrian phase.

4. ***Pedestrian Modelling:***
   - Pedestrian Inputs: Pedestrian volumes for crossing each approach will be based on survey data.
   - Pedestrian Routes: The pedestrian routes across the designated crosswalks will be defined.
   - Pedestrian Behavior: Standard VISSIM pedestrian walking speeds (e.g., average of 1 m/s as mentioned in the previous pedestrian facility design section).
   - Interaction with Signals: In scenario 2, pedestrian movements will be coordinated with the PedP signal phase.

5. ***Data Collection Setup:***
   To assess the performance measures, specific data collection elements will be set up in VISSIM:
   - Queue Counters: Placed upstream of the intersection on each approach to calculate queue lengths (average and maximum).

- Node Evaluation: Collect overall intersection performance metrics such as total delay and stops.

6. ***Simulation Run Parameter:***
   Due to the VISSIM Student Version limitation, each simulation was conducted for 600 seconds (10 minutes). To account for random variations in traffic, multiple simulation runs were performed using different random seeds. For this analysis, average results over the full 0-600s interval are considered.

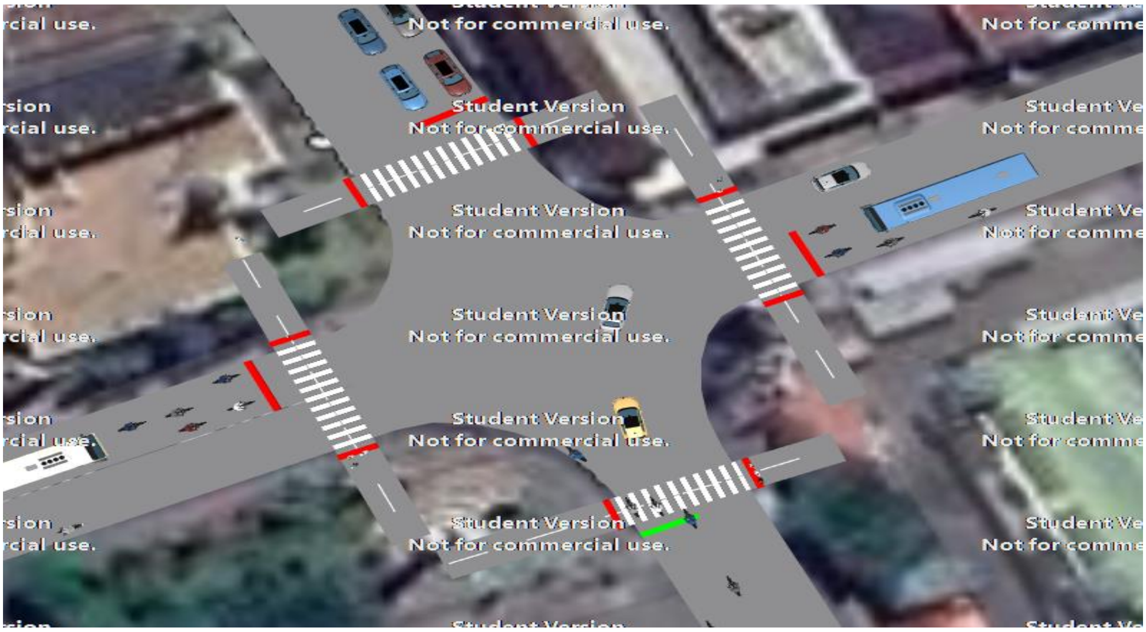

Figure 15. Visual Representation of the 5-Phase Signal Control for Masbagik Intersection (120-second Cycle)

Calibration of the Base Model (Unsignalized Masbagik Intersection)

To ensure the VISSIM simulation model provides a credible representation of existing conditions at the Masbagik Intersection, the base model (scenario 1, unsignalized) went through calibration. This process aims to align the simuation model's performance outputs, particularly average vehicle delays, with the analytical results obtained from the Indonesian Road Capacity Guidelines (PKJI 2023) Chapter 6 methodology. These analytical results in the previous section provides as the primary benchmarks for this calibration.

VISSIM Base Model Calibration Adjustments

The unsignalized Masbagik intersection was modeled in VISSIM with specific attention to the priority rules governing vehicle interactions at conflict points, reflecting the yielding of minor road traffic (North and South approaches) to major road traffic (East and West approaches). These includes the conflict area parameters that sets the right-of-way and how vehicles navigate points where their paths cross or merge, and driving behavior parameters.

In addition, a critical aspect of this calibration involved the refinement of driving behavior parameters within VISSIM to better represent local conditions in Indonesia. Instead of using the default VISSIM parameters (e.g., the standard Wiedemann 99 car-following model), this study used the Wiedemann 74 car-following model, which is often considered more suitable for urban and mixed traffic conditions.

The VISSIM results presented here are the averages obtained from 3 simulation runs, each conducted for a 600-second (10-minute) period, utilizing the customized Indonesian driving behavior parameters with a focus on motorcycle interactions. This relates to using the Wiedemann 74 model parameters like distance driving to account for closer following distances with high motorcycle presence.

Vehicle Delay

Average vehicle delay is a key indicator of an intersection's operational efficiency. The comparison between the analytically calculated delays and simulated delays is as follows:

a. *Overall Average Intersection Delay*

- Analytical result: 11.40 second/pcu
- VISSIM simulated result: 15.56 second/pcu

The VISSIM model predicts an overall average delay that is approximately 4.16 seconds (or about 36.5% higher than the analytical estimate. This implies that, in comparison to the analytical result, the detailed interactions, diverse driver responses (particularly with unique Indonesian behaviors), and inherent randomness modeled in VISSIM lead to a slightly mode higher overall delay prediction.

b. *Average Delay on Major Approaches (East and West)*

- Analytical result (T_major): 9.55 second/pcu
- VISSIM simulated result: 11.81 second/pcu

For vehicles on the major roads, VISSIM estimates an average delay of 11.81 seconds. This is about 2.26 (or approximately 23.7%) higher than the PKJI analytical result. This difference is smaller than the overall intersection delay difference, implying a reasonable representation.

c. *Average Delay on Minor Approaches (North and South)*

- Analytical result (T_minor): 14.64 second/pcu
- VISSIM simulated result: 15.39 second/pcu

This shows a very close agreement with the analytical result of 14.64 seconds, with the VISSIM value being only about 0.75 second (or approximately 5.1% higher.

Queue Lengths

Queue length data from VISSIM, averaged across the 3 simulation runs for the 0-600s interval, provides insights into the physical extent of congestion.

a. *Analytical Expectation*

The overall intersection Degree of Saturation (DJ) was calculated as 0.662. According to PKJI Figure 6-9, This DJ corresponds to a Probability of Queue (Pa) ranging roughly between 35% and 75%. This indicates a moderate to significant likelihood of queues forming, particularly on the minor approaches that yield to major road traffic.

b. *VISSIM Simulated Queue Lengths (0-600s Interval Averages)*

Table 23. VISSIM Simulated Queue Lengths for Scenario 1 (0-600s Interval Averages)

Approaches	AVG QLen (m)	AVG QLenMax (m)
North	0.45	10.65
East	15.45	109.2
South	7.39	40.44
West	12.19	81.35

As shown from the table above, the north approach having the lowest traffic demand with a relatively small average maximum queue. The South approach shows a modest average queue, this indicates that while the typical queue is short, longer queues can develop, which characteristic of yielding approaches experiencing periodic service opportunities. The major approaches display longer average queues lengths compared to the minor approaches, and substantially longer average maximum queue lengths. This can be explained because of the high traffic volumes on major roads, especially east and west approaches that carries substantial traffic volume. Even with priority, this high volume leads to interactions between vehicles on the major road itself (e.g., car-following, minor speed adjustments for turning vehicle) and contributes to queue formation especially during peak surges within the simulation. The gaps from friction from turning movements also can be the issues since the intersection has no dedicated turn lanes exist.

Overall, the general stability of queues (i.e., not growing indefinitely beyond these observed maximums within the 600-second simulation runs) is consistent with the analytical Degree of Saturation of 0.662, which signifies operations below full, continuous saturation. The VISSIM queue data provides important insights for this process, making sure that the model not only matches average delay figures but also represents plausible physical queueing behavior reflective of the intersection's operational state.

Simulation Results and Discussion for Scenario 2 (Signalized Masbagik Intersection)

Following the calibration of the base model, the proposed signalization plan for the Masbagik intersection was implemented and evaluated using VISSIM. Scenario 2 consists of a 5-phase traffic signal system with a 120-second cycle length, including four vehicular phases with adjusted green times and one exclusive pedestrian phase. This section presents the VISSIM simulation results for Scenario 2 and compares them with the analytical performance metrics calculated using PKJI 2023 Chapter 5.

Vehicle Delay

Average vehicle delay is a primary measure of operational efficiency for signalized intersection. In addition, to better understand the distribution of delays and compare performance across different road categories within the signalized intersection, delays are aggregated for major and minor approaches.

a. Overall Average Intersection Delay

- Analytical result: 48.98 second/pcu
- VISSIM simulated result: 54.01 second/pcu

The VISSIM model predicts an average intersection delay of 54.01 s/pcu for the proposed signalized system. This is approximately 5.03 seconds (or about 10.3%) higher than the analytical overall delay calculated. This implies that the natured modeled in VISSIM contribute to higher, more realistic, delay estimates compared to the deterministic analytical model.

b. Average Delay on Major Approaches (East and West)

- Analytical result: 46.39 second/pcu
- VISSIM simulated result: 63.67 second/pcu

The VISSIM simulation result is much higher than the analytical result by around 17.28 second/pcu (by approximately of about 37.2%). Both individual major approaches (East: 57.76 second/pcu; West: 69.59 second/pcu) still showing a considerably elevated delays in the simulation compared to their analytical counterparts. This indicates ongoing operational challenges on these arterial routes in VISSIM even with the longer cycle and increased green times.

c. Average Delay on Minor Approaches (North and South)

- Analytical result: 53.51 second/pcu
- VISSIM simulated result: 44.34 second/pcu

For the minor approaches, the VISSIM simulation result is lower than the analytical result by approximately 9.17 second/pcu (a reduction of about 17.1%). The individual minor approach delays from VISSIM (North 44.96 second/pcu; South: 43.72 seconds/pcu) are also lower than the individual analytical counterparts (North: 59.73; South: 50.11). This suggests that the minor roads perform efficiently in the simulation with the 120s cycle plan.

This reversal in the delay hierarchy (VISSIM: Major > Mino; Analytical by PKJI: Minor > Major) persists with the 120-second cycle. It strongly suggests that the VISSIM model, using specific Indonesian driving behaviors and detailed traffic dynamics, predicts that the major arterial roads will still face considerable congestion and perform no better than the minor roads under this signal plan.

Queue Lengths

Physical lengths of queues are a vital indicator for assessing required storage capacity and identifying potential spillback. The table below will directly compare between the average physical queue lengths estimated by the analytical methodology for the 120-second signal cycle plan and those generated by the VISSIM microsimulation for the same scenario.

Table 24. Comparison of Analytical and Simulated Average Queue Lengths for the Proposed Signalized Intersection

Approach	P_A (m)	Average QLen (m)	Difference (m) (VISSIM - PKJI)	Difference (%)
North	14.94	10.67	-4.27	-28.6%
East	38.75	79.68	+40.93	+105.6%
South	34.00	22.38	-11.62	-34.2%
West	40.99	85.60	+44.61	108.8%

For the north and south approaches, VISSIM predicts an average queue length that is shorter than the analytical result. This indicates that the simulation, with its detailed behavioral modeling, shows this low-volume minor approach performing better in terms of average queue accumulation. For the major approaches, a significantly different result, which is more than double, than the analytical estimation. These results might indicate that the simulation, including the specific Indonesian driving behaviors (especially for motorcycles) and dynamic traffic interactions, predicts longer average queues on the major approaches. This is consistent with the simulation delay results, which also showed higher delays for these major approaches compared to analytical predictions.

The design implications are that the long average queues on the major approach point to a valuable operational issue with the 120-second cycle plan, as it is currently set up with green splits. This suggests that either the simulated capacity on the East and West approaches is significantly lower than what is analytically expected, or the signal timings need to be further refined emphasizing we need to improve conditions for these approaches.

SURVEY

To assess the feasibility of implementing an IoT technologies to improve the signalized intersection, a survey is conducted to gather comprehensive insights into traffic challenges and the potential implementation of IoT-based smart traffic systems. The goal is to assess public perception, pedestrian behavior, and acceptance levels toward smart traffic technologies while also collecting relevant data for improving traffic safety and infrastructure management. The survey's target respondents are diverse groups of Indonesian residents. The target groups include pedestrians, drivers and motorcyclists, public transport users, students, employees, and business owners.

Survey Goal

The primary objective of this survey is to:

1. ***Assess public perception*** – this is to understand how citizens perceive current traffic conditions and their views on implementing smart traffic systems.
2. ***Identify existing challenges*** – to capture issues such as traffic congestion, road safety concerns, and inadequate infrastructure at intersections.
3. ***Find out technology acceptance*** – to examine the awareness, understanding, and willingness to adopt IoT-based smart traffic systems in urban and semi-urban areas in the future.

The data collected from this survey, combined with traffic simulation and analysis, will help develop recommendations for enhancing traffic efficiency and safety using intelligent traffic technologies.

Questionnaire

The questionnaire was designed to include 22 questions divided into four main sections, each targeting specific aspects of public perception, traffic challenges, potential technology implementation, and expectations. The survey aims to evaluate respondent demographic diversity, experiences in mixed traffic environments, familiarity with IoT-based technologies, and perspective on traffic safety and management. The survey structure below will be mentioned to ensure a structured and logical flow of information:

Demographics Question

The demographic information is important for identifying patterns and contextualizing the responses. The questions in this section include:

- ***Age group and gender:*** These factors contribute to an understanding of how different age groups and genders perceive traffic issues and technological adoption. For instance, younger respondents might be more receptive to smart systems, whereas older respondents might have different priorities.
- ***Occupation:*** This question indicates professional roles that may affect traffic experiences. For example, delivery drivers might prioritize time efficiency.
- ***Mode of transport:*** Participants primary mode of transportation reveals how they interact with the road system. Motorcyclists may face different challenges at intersections than other drivers or pedestrians.
- ***Residential area:*** Knowing whether respondents live in an urban, suburban, or rural setting is critical for understanding geographic differences in traffic challenges.

Mixed Traffic Question

In this section, we will explore the complexity of mixed traffic, where different types of vehicles and pedestrians share the same roads. This section will establish a clear picture of the challenges that the smart traffic light systems aim to address. The key questions include:

- ***Experience with mixed traffic:*** The participants are asked whether they have experienced mixed traffic as drivers or passengers.

- ***Common challenges:*** Multiple-choice questions help to identify the most significant issues, such as congestion during peak hours, delays due to poor signal timing, and risks at intersections.
- ***Agreement statements:*** Respondents rate their agreement with statements like "mixed traffic increases the risks of accidents due to unpredictable behavior" and other issues will be mentioned.

IoT-based Smart Traffic Light Systems

This section will evaluate public knowledge and perceptions of smart traffic light technologies. The goal is to understand whether respondents believe these systems can effectively address traffic issues and what barriers may exist. It includes:

- ***Familiarity with IoT systems:*** Respondents will be asked if they have heard of IoT-based traffic solutions, particularly smart traffic light system, and how familiar they are with these concepts.
- ***Key features:*** Questions focus on which features respondents find most beneficial, such as adaptive signal timing, pedestrian detection, and vehicle prioritization.
- ***Potential concerns:*** Participants will be asked some questions to help identify challenges related to the technology.
- ***Support for implementation:*** This question examines the overall public support for implementing smart traffic systems in their area.

Traffic Safety

In this section, we will investigate participant perceptions of road safety and the role of technology in improving it. The following are some key questions:

- ***Current safety levels:*** Participants will rate how safe they feel on the road as a road user.
- ***Primary causes of accidents:*** Multiple-choice questions will help identify issues like poor visibility, reckless driving, and non-compliance with traffic signals.
- ***Effectiveness of smart systems:*** Agreement statements analyze the respondent belief that the IoT-based traffic light systems can improve safety and reduce accidents.
- ***Open-ended questions:*** The section concludes with a question inviting the respondent to suggest improvements for enhancing road safety, allowing them to provide detailed feedback.

This questionnaire is an essential component of this study, providing valuable insights into public opinions and behavior that will help to form practical suggestions for implementing the IoT-based smart traffic light systems in the future works. A detailed overview of the questionnaire questions can be found in the Annex 1.

SURVEY ANALYSIS

Qualtrics XM was used to create and collect data for the survey. The software provides basic statistics and percentage analysis, which are sufficient for this research. In addition, for more details on the survey are shown in the Annex 1. This chapter presents the survey's result.

Demographics Interpretation

In this survey, a total of 367 Indonesian participants provided their insights in the research's survey, and two of them chose not to continue to fill the survey in.

From the total participants, male participants made up 53.42% (195 people), while female participant accounted for 46.03% (168 people). A very small percentage, 0.55% (2 people), preferred not to disclose their gender.

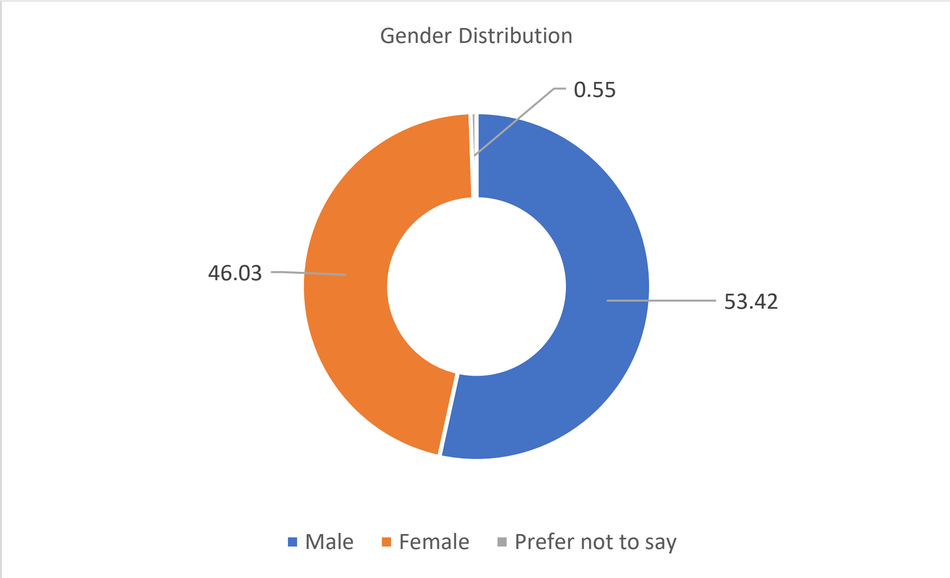

Figure 16. Gender Distribution (Qualtrics, Author's survey, 2025)

The second chart highlights the age distribution of the participants. Most participants are between the ages of 25 and 34, accounting for 67.40% (246 people), with 16 to 24 years old at 18.63% (68 people). The 34 to 44 age group represents 9.86% (36 people), while 45 to 65 years old make up 3.56% (13 people). Only 0.55% (2 people) are aged 65 or older. This indicates that most respondents are young adults, especially those in their late twenties and early thirties, who are likely familiar with modern technology and traffic systems.

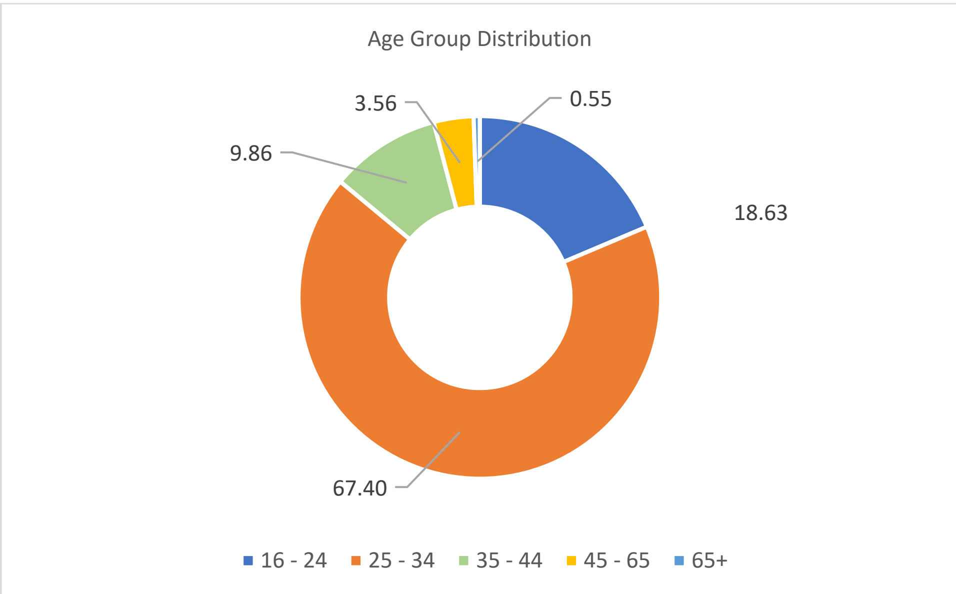

Figure 17. Age Group Distribution (Qualtrics, Author's survey, 2025)

This figure below illustrates the distribution of driving license ownership among different gender groups. A large majority of male and female respondents claimed to own a driver's license, with males slightly more likely than females. A small proportion of female respondents (around 20 people) indicated that they do not have a driver's license. Surprisingly, all respondents who chose not to disclose their gender reported owning a driver's license. This implies that most participants are able to drive, which is important for analyzing their perspectives for this research work.

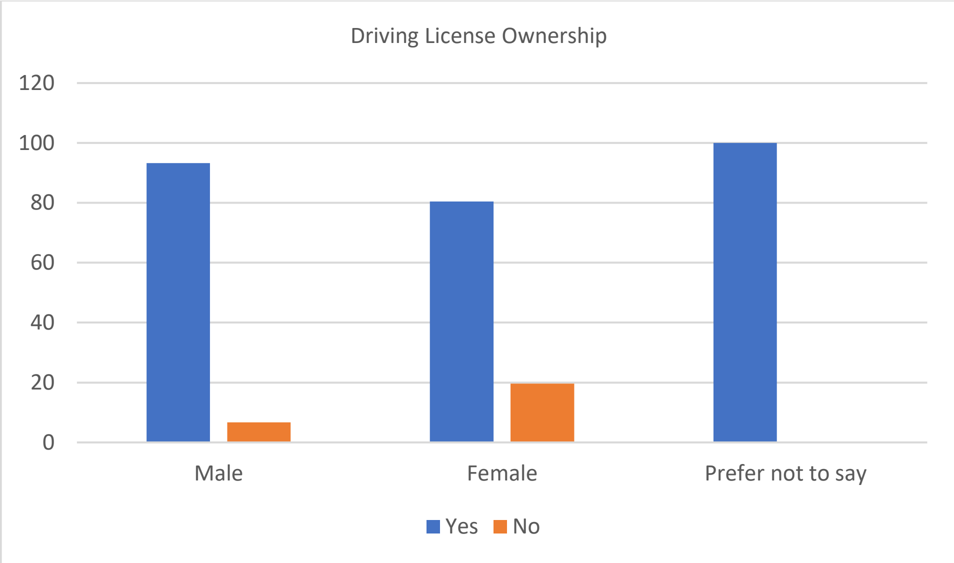

Figure 18. Driving License Ownership (Qualtrics, Author's survey, 2025)

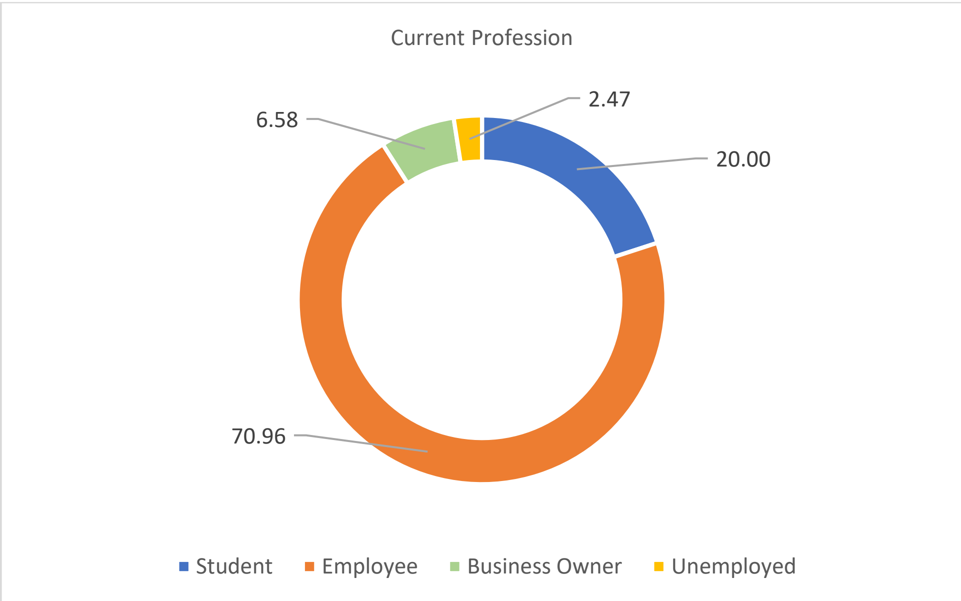

Figure 19. Current Profession (Qualtrics, Author's survey, 2025)

Figure 19 as shown above is about the current professions of respondents. The majority, 70.96% (259 people), are identified as employees. Students accounted for 20% (73 people), followed by business owners at 6.58% (24 people). A small percentage, 2.47% (9 people) were unemployed. Because working professionals predominate, the viewpoints revealed in the study may represent those of people who actively commute and interact with traffic systems on a regular basis.

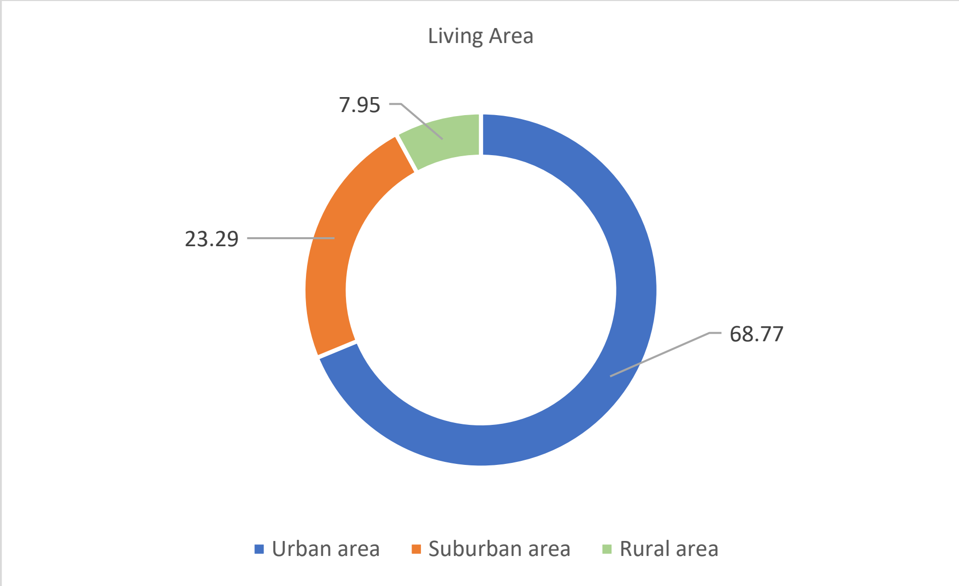

Figure 20. Living Area (Qualtrics, Author's survey, 2025)

The next question is about the residential distribution of respondents. Most participants, 68.77% (251 people) reside in urban area, with 23.29% (85 people) in suburbs and only 7.95% (29 people) in rural areas. A large proportion of urban people indicate that insights into traffic and IoT applications will be heavily influenced by city-related traffic constraints rather than rural or suburban concerns.

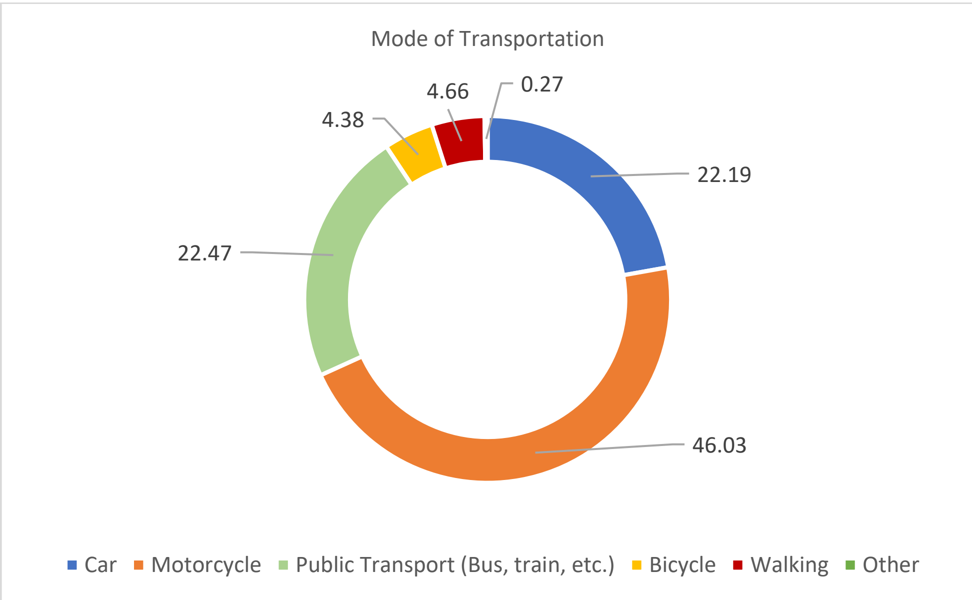

Figure 21. Modes of Transportation (Qualtrics, Author's survey, 2025)

Regarding the mode of transportation used by respondents, motorcycles are the most popular, reached 46.03% (168 people). Followed by cars 22.19% (81 people) and public transportation 22.47% (82 people). Other modes, including walking 4.38% (11 people) and bicycles 4.66% (17 people). In addition, 0.27% (1 people) for the alternative transportation such as motorbike taxis. The significant use of motorbikes and cars implies that most respondents prefer private vehicles to public transportation, which may influence their perspectives on traffic safety and smart traffic solutions.

To provide a clear overview of the survey respondent's demographic characteristics, the table below covers major features such as age distribution, residing area, driving license ownership, employment status, and primary means of transportation. The data represents the responses of 365 Indonesian individuals, providing insight into their backgrounds and mobility patterns.

Table 25. Demographic Summary (Qualtrics, Author's survey, 2025)

No	Category	Answer	Percentage (%)
1	***Age Distribution***		
	16 – 24	68	18.63
	25 – 35	246	67.40
	35 – 44	36	9.86
	45 – 65	13	3.56
	65+	2	0.55
	Total	365	100
2	***Living Area***		
	Urban	251	68.77
	Suburban	85	23.29
	Rural	29	7.95
	Total	365	100
3	***Driving License Ownership***		
	Yes	319	87.40
	No	46	12.60
	Total	365	100
4	***Current Profession***		
	Student	73	20
	Employee	259	70.96
	Business Owner	24	6.58
	Unemployed	9	2.47
	Total	365	100
5	***Means of Transport***		
	Car	81	22.19
	Motorcycle	168	46.03
	Public Transport	82	22.47
	Bicycle	16	4.38
	Walking	17	4.66
	Other	1	0.27
	Total	365	100

Mixed Traffic Question Interpretation

Mixed traffic environments involve multiple types of road users, including private vehicles, public transportation, motorcycles, pedestrians, and bicycles, with all sharing the same space. Understanding how people interact in mixed traffic, whether as drivers, passengers, or pedestrians, gives us valuable insights into their experiences and concerns. This section examines respondents' level of involvement in mixed traffic and the common problems they face. By analyzing these patterns, we can gain a better understanding of the elements that influence road conditions and discover opportunities for improvement in traffic management and urban mobility planning.

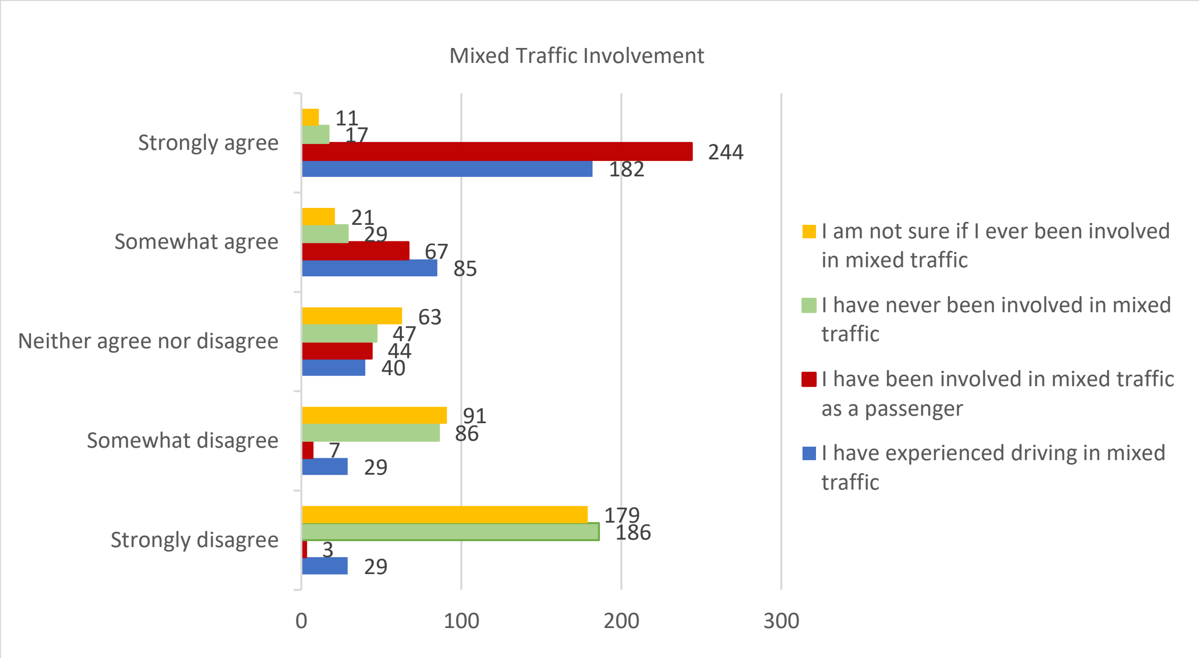

Figure 22. Mixed Traffic Involvement (Qualtrics, Author's survey, 2025)

The figure above presents different levels of involvement in mixed traffic from various perspectives. The answers were from the question "*Mixed traffic refers to the situation where different types of vehicles share the same road infrastructure. Have you experienced being in mixed traffic in your daily commute? To what extent do you agree with the following statements?"*. From the responses, 182 participants strongly agreed that they have been involved as drivers, while 244 strongly agreed that they have been involved as passengers. This shows that a sizable proportion of respondents have experience with mixed traffic situations, either as active drivers or passengers.

On the other hand, 40 respondents neither agreed nor disagreed about their involvement as drivers, and 44 people had a neutral stance as passengers, indicating some uncertainty about their traffic participation. Additionally, 29 respondents somewhat disagreed and 29 strongly disagreed with being involved as drivers, suggesting that a smaller group may not drive frequently or at all. In contrast, only 7 people somewhat disagreed and 3 strongly disagreed about being passengers, which could imply that nearly all respondents have at some point traveled in mixed traffic, even if they were not in control of the vehicle.

Interestingly, a portion of responders are unsure about their involvement in mixed traffic. 11 respondents strongly agreed, 21 people slightly agreed that they were unsure, and 63 respondents were neutral. Furthermore, 186 respondents strongly disagreed that they had ever been involved in mixed traffic, while 91 of them somewhat disagreed, indicating a wide divide between those who actively participate and those who do not deal with traffic settings.

The large number of participants who confirmed their participation in mixed traffic as drivers or passengers demonstrates the importance of traffic conditions in their daily lives. However, the high proportion of ambiguous responses shows a potential lack of understanding or clarity in defining mixed traffic scenarios.

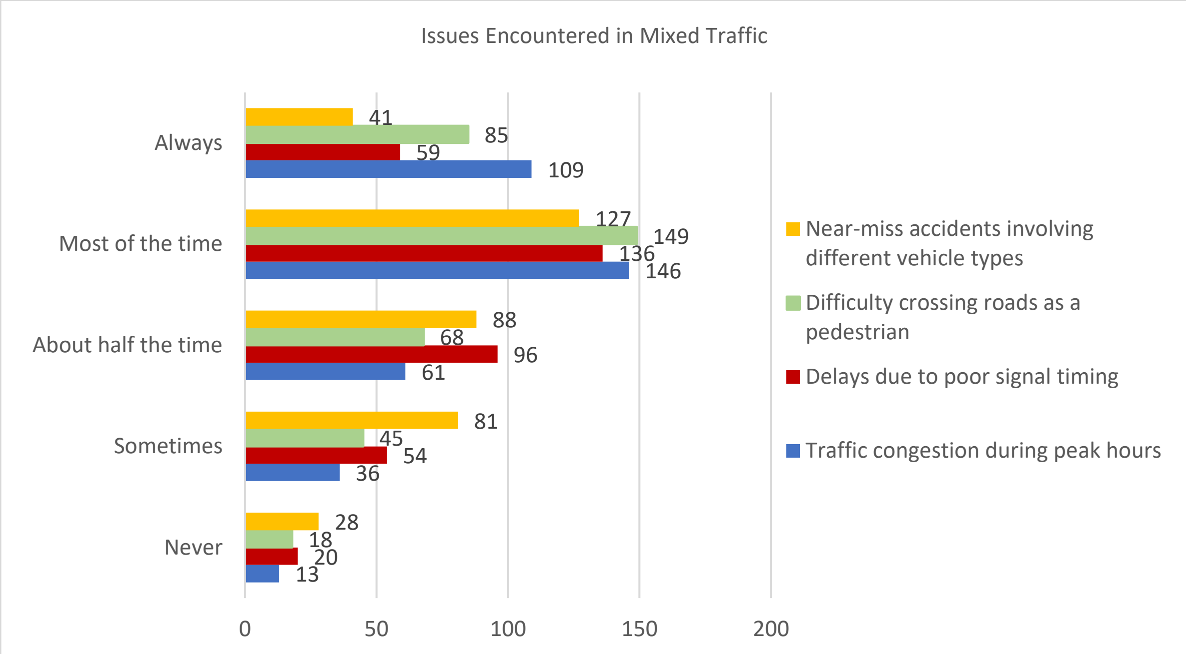

Figure 23. Issues Encountered in Mixed Traffic (Qualtrics, Author's survey, 2025)

The question from the figure above is "*How often do you encounter the following issues in mixed traffic conditions, particularly in intersections?".* The responses were categorized into different frequency levels, ranging from "Always" to "Never", for four major traffic-related challenges.

Traffic congestion during peak hours is the most frequently cited "most of the time" issue, with 149 respondents reporting that they face it on a regular basis. This closely followed by delays caused by poor signal timing (146 respondents) and difficulties crossing roadways as a pedestrian (136 respondents). Furthermore, 127 respondents reported frequent near-miss incidents with various vehicle kinds, emphasizing the risks associated with mixed traffic circumstances.

The most common concerns among those who reported facing these issues "Always" were traffic congestion (109 people) and difficulty crossing roadways as a pedestrian (85 people). Similarly, delays caused by improper signal timing (59 respondents) and near-miss accidents (41 respondents) were identified as persistent challenges by a smaller but still considerable group. When considering the respondents who face these issues "About half the time," traffic congestion (96 respondents) and delays due to improper signal timing (88 respondents) remain the most often cited concerns.

Some respondents reported encountering these concerns "Sometimes", notably near-miss accidents (81 people) and delays caused by improper signal timing (68 people), while a smaller proportion indicated they rarely or never encounter these challenges. For example, less than 30 people answered never experiencing congestion, signal delays, or near-miss accidents.

Knowledge and Perception on IoT-based Smart Traffic Light Systems Questions Interpretation

The third section of the questions focuses on responders' perceptions and knowledge of the smart traffic light systems. In this chapter, I shall interpret the responses to the questions.

Public Awareness and Familiarity on Smart Traffic Light Systems

The question asked for this is *"Have you ever heard of IoT (Internet of Things)-based smart traffic light systems before?"*. The survey results reveal a wide range of awareness for IoT-based smart traffic light systems. While 110 respondents said they had "probably" heard of these systems, only 61 people were certain about their knowledge ("Definitely yes"). On the other hand, 81 respondents chose "Probably not", and 63 respondents had never heard of such systems ("Definitely not"). This means that, while some participants have encountered the concept, a significant portion are still unfamiliar with it.

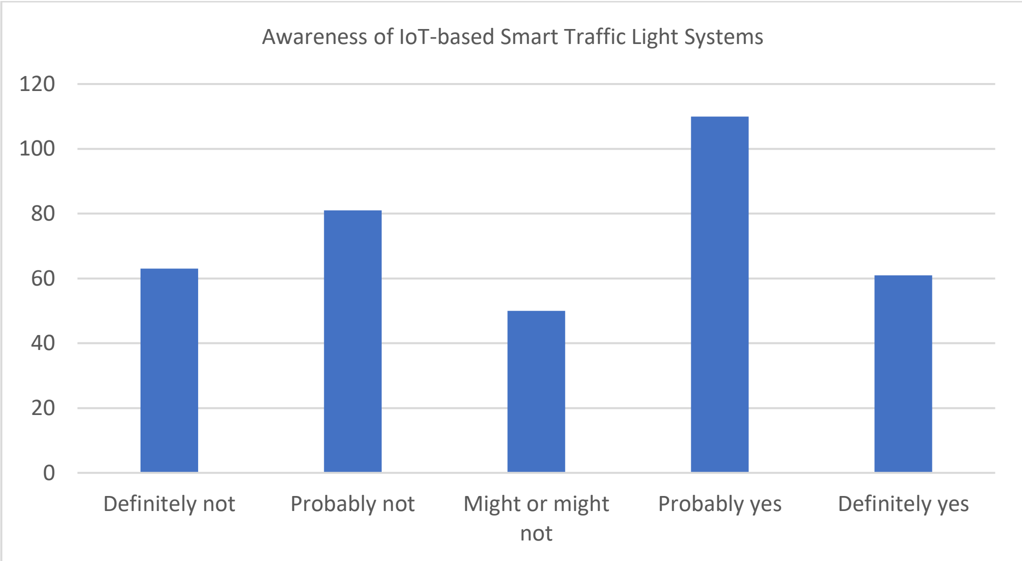

Figure 24. Awareness of IoT-based Smart Traffic Light Systems (Qualtrics, Author's survey, 2025)

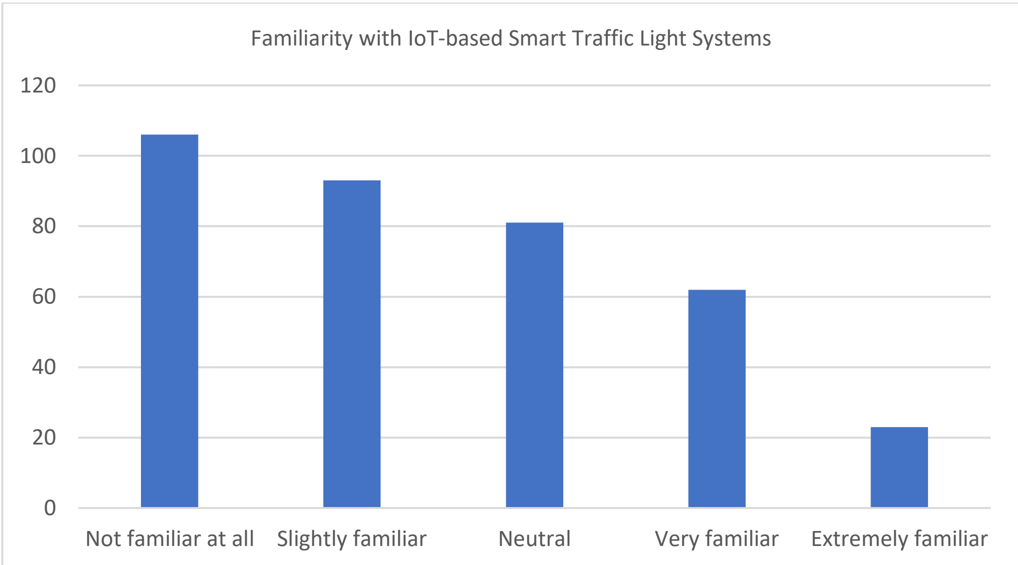

Figure 25. Familiarity with IoT-based Smart Traffic Light Systems (Qualtrics, Author's survey, 2025)

And for Figure 25, the question asked is *"How familiar are you with the concept of IoT-based smart traffic light systems?"*. When it comes to familiarity with how these system works, the responses show that most people have a limited knowledge about the IoT-based smart traffic light systems. A large portion of respondents, 106 people claimed that they are "Not familiar at all" with smart traffic light systems, while 93 people were only "Slightly familiar". This indicates more than a half of the participants have little to no understanding of how IoT-based traffic light systems work. Meanwhile, 81 respondents remained neutral, implying that they may have some knowledge but are not confident in it. A smaller number of respondents, 62 people, were “Very familiar”, and only 23 people considered themselves “Extremely familiar” with the concept. From these findings, we can conclude that while some people have heard of IoT-based smart traffic lights, the majority still have a vague knowledge of what they are and how they can improve traffic conditions. This emphasizes the need for public awareness and education about the systems so that more people can understand it benefits and support the implementation in the future.

Perspectives on Smart Traffic Light Systems

The question focuses on participants perceptions of the smart traffic light systems. The full question is *“Smart traffic light system aims to address challenges at intersections. Please share your opinion on the following statements about smart traffic light systems.”.* According to the survey results, most people have a positive view of smart traffic light systems, believing they can improve traffic flow and safety. A significant number of respondents (148 people agreed and 79 strongly agreed) believe that implementing these systems is necessary to effectively manage mixed traffic. Only a few people (9 respondents) disagreed or partially disagreed, indicating that most of participants see smart traffic light systems as an appropriate option for improving the current systems.

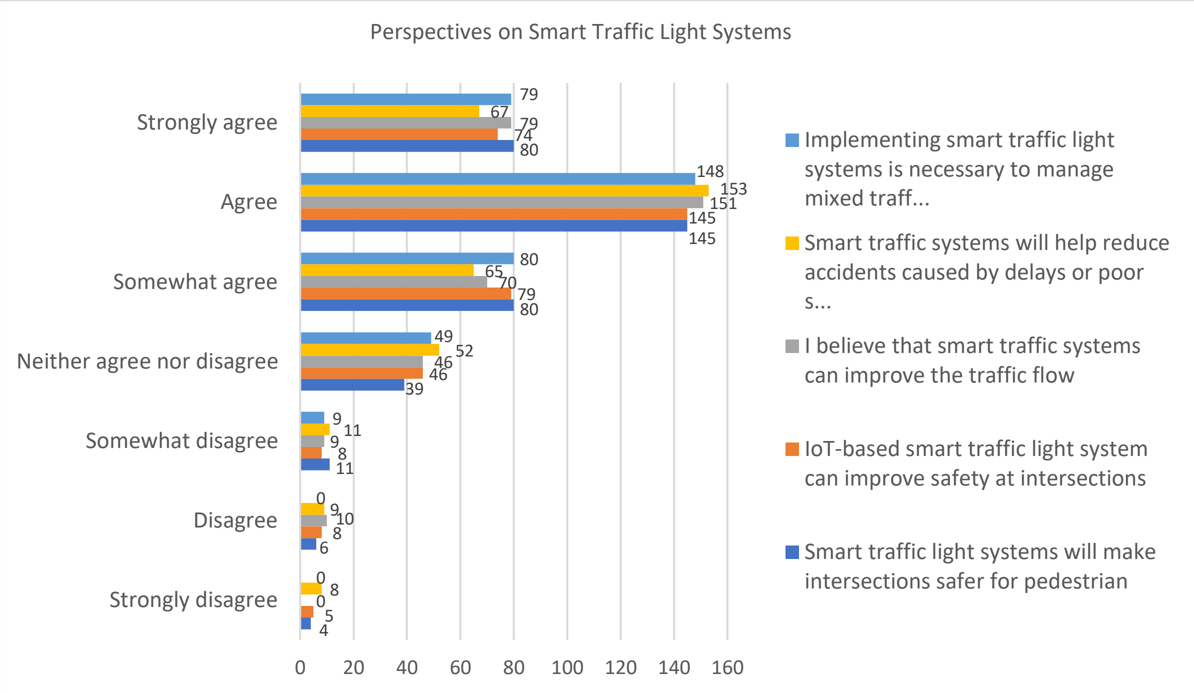

Figure 26. Perspectives on Smart Traffic Light Systems (Qualtrics, Author’s survey, 2025)

When it comes to safety at intersections, most respondents believe that smart traffic lights can make roads safer for both drivers and pedestrians. 145 respondents agreed and 80 people strongly agreed that these systems can improve pedestrian safety. In addition, 145 respondents agreed and 74 people strongly agreed that IoT-based smart traffic light systems can improve safety at intersections. This suggests that many people trust that these systems can help prevent accidents and create a safer traffic environment. In terms of traffic efficiency, most participants also had positive takes. 151 people agreed, and 79 people strongly agreed that smart traffic light systems can improve traffic flow by reducing delays and congestion. Additionally, 153 respondents agreed, with 67 strongly agreed what these systems can help prevent accidents caused by bad signal timing. This displays that people believe these systems can improve daily commuting and reduce sudden traffic stops or confusion at intersections.

While most participants supported the concept, some were unsure about the effectiveness of the system. A small number of respondents chose “Neither agree nor disagree”, meaning that they may require additional information or real-world examples to be convinced. However, few people strongly disagreed with the positive effects of these systems, indicating that resistance to these systems is low.

Overall, the findings highlight that people generally support the idea of smart traffic light systems and believe they can improve the current traffic environment.

Support for the Implementation of Smart Traffic Light Systems

The full question is *“Would you support implementing IoT-based Smart Traffic Light Systems in your area?”*. From the figures shown below, most respondents (239 people, 65.48%) fully support the implementation, indicating widespread belief in the potential of these systems. However, 107 respondents (29.32%) expressed support but with some concerns. It may suggest that while they recognize the benefits, they also worry about possible challenges. Their hesitancy implies that clear communication and reassurances about the systems are needed. And a smaller group, 19 respondents (5.21%), remained unsure about whether they support the idea. This can mean that their uncertainty may stem from a lack of information about how these systems function or doubt about their necessity in their local area.

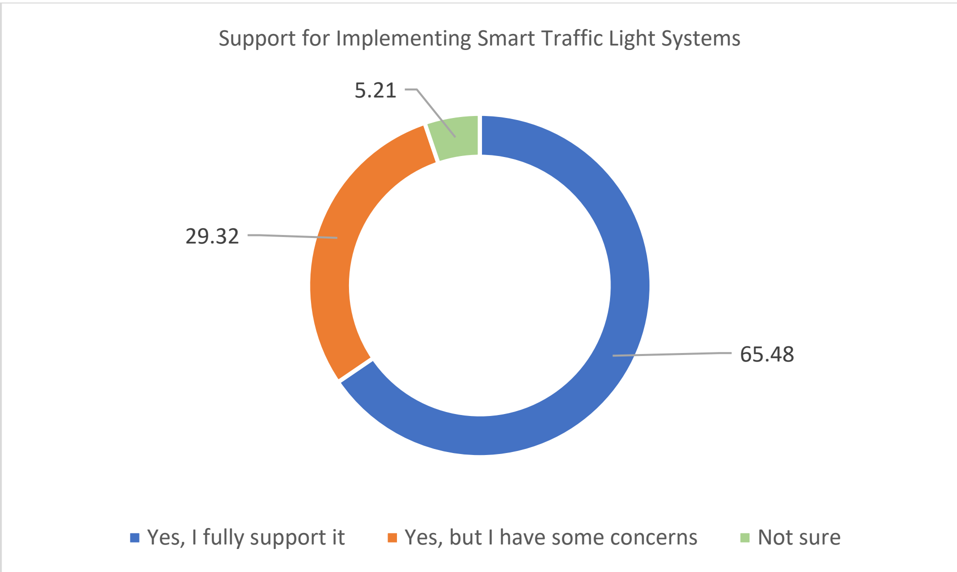

Figure 27. Support for Implementing Smart Traffic Light Systems (Qualtrics, Author’s survey, 2025)

Challenges in Future Implementations

The full question for this is *“What challenges do you think smart traffic light systems might face in your area?”*. They can also choose multiple choices given. From the responses, we can highlight several key obstacles that could make the system implementation difficult. The biggest concern among respondents was a lack of public understanding or awareness, with 220 people selecting this option. Another major challenge raised by 209 respondents was the high cost of installation and maintenance. From this response, in the future work it is important to securing funding and ensuring long-term viability for a successful implementation.

Other concern is about the technical issues such as potential malfunctions, voted by 115 respondents. In addition, 107 respondents pointed out that detecting all types of vehicles could be a challenge. This suggest that some people are concerned if the system can effectively recognize motorcycles, bicycles, or non-standard vehicles, which are common in many urban areas in Indonesia.

Interestingly, a small number of respondents (12 people) mentioned other challenges. The most mentioned is about the security and vandalism. There are concerns that the equipment and sensors could be stolen or destroyed, especially in areas where public awareness and law enforcement are weaker. The next one is their concern of lacking the facilities and infrastructure because some areas do not have proper roads, electricity, internet connectivity, and other supporting technology to ensure the system can functions effectively. Other concern mentioned is about the maintenance and longevity. Some fear that lacking of regular maintenance or delays in repairing broken components could reduce the system effectiveness or cause it to fail completely.

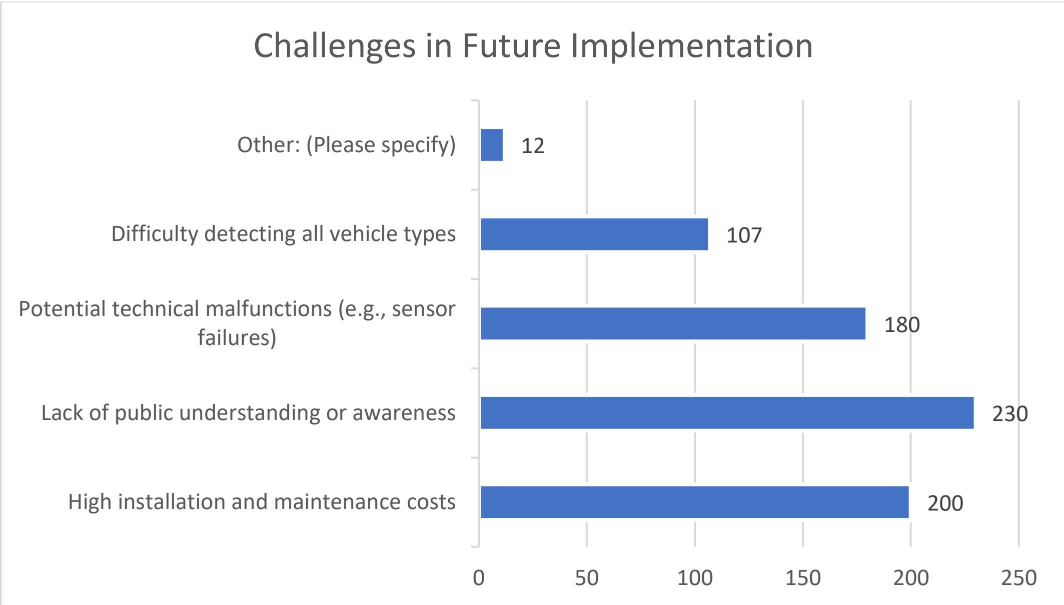

Figure 28. Challenges in Future Implementation (Qualtrics, Author's survey, 2025)

Public Perception of Traffic Safety Across Different Regions

The question asked is *"How safe do you feel as road users? (e.g., driver, pedestrian, cyclist) in your area?"*. From the survey results, it shows how people in different regions feel about traffic safety in their environment. Responses vary, with some feeling safe, other feeling unsafe, and many remaining neutral.

In urban areas, traffic safety issues are more common. Most respondents (88 people) chose neutral. A significant number of people (73 respondents) feel unsafe, with 17 respondents feeling extremely unsafe. On the other hand, 45 people feel safe, with 9 people feeling safer, indicating that while some people trust the traffic system, the majority remain unsure or concerned about traffic safety.

Suburban areas have a slightly better than in urban areas. 30 respondents feel safe, while 30 other respondents feel neutral, showing a balance of confidence and uncertainty. Yet, 21 people feel unsafe, but no one reported feeling very safe, which suggests room for improvement in traffic safety.

People in rural areas feel safer than they do in urban and suburban areas. 16 people feel safe, 13 people are neutral. Only 7 respondents reported feeling unsafe, 2 respondents feel very unsafe, and no one reported very safe. This can also indicate that while rural areas may have less traffic congestion, there are still some risks.

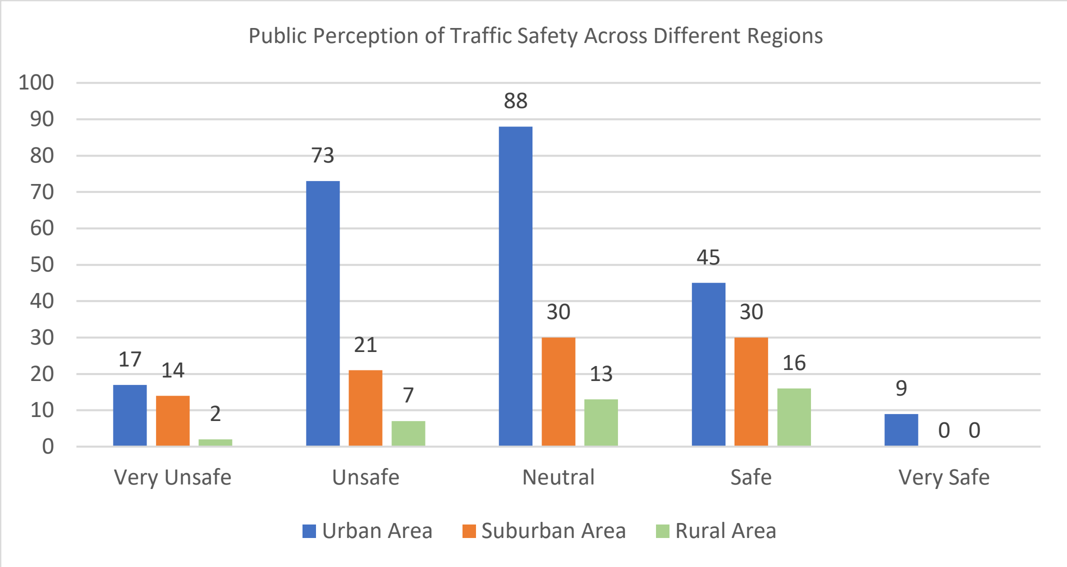

Figure 29. Public Perception of Traffic Safety Across Different Regions (Qualtrics, Author's survey, 2025)

Factors Contributing to Intersection Accidents

The full question is *"What do you think are the primary causes of road accidents in your area, particularly at intersections? (Multiple choices allowed)"*. From the survey results, it highlights the most common causes of road accidents at intersections based on public perception.

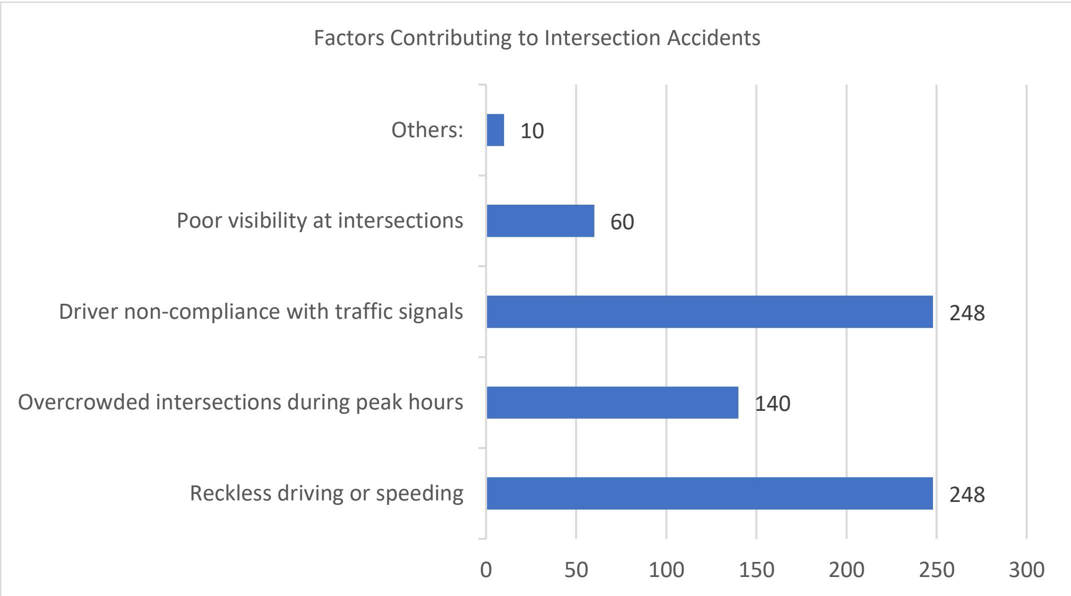

Figure 30. Factors Contributing to Intersection Accidents (Qualtrics, Author's survey, 2025)

Top causes of accidents start with reckless driving or speeding (248 votes), equally concerning with driver non-compliance with traffic signals (248 votes). Next issue is the overcrowded intersections during peak hours (140 votes), the more vehicles trying to pass through, the higher the chance of mistakes and risky maneuvers. Following the poor visibility at intersections with total 60 votes. Interestingly, there are 10 votes for "Others" category which can be summarized as follows: road conditions and infrastructure issues, drunk driving, and traffic light and signage problems.

LIMITATIONS

While this research provides valuable insights, it is important to acknowledge certain constraints that influences the scope and outcomes of the study. These limitations, that comes with the research process and the study area's specific context, should be considered when interpreting the results and planning future works.

1. *Data Limitation:*
   The study acknowledges that the reliability and accuracy of the results are determined by the quality of the collected data and the suitability of the statistical techniques used in the analysis. In this case, my data is only for one day at the specific hours in the morning, afternoon, and evening, which might not be representative of reality. This also specifically impacted the depth of quantitative performance analysis for the existing road network. As a result, the findings are representative only on the peak-hour conditions and may not reflect off-peak or irregular traffic patterns (e.g., during religious events). In addition, quantitative data for the bicycles users was not comprehensively collected in the study area that may give a huge influence on intersection delay and safety, and therefore be underrepresented in both analytical and simulation outcomes.

2. *Scope of Study:*
   The research focuses on the Masbagik Intersection in East Lombok, Indonesia. While this allows for a thorough case study, the results and proposed system design may not be directly applicable to all other intersections without site-specific adjustments and additional research. Furthermore, while the study included public survey responses about IoT readiness and reviewed successful case studies globally, it did not implement or simulate IoT-based traffic systems directly. As a result, the findings on smart traffic systems are forward-looking and exploratory rather than practical.

3. *Survey Limitation:*
   While the survey provides valuable insights into public perceptions of traffic issues and IoT-smart solutions, the responses may have been influenced by the respondent's demographics, which primarily young adults (25 – 34 years old) and urban residents. This demographic concentration might mean the views expressed are not fully representative of the entire community, including older individuals or those residing in more rural settings. A sizable proportion of survey respondents reported limited familiarity with IoT-based smart traffic light systems, which may have influenced their perceptions of potential benefits and challenges.

4. *Analytical Constraints:*
   Although PKJI 2023 offers valuable local adaptation for Indonesian traffic conditions, it still assumes certain levels of driver discipline, lane usage, and compliance that may not fully represent real-world behaviors at the Masbagik intersection. Informal driving behaviors such as motorcyclists using pedestrian spaces or creating informal turning lanes, are difficult to model accurately using purely analytical methods.

5. *Microsimulation Limitation:*
   The student version of PTV VISSIM used in this research had certain functional restrictions. This limitation may have influenced the depth of scenario analysis and evaluating capabilities.

CONCLUSION

The persistent ongoing traffic congestion and road safety risks at the unsignalized Masbagik intersection in East Lombok, Indonesia, highlight the urgent need for a traffic management solution. This study set out to evaluate the operational performance of the Masbagik intersection, unsignalized junction in East Lombok, by proposing and testing a fixed-time signal control design using Indonesian Road Capacity Guidelines (Pedoman Kapasitas Jalan Indonesia - PKJI) 2023 and microsimulation modelling in PTV VISSIM. In addition to investigating public preparedness and the potential of IoT-based smart traffic systems in the future, the main goal was to find out whether the installation of traffic signals could increase intersection efficiency and safety.

The results from the analysis indicated that the existing unsignalized intersection experiences significant operational inefficiencies, especially during peak hours. High delay values and high degree of saturation were observed, particularly on minor approaches that struggle to access gaps in the major road flow. Based on these findings, a fixed-time signal plan was designed to distribute right-of-way in a structured and controlled manner, accounting for critical lane groups and peak-hour volumes. The proposed design's analytical results showed notable improvements in the degree of saturation and average vehicle delay, indicating increased capacity and less intersection conflict.

An essential finding of this study is the apparent contradiction wherein the proposed signalized intersection results in a higher overall vehicle delay (e.g., 48.98 s/pcu analytically and 54.01 s/pcu in simulation) compared to the existing unsignalized state (11.40 s/pcu). However, this increase should not be interpreted as a failure of the design but rather as a positive and necessary trade-off for substantial improvements in intersection equity, safety and predictability. The main advantage is the removal of many points of conflict between vehicles and pedestrians, which are present in the unsignalized design and are currently affected by uncontrolled interactions and traffic conflicts. The signalized system reduces the unpredictable interactions and dangerous maneuvers that can cause crashes by implementing a structured right-of-way. Moreover, a more equitable distribution of service is reflected in the higher average delay. Most importantly, the fixed-time signal offers a protected, exclusive phase for pedestrians, converting a high-risk crossing environment into one that is safer and more accessible. The time allocated to this pedestrian phase is a direct investment in pedestrian safety, which is necessary for a safe multi-modal system but also adds to the average vehicle delay overall. The signalization essentially exchanges a slightly higher but much more predictable, orderly, and safe operating environment for all road users in exchange for a lower, but more volatile and inequitable average delay

The VISSIM microsimulation model supplemented the analytical work by offering a more realistic evaluation of traffic operations under the suggested and current scenarios. The simulated results for the proposed signalized intersection aligned with the analytical findings, showing reductions in vehicle delay and shorter queues. This validated the feasibility and effectiveness of the fixed-time traffic signal control strategy in addressing congestion and improving performance at the intersection.

In addition to the quantitative performance assessment, this study also included a public perception survey to learn community awareness and acceptance of potential future applications of IoT-based smart traffic light systems. The responses revealed strong support for improving traffic control at intersections, and generally positive attitude toward them. However, awareness of IoT technology and its capabilities in traffic management remains relatively limited. Cost, system reliability, and the need for proper infrastructure were cited as key concerns, indicating the importance of phased implementation and public education before adopting more advanced systems. This insight directly informs and validates the recommendation for a phased approach which is introducing a foundational fixed-time system first to build public trust and institutional capacity before advancing to more complex technologies.

Should this system be implemented, the system is expected to yield substantial tangible benefits, including reduce vehicle delays, smoother traffic flow, more structured pedestrian crossings, and increased safety by minimizing conflict points. The primary anticipated outcome is a noticeable improvement in daily commuter experience and a reduction in accident risk. The design will directly address the core goals of this research: identifying how IoT can be applied to improve urban mobility in the current research area. In conclusion, this study provides a foundational blueprint for improving urban mobility in East Lombok, which could serve as an adaptable model for other rapidly urbanizing areas in Indonesia and similar developing regions that face similar transportation challenges. aa

RECOMMENDATIONS AND FUTURE RESEARCH

This study demonstrates that implementing a fixed-time signal system at the Masbagik intersection, East Lombok, Indonesia, can reduce delays and improve traffic performance in a mixed-traffic environment. Based on the findings, several practical and strategic recommendations are proposed.

Key recommendations for local authorities are encouraged to adopt the proposed fixed-time signal plan, designed using PKJI 2023 and validated through VISSIM microsimulation. To maximize its effectiveness, the signal should be supported by clear road markings, pedestrian crossings, and enforcement to ensure driver compliance. Public awareness campaigns should be carried out to help road users to understand and adapt to the new traffic system. In addition, at policy level, this research supports expanding signalization in other busy intersections across East Lombok.

It is also recommended to monitor the intersection post-implementation, adjusting cycle lengths and green times based on real-time conditions, moving towards an advanced IoT-based smart traffic light system. Furthermore, establishing strong inter-agency coordination and sustainable funding are essential for the long-term viability and effectiveness of such intelligent transportation systems.

Future research should build upon this study by first focusing on more comprehensive data collection to enable good traffic simulation and quantitative impact analysis of the proposed system. This would involve gathering data over extended periods (multiple days, varied times including off-peak, and different months) to capture the full spectrum of traffic dynamics. Expanding the scope to other intersections will test the solution’s scalability and adaptability. Subsequently, this study recommends a strategic, long-term evolution towards an IoT-based smart traffic system. The initial fixed-time signal infrastructure should be designed to be more upgradable that allows for future integrations of real-time data analytics, sensors, and adaptive control algorithms. This phased strategy is practical. It allows local authorities to realize immediate safety and operational benefits while simultaneously building the technical expertise, institutional frameworks, and public awareness for the successful adoption of more adaptive and advance technologies. It can directly address the community concerns about cost and complexity identified in the survey, positioning smart traffic systems as a future goal rather than an immediate, overwhelming investment.

Furthermore, conducting thorough socio-economic analyses post-implementation, including detailed cost-benefit assessments, evaluations of impacts on local businesses, and improvements in the overall quality of life for residents, will provide meaningful insights into the broader community benefits and justify future investments. Such research could benefit greatly from interdisciplinary collaborations, for instance with urban planners to ensure system alignment with broader city development goals and the development of localized policy frameworks, will be important to guide the optimization of these intelligent transportation solutions in East Lombok and similar regions.

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ANNEXES

Annex 1: Survey

INTRODUCTION

Skip to

End of Survey if I disagree and would not li... Is Selected

My name is Amelia Nurul Damayanti, and I am a master's student at Hasselt University in the Transportation Sciences program. The purpose of this research is to examine traffic challenges and explore the potential implementation of IoT-based (Internet of Things) smart traffic systems to improve the road safety and traffic efficiency. This survey will take approximately 10 minutes to complete, and all your information will be treated with strict confidentiality.

Before starting the survey, please read the information below thoroughly:
- I confirm that I have read and understood the above information about this study.
- I understand the purpose of this study and what is expected of me as a participant.
- I acknowledge that my participation in this study is voluntary and that I have the right to withdraw at any point during the survey (e.g., by closing the browser window) without providing a reason.
- I understand that no disadvantages or penalties will arise if I choose to discontinue my participation.
- I understand that the results of this research may be used for academic purposes and published in an anonymous form. My personal information will remain confidential at all stages of the research.
- I acknowledge that the results of this research will be securely stored for a period of 6 months after the survey ends and will be permanently deleted thereafter.
- For any questions or further information regarding this research, I can contact the researcher at: amelianurul.damayanti@student.uhasselt.be

By submitting this survey form, you are indicating that you have read and understood the purpose of the study and agree to the terms of participation.

Thank you in advance for your valuable input!

- ○ I agree and would like to fill in the survey
- ○ I disagree and would not like to fill in the survey

What is your gender?

- ◯ Male
- ◯ Female
- ◯ Prefer not to say

Q1.2

What is your age group?

- ◯ 16 - 24
- ◯ 25 - 34
- ◯ 35 - 44
- ◯ 45 - 65
- ◯ 65+

Q1.3

What is your current profession?

- ◯ Student
- ◯ Employee
- ◯ Business Owner
- ◯ Other: (Please specify)

Q1.4

What is your primary mode of transport for daily commuting?

- ◯ Car
- ◯ Motorcycle
- ◯ Public Transport (Bus, train, etc.)
- ◯ Bicycle
- ◯ Walking
- ◯ Other: (Please specify)

Q1.5

Do you own a driving license?

- ○ Yes
- ○ No

Q1.6

In what kind of area do you live in?

- ○ Urban area
- ○ Suburban area
- ○ Rural area

-- Page Break --

Q2.1

Mixed Traffic refers to the situation where different types of vehicles share the same road infrastructure. Have you ever experienced being in mixed traffic in your daily commute?

To what extent do you agree with the following statements?

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
I have experienced driving in mixed traffic	○	○	○	○	○
I have been involved in mixed traffic as a passenger	○	○	○	○	○
I have never been involved in mixed traffic	○	○	○	○	○
I am not sure if I ever been involved in mixed traffic	○	○	○	○	○

How often do you encounter the following issues in mixed traffic conditions, particularly in intersections?

	Never	Sometimes	About half the time	Most of the time	Always
Traffic congestion during peak hours	○	○	○	○	○
Delays due to poor signal timing	○	○	○	○	○
Difficulty crossing roads as a pedestrian	○	○	○	○	○
Near-miss accidents involving different vehicle types (e.g., cars and motorcycles)	○	○	○	○	○

Page Break

Q3.1

Have you ever heard of IoT (Internet of Things)-based smart traffic light systems before?

- ○ Definitely not
- ○ Probably not
- ○ Might or might not
- ○ Probably yes
- ○ Definitely yes

Q3.2

How familiar are you with the concept of IoT-based smart traffic systems?

- ○ Not familiar at all
- ○ Slightly familiar
- ○ Neutral
- ○ Very familiar
- ○ Extremely familiar

Smart traffic light system aim to address challenges at intersections. Please share your opinion on the following statements about smart traffic light systems.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Smart traffic light systems will make intersections safer for pedestrian	○	○	○	○	○	○	○
IoT-based smart traffic light system can improve safety at intersections	○	○	○	○	○	○	○
I believe that smart traffic systems can improve the traffic flow	○	○	○	○	○	○	○
Smart traffic systems will help reduce accidents caused by delays or poor signal timing	○	○	○	○	○	○	○
Implementing smart traffic light systems is necessary to manage mixed traffic efficiently	○	○	○	○	○	○	○

Q3.5

Would you support implementing IoT-based smart traffic light systems in your area?

○ Yes, I fully support it

○ Yes, but I have some concerns

○ No, I do not support it

○ Not sure

Q3.6

What challenges do you think smart traffic light systems might face in your area? (Multiple choices allowed)

☐ High installation and maintenance costs

☐ Lack of public understanding or awareness

☐ Potential technical malfunctions (e.g., sensor failures)

☐ Difficulty detecting all vehicle types

☐ Other: (Please specify)

How safe do you feel as road user? (e.g., driver, pedestrian, cyclist) in your area?

- ○ Very unsafe
- ○ Unsafe
- ○ Neutral
- ○ Safe
- ○ Very safe

Q4.2

What do you think are the primary causes of road accidents in your area, particularly at intersections? (Multiple choices allowed)

- ☐ Reckless driving or speeding
- ☐ Overcrowded intersections during peak hours
- ☐ Driver non-compliance with traffic signals
- ☐ Poor visibility at intersections
- ☐ Other: (Please specify) ________

Q4.3

To what extent do you agree with the following statements about traffic safety in your area?

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Current traffic light systems are not effective in preventing accidents	○	○	○	○	○	○	○
Poor timing signals contribute to congestion and crashes	○	○	○	○	○	○	○
Mixed traffic conditions increase the risk of accidents	○	○	○	○	○	○	○
Insufficient safety measures for pedestrians at	○	○	○	○	○	○	○

Annex 2: Analytical Calculations Part with Ms. Excel

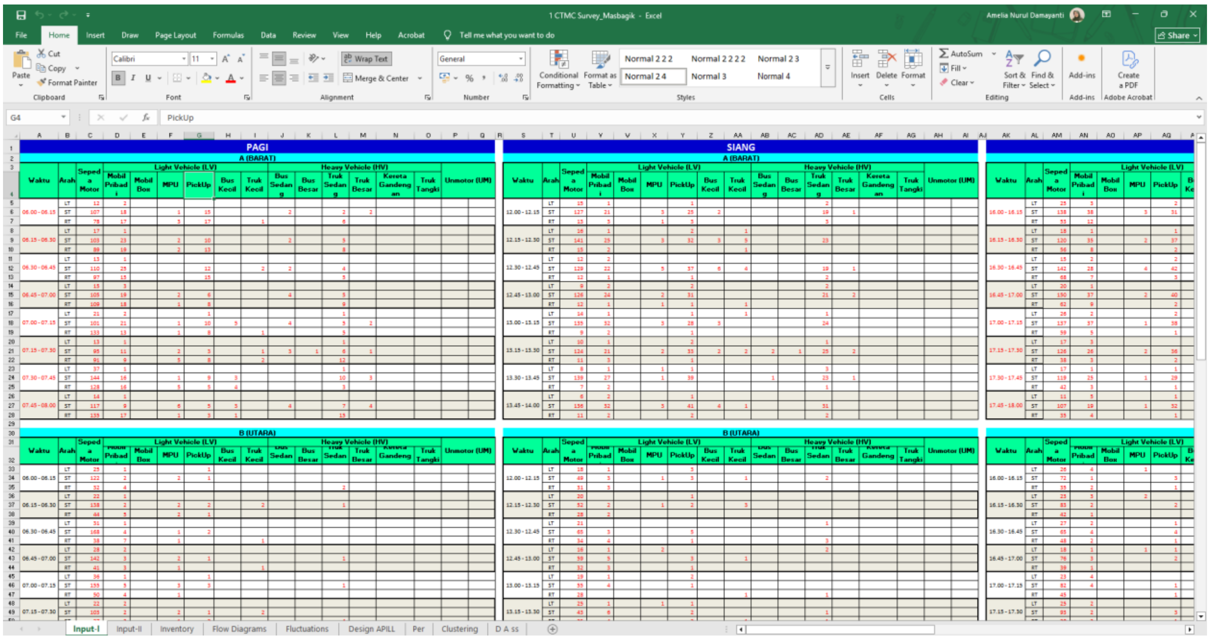


Figure 31. Vehicle Volume Data Table

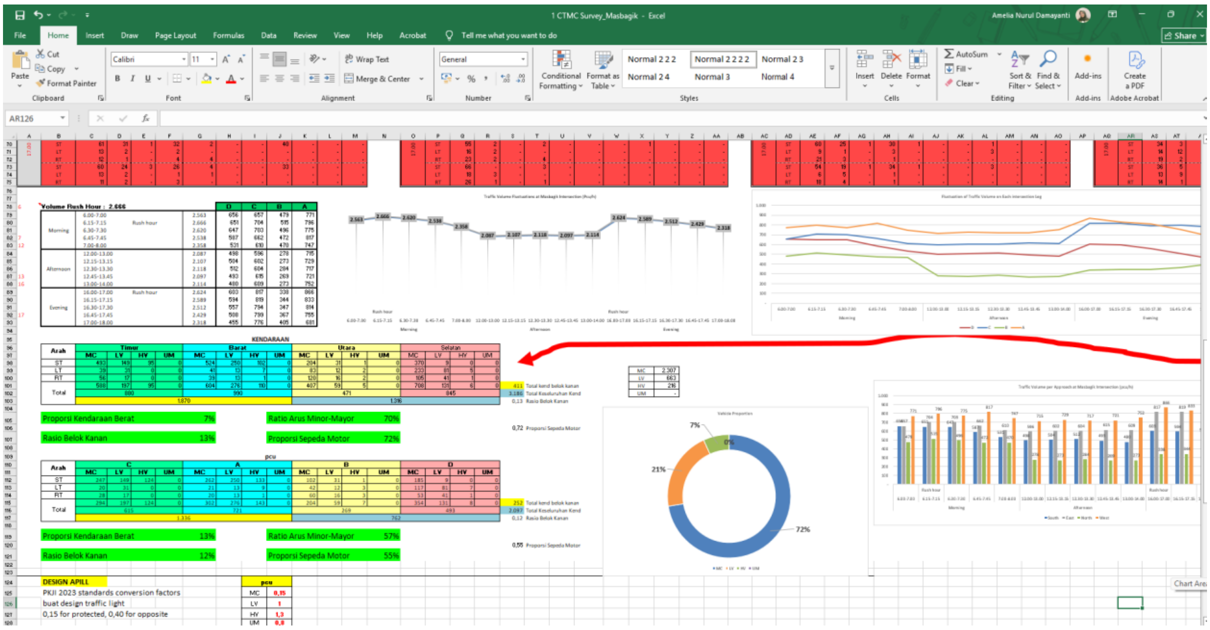


Figure 32. Traffic Volume Fluctuations (Author's Edit)

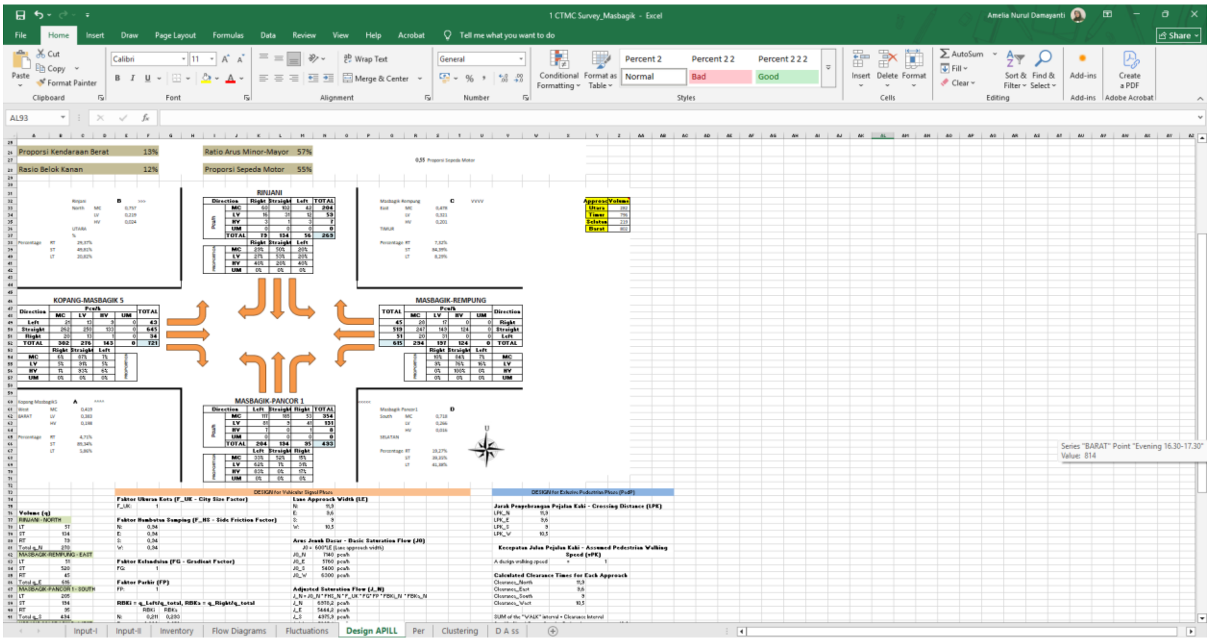
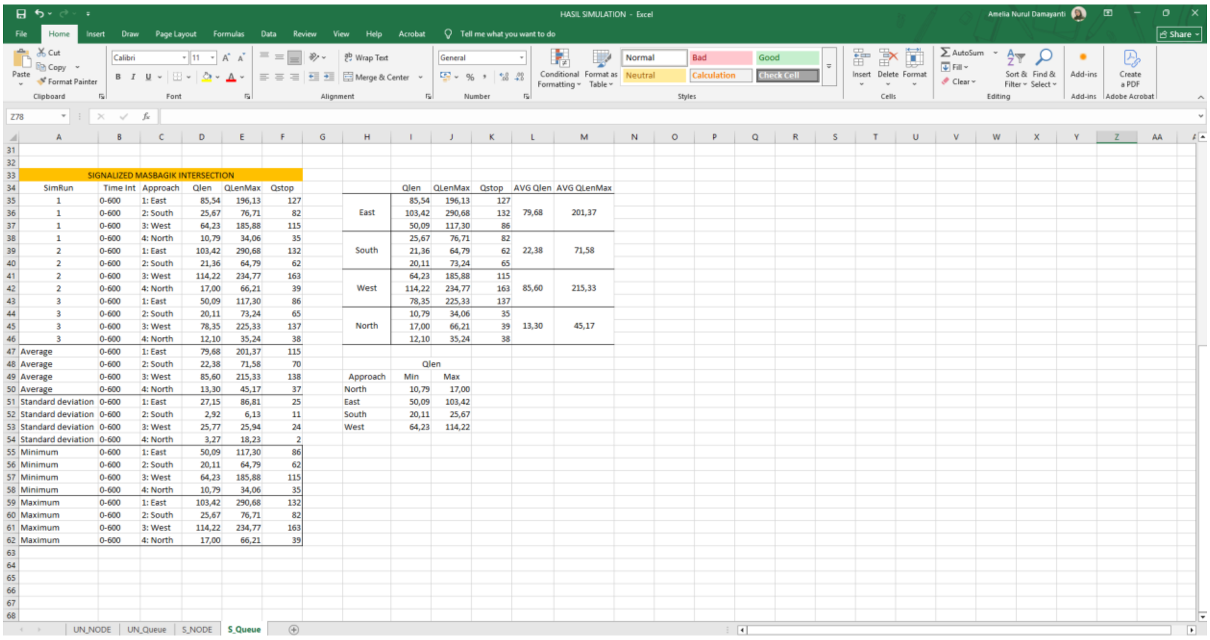


Figure 33. CTMC Survey Result and Analytical Calculations (Author's Edit)

Annex 3: Simulation Results Exported from VISSIM



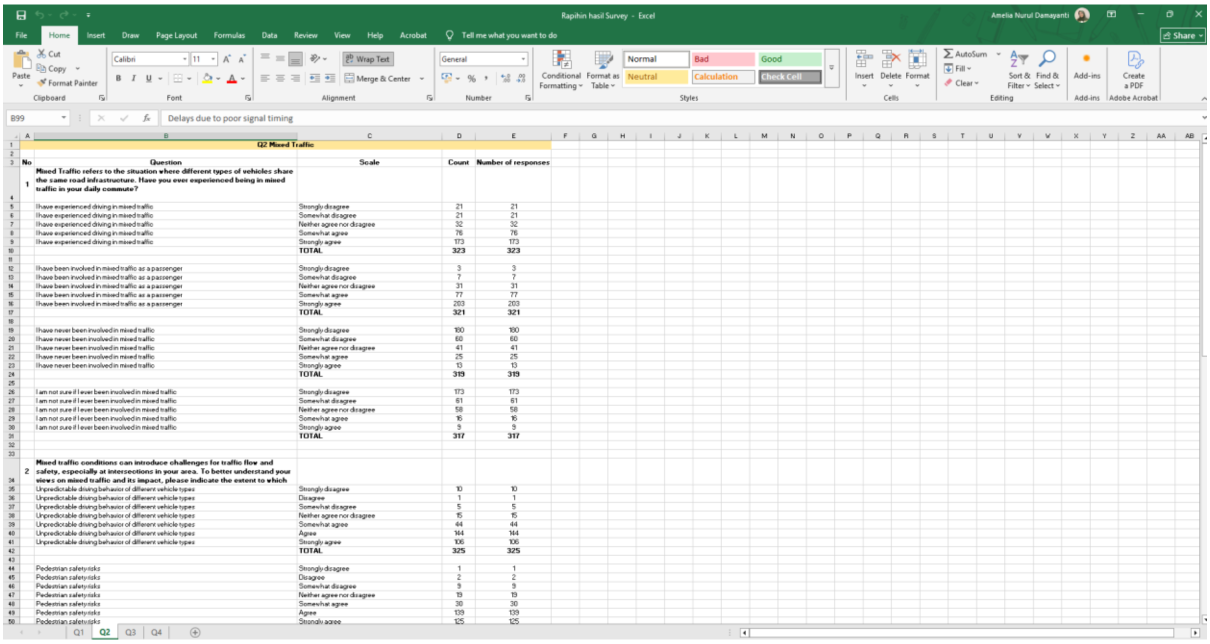
SIGNALIZED MASBAGIK INTERSECTION					
SimRun	Time Int	Approach	Qlen	QLenMax	Qstop
1	0-600	1: East	85,54	196,13	127
1	0-600	2: South	25,67	76,71	82
1	0-600	3: West	64,23	185,88	115
1	0-600	4: North	10,79	34,06	35
2	0-600	1: East	103,42	290,68	132
2	0-600	2: South	21,36	64,79	62
2	0-600	3: West	114,22	234,77	163
2	0-600	4: North	17,00	66,21	39
3	0-600	1: East	50,09	117,30	86
3	0-600	2: South	20,11	73,24	65
3	0-600	3: West	78,35	225,33	137
3	0-600	4: North	12,10	35,24	38
Average	0-600	1: East	79,68	201,37	115
Average	0-600	2: South	22,38	71,58	70
Average	0-600	3: West	85,60	215,33	138
Average	0-600	4: North	13,30	45,17	37
Standard deviation	0-600	1: East	27,15	86,81	25
Standard deviation	0-600	2: South	2,92	6,13	11
Standard deviation	0-600	3: West	25,77	25,94	24
Standard deviation	0-600	4: North	3,27	18,23	2
Minimum	0-600	1: East	50,09	117,30	86
Minimum	0-600	2: South	20,11	64,79	62
Minimum	0-600	3: West	64,23	185,88	115
Minimum	0-600	4: North	10,79	34,06	35
Maximum	0-600	1: East	103,42	290,68	132
Maximum	0-600	2: South	25,67	76,71	82
Maximum	0-600	3: West	114,22	234,77	163
Maximum	0-600	4: North	17,00	66,21	39

	Qlen	QLenMax	Qstop	AVG Qlen	AVG QLenMax
East	85,54	196,13	127	79,68	201,37
	103,42	290,68	132		
	50,09	117,30	86		
South	25,67	76,71	82	22,38	71,58
	21,36	64,79	62		
	20,11	73,24	65		
West	64,23	185,88	115	85,60	215,33
	114,22	234,77	163		
	78,35	225,33	137		
North	10,79	34,06	35	13,30	45,17
	17,00	66,21	39		
	12,10	35,24	38		

	Qlen	
Approach	Min	Max
North	10,79	17,00
East	50,09	103,42
South	20,11	25,67
West	64,23	114,22

Figure 34. Traffic Queue Results Table

Annex 4: Qualtrics Raw Survey Result



Q2 Mixed Traffic				
No	**Question**	**Scale**	**Count**	**Number of responses**
1	**Mixed Traffic refers to the situation where different types of vehicles share the same road infrastructure. Have you ever experienced being in mixed traffic in your daily commute?**			
	I have experienced driving in mixed traffic	Strongly disagree	21	21
	I have experienced driving in mixed traffic	Somewhat disagree	21	21
	I have experienced driving in mixed traffic	Neither agree nor disagree	32	32
	I have experienced driving in mixed traffic	Somewhat agree	76	76
	I have experienced driving in mixed traffic	Strongly agree	173	173
		TOTAL	**323**	**323**
	I have been involved in mixed traffic as a passenger	Strongly disagree	3	3
	I have been involved in mixed traffic as a passenger	Somewhat disagree	7	7
	I have been involved in mixed traffic as a passenger	Neither agree nor disagree	31	31
	I have been involved in mixed traffic as a passenger	Somewhat agree	77	77
	I have been involved in mixed traffic as a passenger	Strongly agree	203	203
		TOTAL	**321**	**321**
	I have never been involved in mixed traffic	Strongly disagree	180	180
	I have never been involved in mixed traffic	Somewhat disagree	60	60
	I have never been involved in mixed traffic	Neither agree nor disagree	41	41
	I have never been involved in mixed traffic	Somewhat agree	25	25
	I have never been involved in mixed traffic	Strongly agree	13	13
		TOTAL	**319**	**319**
	I am not sure if I ever been involved in mixed traffic	Strongly disagree	173	173
	I am not sure if I ever been involved in mixed traffic	Somewhat disagree	61	61
	I am not sure if I ever been involved in mixed traffic	Neither agree nor disagree	58	58
	I am not sure if I ever been involved in mixed traffic	Somewhat agree	16	16
	I am not sure if I ever been involved in mixed traffic	Strongly agree	9	9
		TOTAL	**317**	**317**
2	**Mixed traffic conditions can introduce challenges for traffic flow and safety, especially at intersections in your area. To better understand your views on mixed traffic and its impact, please indicate the extent to which**			
	Unpredictable driving behavior of different vehicle types	Strongly disagree	10	10
	Unpredictable driving behavior of different vehicle types	Disagree	1	1
	Unpredictable driving behavior of different vehicle types	Somewhat disagree	5	5
	Unpredictable driving behavior of different vehicle types	Neither agree nor disagree	15	15
	Unpredictable driving behavior of different vehicle types	Somewhat agree	44	44
	Unpredictable driving behavior of different vehicle types	Agree	144	144
	Unpredictable driving behavior of different vehicle types	Strongly agree	106	106
		TOTAL	**325**	**325**
	Pedestrian safety risks	Strongly disagree	1	1
	Pedestrian safety risks	Disagree	2	2
	Pedestrian safety risks	Somewhat disagree	9	9
	Pedestrian safety risks	Neither agree nor disagree	19	19
	Pedestrian safety risks	Somewhat agree	30	30
	Pedestrian safety risks	Agree	139	139
	Pedestrian safety risks	Strongly agree	125	125

Figure 35. Qualtrics Raw Data