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**INVESTIGATING THE IMPACT OF MOTORCYCLE  
DRIVING PATTERNS ON URBAN TRAFFIC**

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Degree of Master of Engineering

Department of Civil Engineering

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May 2024

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Thesis submitted in partial fulfilment of the requirements for the degree Master of  
Engineering in Civil Engineering

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## DECLARATION

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## ABSTRACT

Heterogeneous traffic conditions are prevalent in countries across the South Asian region, setting them apart significantly from many other nations worldwide. Moreover, distinct driving behaviours, a tendency to disregard rules and regulations, and a non-lane following driving style further differentiate traffic in these areas. Motorcycles (MC) are widely used and easily accessible modes of transportation in South Asian countries, experiencing rapid growth in usage over the years. For instance, in Sri Lanka, a South Asian nation, motorcycles now constitute 30% of urban traffic flow, reflecting a substantial increase from 2016 to 2020. This surge is fuelled by a notable 30% rise in registered motorcycles annually, growing at a rate of 8% annually during the mentioned period.

Motorcycles, known for their manoeuvrability, exert significant influences on traffic dynamics, safety, and environmental concerns. According to the World Health Organization (WHO), nearly 30% of road crash fatalities involve motorized two and three-wheeled vehicles, including motorcycles, scooters, and electric bikes, with this statistic trending upward globally. Notably, in the Southeast Asian Region, this figure stands at approximately 43%. In Sri Lanka, motorcycle-related fatalities consistently represent over 40% of total annual fatal crashes, contributing to about 34% of all road accidents in recent years. The country's roads often witness erratic driving behaviour and a lack of lane discipline among motorcycle riders, characterized by zigzag manoeuvres, slow progression at signalized intersections, and disruptions to traffic flow, impacting the movement of other vehicles. Additionally, studies indicate that the high presence of motorcycles on urban roads significantly compromises air quality in these areas. Consequently, close monitoring and regulation of motorcycle behaviour on Sri Lankan roads are imperative to comprehend and address their impacts. This study's primary objective is to assess and quantify the influence of motorcycles on urban traffic flow in Sri Lanka, intending to propose effective measures to mitigate their impact.

This research utilized handheld cameras to gather data from mid-block road segments and signalized intersections. Both manual techniques and software-based methods were employed to ensure accurate data extraction. Various data types, including headway, vehicle types, and vehicle counts, were extracted for subsequent analysis. A key objective was to examine the behaviour of motorcycles across different traffic and roadway conditions, focusing on aspects such as trajectory, lane position, speed, headway, and lane splitting. Additionally, the study aimed to evaluate the impact of motorcycles on urban traffic by assessing variations in Passenger Car Units (PCU) under different traffic and road scenarios. PCU values were determined through the spatial headway approach, with the Road Development Authority (RDA) Design Guideline recommending a PCU of 0.4 for motorcycles, while the Highway Capacity Manual (HCM 2000) did not offer a specified value. The findings indicated that PCU values for motorcycles ranged from 0.35 to 0.60 in areas with low motorcycle compositions (0%-25%) and between 0.40 to 0.75 in areas with high motorcycle compositions (25%-50%) across various traffic flow conditions.

Moreover, the research aimed to assess the influence of motorcycles at signalized intersections, particularly focusing on saturation headway and start-up lost time. The results revealed an average saturation headway of approximately 2.5 seconds at these intersections. Additionally, the presence of motorcycles in the queue was found to significantly affect the achievement of saturation headway. Furthermore, a robust positive correlation was identified between start-up lost time and the number of motorcycles in the queue. Each motorcycle was found to contribute 0.5 seconds to start-up lost time, resulting in a total of 3.9 seconds of lost time in the absence of motorcycle storage, as evidenced by the analysis.

This study aids in comprehending the driving behaviours of motorcycles (MCs) and quantifying their effects on traffic flow at both mid-block road sections and signalized intersections. Furthermore, the findings of this research would enable the establishment of accurate Passenger Car Unit (PCU) factors for motorcycles, tailored to various traffic conditions and compositions of motorcycles. Such insights would assist designers in refining their designs by employing the most appropriate PCU factors for motorcycles, taking into account specific road and traffic attributes. Ultimately, this study sets the stage for future investigations aimed at quantifying the impacts of motorcycles on safety and emissions.

Keywords: Motorcycle, Driving Behaviour, Lane discipline, Headway, PCU

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## **LIST OF ABBREVIATIONS**

<b>Abbreviation</b>	<b>Description</b>
MC	Motorcycle
MCs	Motorcycles
PCU	Passenger Car Units
RDA	Road Development Authority
HCM	Highway Capacity Manual
LHS	Left-Hand Side
RHS	Right-Hand Side
SLT	Start-Up Lost Time
STDV	Standard Deviation
TRL	Transport Research Laboratory
TRRL	Transport and Road Research Laboratory
LT	Light Truck
MT	Medium Truck
HT	Heavy Truck

# 1 INTRODUCTION

## 1.1 Research Background

Due to the diverse range of vehicles and driving habits among motorists, traffic in South Asian countries differs significantly from that of many other nations (MINH et al., 2005). Sri Lanka, being one such South Asian country, shares similar traffic conditions on its roads. In Sri Lanka, traffic congestion has become a main problem in urban areas, leading to increased travel times, fuel consumption, environmental pollution, and road user costs (MINH et al., 2005). Among the wide varieties of vehicles on the road, motorcycles (MCs) have become a progressively popular mode of transportation in urban areas (Shajith et al., 2019). The popularity of motorcycles stems from their low transportation cost, easy manoeuvrability, convenient parking, affordability, and suitability for narrow road spaces, such as pathways and access roads. Additionally, their ability to navigate traffic with less road space contributes significantly to reducing travel time, furthering their attraction. Moreover, the inadequate improvements in the country's public transport sector have also increased the attraction for motorcycles. (Shajith et al., 2019)

The motorcycle composition of the traffic flow on most Sri Lankan highways is nearly 30% (Jayaratne,2018). "From 2012 to 2016, the number of registered motorcycles increased by 45% with a growth rate of 11% per year". The figures presented illustrate the notable increase in the motorcycle population within the country between 2012 and 2016. (Shajith et al., 2019). Figure 1.1 shows the vehicle composition of Sri Lankan highways.

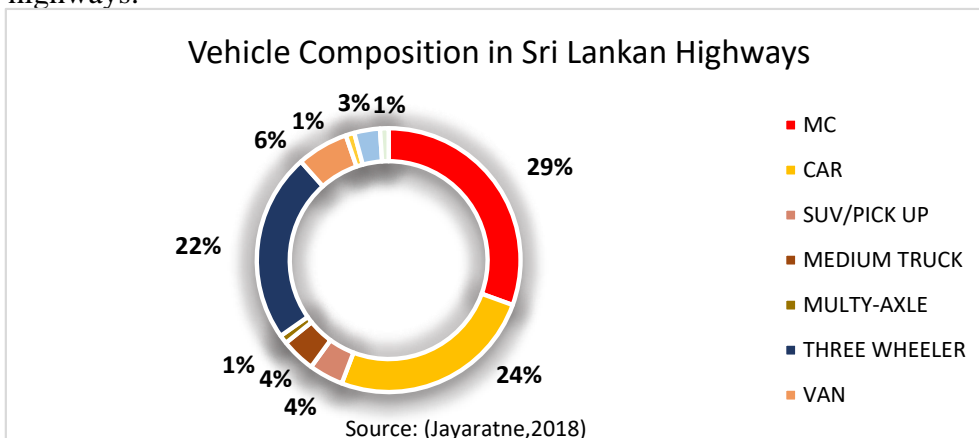


Figure 1. 1 Vehicle composition of Sri Lankan highways

As per the data from the Department of Motor Traffic from 2016 to 2020, the number of registered motorcycles increased by 30% with a growth rate of 7% per year”. Figure 1.2 shows the variation of registered motorcycles from 2016 to 2020 in Sri Lanka.

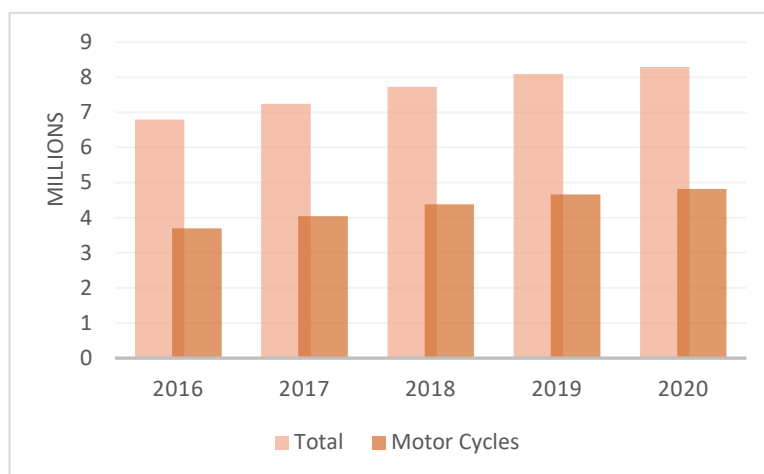


Figure 1. 2 Number of registered motorcycles in Sri Lanka from 2016 to 2020

Presently, Sri Lanka possesses a fleet of 2.7 million functional vehicles, indicating an ownership rate of 129 vehicles per 1000 individuals. It is indicated in Table 2.1 that Motorcycles have the highest Vehicle ownership rate (VOR) which is 66 per 1000 persons in Sri Lanka (Madhuwanthi et al., 2016). This figure clearly shows the high demand for motorcycles in Sri Lanka. Table 1.1 shows the vehicle ownership rates.

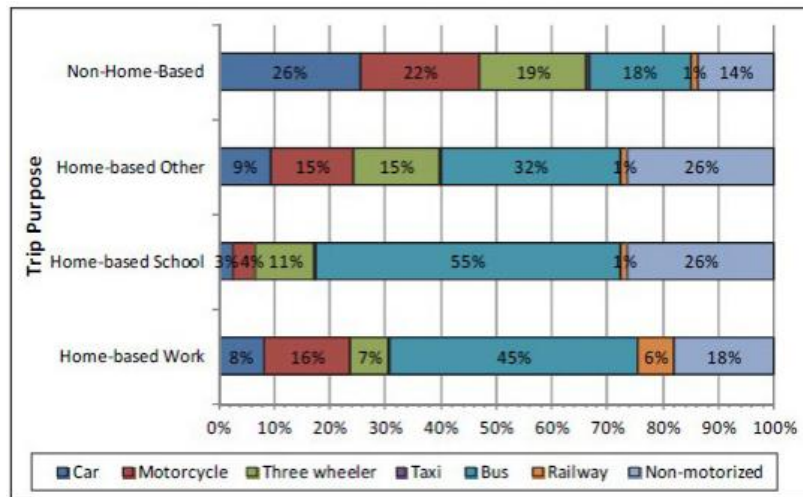
Table 1. 1 Vehicle ownership rates (VOR)

Vehicle Type	VOR per 1000 persons	Province	VOR per 1000 persons
Buses	2	Western	182
Dual Purpose vehicle	9	Southern	128
Private Cars	14	Sabaragamuwa	83
Land vehicles	10	North Western	150
Goods Transport vehicles	4	Central	84
Motor Cycles	66	Uva	73
Three wheelers	23	North Central	140
Others	0	Eastern	123
		Northern	53
<b>Total</b>	<b>129</b>	<b>Sri Lanka</b>	<b>129</b>

Source: Sri Lanka Transport Sector Policy Note by Amal Kumara

As per the CoMTrans Home Visit survey carried out by the Ministry of Transport and Japan International Cooperation Agency (JAICA) for the western province of Sri Lanka in 2013, It is clearly shown that other than public transport and Non-motorized transport, motorcycle is the most preferred travel mode among the Home-Based trips. (Madhuwanthi et al., 2016). Figure 1.3 shows the Model Share by Trip Purpose in the Western Province.

Figure 1.3 Model Share by Trip Purpose in the Western Province



Source: CoMTrans Home Visit Survey 2013

As per a study done by Shajith et al.(2019), motorcycles are involved in over 40% of traffic incidents in Sri Lanka. Moreover, they are responsible for around 29% of fatalities for pedestrians and 9% for cyclists. According to the study, this categorizes motorcycle riders as vulnerable road users, underscoring their greater vulnerability to collisions and highlighting the necessity of heightened safety precautions and awareness on the roadways. Further, Hungdung Cho et al (2004) expressed that the increasing number of motorcycles on the road has also led to safety concerns, specifically due to the risky driving behaviour of some riders. The driving behaviour of MCs is dependent on many factors (Abdulwahid et al., 2022). Further, Abdulwahid et al., 2022 have stated that one of the key factors is the road infrastructure, which may not be designed to accommodate motorcycles, leading to unsafe or inefficient driving behaviour. Therefore, special attention should be given to the MCs in traffic flow when

designing road networks and developing strategies to improve traffic flow and safety for all road users (Abdulwahid et al., 2022).

As per the study done by Shengqian Zong et al, 2022, Motorcycles have different and unique driving patterns compared to other vehicles due to their manoeuvrability, size and speed. Acceleration and deceleration are unique to motorcycles since they have a higher power-to-weight ratio compared to other vehicles. Due to that motorcycles can accelerate and decelerate more quickly than other vehicles. Therefore, motorcycles are capable of moving through traffic more efficiently, especially in congested conditions and it can affect the traffic flow (Shengqian Zong et al, 2022). Furthermore, they are capable of riding between lanes and vehicles. This can cause to improve the traffic flow of motorcycles but it creates safety risks for both motorcycles and other road users. Moreover, motorcycles can make sharper turns than cars. As a result, they may also be able to make U-turns in smaller spaces which can create potential conflicts with other vehicles (Shengqian Zong et al, 2022).

In urban areas, the environmental implications of motorcycles are a crucial aspect to consider. Motorcycles release gases such as hydrocarbons (HC), nitrogen oxides (NO<sub>x</sub>), and carbon monoxide (CO), with differences seen between emissions between normal and aggressive driving behaviours, according to a study by Kumar & Saleh (2015). According to the study's findings, driving more slowly through cities can result in significant fuel savings and lower emissions. This implies that driving behaviours that are altered to reduce speeds have the potential to lessen their negative effects on the environment by reducing emissions and fuel use.

Accordingly, by investigating the impacts of motorcycles on urban traffic, decision-makers can identify potential problems and develop strategies to improve traffic flow, safety, and efficiency. This may include providing dedicated infrastructure, modifying traffic signals, or implementing traffic calming measures to control the behaviour of motorcycles and improve overall traffic safety (Abdulwahid et al., 2022).

Despite the prevalence of motorbikes in Asian urban traffic, there exists a shortage of empirical research on the attributes of this mode of transportation in the region. Hsu et al. (2003) presented an overview and comparison of motorcycle and car speeds across

various Asian cities. Minh et al. (2005) examined motorcycle speeds in Hanoi and found that motorcycles in heterogeneous traffic moved considerably slower than those in homogeneous traffic, despite having access to wider lanes. Rongviriyapanich and Suppatrakul (2005) studied the impact of motorcycles on traffic flow at signalized intersections and mid-block locations in Bangkok, revealing that motorcycles increased start-up time for passenger vehicles at junctions and influenced the variation of Passenger Car Units (PCU) at mid-blocks under different traffic conditions. Additionally, Nguyen and Montgomery (2007) investigated the effect of flow counting periods on the study of saturation flow for Hanoi's urban highways, which are predominantly occupied by motorcycle traffic. While these studies offer valuable insights, none specifically delve into the influence of motorcycle driving behaviours on urban roadways in Sri Lanka, considering local conditions and characteristics.

Empirical research on the traffic operation of motorcycles has been limited thus far, likely due to their relatively low proportion of traffic flow, particularly in developed countries. (Minh et al., 2005) (Abdulwahid et al., 2022). Since it can help to identify the elements that contribute to traffic congestion and provide information for the formulation of policies and interventions to improve traffic flow and safety, understanding the effects of motorcycle driving patterns on traffic is important. Achieving a deeper understanding of the impact of motorcycles on traffic flow can lead to more accurate traffic models and better interpretation of motorcycle behaviour within overall traffic modelling. (Minh & Sano, 2003)

## **1.2 Significance of research**

The growth of motorcycle users on the road is a significant characteristic in Sri Lanka and the South Asian region. As a result, urban traffic is highly affected by the driving patterns of motorcycles. From a safety point of view, the number of crashes related to motorcycles is significantly high concerning other vehicle types. However, the literature shows that the attention given to the impacts of motorcycles and driving patterns is not at a sufficient level. Generally, vehicular traffic is quantified in terms of cars, and the roadway facilities are predominantly oriented for larger vehicles, even though there is a significant portion of motorcycles in the traffic stream. Therefore,

there is a necessity to investigate the impacts of the driving patterns of motorcycles in order to find solutions for the rapidly growing urban traffic.

### **1.3 Objectives**

Mainly, three key objectives are considered in this study. One of the key objectives of this study is to identify the state of knowledge on motorcycles in heterogeneous traffic conditions. The second objective is to investigate the dynamics of motorcycles under different traffic and roadway conditions. The third objective is to evaluate the effects motorcycle traffic has on urban traffic.

### **1.4 Thesis outline**

The thesis contains 5 chapters and 3 appendices.

The present chapter provides an overview of the research area, objectives and methodology adopted.

Chapter 2 offers a literature review, which gives an insight into the prior research conducted in the field related to the present state, growth, behaviours, and impacts of motorcycles.

Chapter 3 presents the data used for the analysis. It provides an overview of the data collection, data extraction and data analysis methods that are adopted in the study.

Chapter 4 presents the results of the study. It provides an overview of the relationships and other results obtained from the analysis.

Chapter 5 presents the conclusions and recommendations of the study. It further elaborates on the positive aspects and limitations of the study.

## **2 LITERATURE REVIEW**

### **2.1 Introduction**

The purpose of the research study, "Investigating the Impact of Motorcycle Driving Patterns on Urban Traffic," is to investigate the complex dynamics of motorcycles in a variety of traffic conditions. This investigation's main aims are to identify the state of knowledge on motorcycles in heterogenous traffic, investigate the dynamics of the motorcycles under different traffic conditions and evaluate the effects motorcycle traffic has on urban traffic.

The following chapter will present a thorough literature review that closely examines a number of relevant topics, including the varied impacts of motorcycles, the characterization of motorcycle driving patterns, and the various methodologies used to quantify their impacts. This study aims to add insightful knowledge into the complicated interactions between motorcycle dynamics and urban traffic systems by exploring and critically evaluating existing literature. This will allow for a thorough understanding of the varied effects of motorcycle use in urban environments.

### **2.2 Effects of motorcycles on road safety and environment**

#### **2.2.1 Impact to environment**

One of the key impacts of motorcycles is air pollution. Motorcycles emit Carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>), and particulate matter (PM) (Kumar & Saleh, 2015). According to a study by Yao et al. (2020), motorcycles were found to be a significant contributor to PM emissions in urban areas. Another study by Zhang et al. (2021) found that the emissions of CO and NO<sub>x</sub> from motorcycles are significant and could be reduced by using cleaner fuels and improving engine technology.

Chen et al. (2003) have used dynamometer experiments to evaluate fuel efficiency in urban and rural driving circumstances and to calculate motorbike emission factors for different pollutants. One urban cycle can be substituted for another after the study discovered that representative driving cycles in urban regions did not differ

considerably across the three cities. Rural driving cycles, on the other hand, displayed unique features, including greater travel distances and quicker speeds. Although it often uses more fuel, driving in cities produces emissions that are comparable to those in rural areas. In comparison to four-stroke motorcycles, two-stroke motorcycles exhibited reduced nitrogen oxide emissions and greater hydrocarbon emissions. Road conditions and vehicle-related factors were found to have an impact on the variation in emission factors. Despite the small sample sizes, the results provided insight into the typical behaviour of motorcycle emissions in real-world settings, indicating the necessity for additional dynamometer testing to confirm the findings.

Another study conducted by Szymlet et al. (2019) carried out laboratory tests on motorcycles and passenger cars to analyze their emissions in urban environments. It was found that motorcycles emitted significantly higher levels of CO<sub>2</sub> and fuel consumption compared to passenger cars, but exhibited lower levels of CO and NO<sub>x</sub> emissions. This discrepancy was attributed to the efficient exhaust after-treatment systems in motorcycles, particularly the three-way catalytic converter.

Koossalapeerom et al. (2019) have developed onboard systems to accurately measure and record the real-world driving patterns, energy consumption, and CO<sub>2</sub> emissions of electric and gasoline motorcycles along a congested urban corridor. The systems were validated with highly accurate results, enabling comparison between the two motorcycle types. Results showed that while the driving parameters of electric motorcycles closely resembled those of gasoline motorcycles in terms of average speed and running time, differences were observed in maximum speed and acceleration patterns. Electric motorcycles exhibited lower maximum speeds and acceleration-deceleration times but higher cruising times and average acceleration. Importantly, energy consumption, CO<sub>2</sub> emissions, and travel costs were significantly lower for electric motorcycles compared to gasoline motorcycles in congested urban conditions.

Another impact of motorcycles is noise pollution. Motorcycles can also contribute to noise pollution, which can have negative impacts on human health and wildlife. According to a study by Hjortenkrans et al. (2006), motorcycles were found to be a major source of traffic noise in urban areas.

Perera & Abeyratne (2019) evaluated the environmental sound pressure levels (ESPL) of motorcycles and other vehicles in Sri Lanka, comparing them against international noise regulations. Results indicated that motorcycles generally complied with noise limits set by India, ECE R41, and Central Motor Vehicle noise standards. However, some motorcycles exceeded the noise limits specified in Japan and Australia. Factors influencing ESPL included vehicle type, transmission type, engine power, and vehicle age.

Further, the study conducted by Kalansuriya et al. (2015) has shown that throughout the day, there is a considerable amount of noise pollution caused by traffic on roads classified as A, B, and C. The noise levels frequently surpass the suggested permissible values for residential areas. It was discovered that while motorbikes and three-wheelers were major contributors to noise levels on minor roads, heavy vehicles like lorries and buses made a considerable contribution on main and secondary routes. The study underscored the necessity of implementing noise regulations to reduce noise levels to manageable levels, especially in regions near busy thoroughfares. Furthermore, a linear association between the noise descriptors was found, indicating that vehicle flow rates may be used to accurately estimate noise levels. In order to put medium- and long-term traffic noise reduction initiatives into action, the study suggested conducting additional community noise assessments. This highlighted the need to tackle noise pollution from numerous sources, including motorbikes.

### **2.2.2 Impact on road safety**

Motorcycle-related crashes are more common on Sri Lankan highways. According to information accessible at police headquarters, the average number of deaths per day in 2015 was four due to motorcycle-related incidents, whereas the total number of deaths per day for all vehicle-related crashes was slightly over eight. Children are often involved in motorbike crashes, which is highly important. Motorcycle riders between the ages of 21 and 25 make up the majority of those involved in crashes, and aggressive or careless driving is a major contributing factor.(Shajith et al., 2019). According to WHO figures, motorcyclists, cyclists, and pedestrians account for half of all road

traffic fatalities worldwide, while in low- and middle-income countries, motorcycle injuries account for more than 50% of all road traffic injuries (Hyder et al., 2007).

According to the statistics of the Ministry of Transport and Highways, taking into account the data on fatal crashes spanning the years 2016 through 2019, it becomes evident that annually, a significant majority of fatal crashes, exceeding 40% each year, are attributed to motorcycle involvement. Figure 2.1 shows the fatal crashes from year 2016 to 2019.

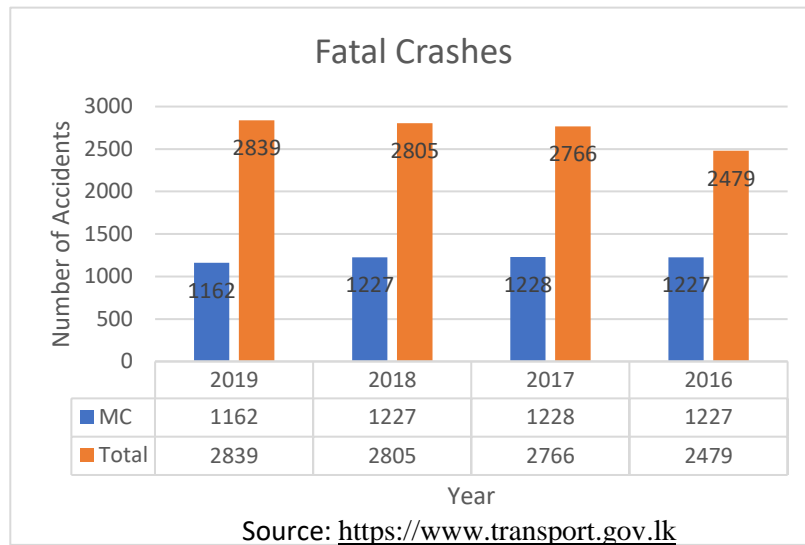


Figure 2. 1 Number of Fatal Crashes Reported on Sri Lankan roads.

Moreover, as per the study conducted by Shajith et al. (2019), Motorcycles were found to be involved in about 40% of all traffic incidents, which had a significant effect on the number of fatalities among cyclists and pedestrians. Motorcycle crashes that result in death are more likely when there are risk factors such as driving at night, colliding with lorries and buses, and rainy weather. Furthermore, it was shown that pedestrians 60 years of age and older were most susceptible to motorcycle crashes, particularly when they occurred in the middle of blocks. The study emphasizes how crucial it is to pinpoint these risk variables in order to develop practical solutions meant to increase motorcycle riders' safety on the road. The recommendations encompass incorporating safety factors into the design of highways, improving the training prerequisites for motorcycle license holders, establishing guidelines for motorbikes, and executing focused awareness campaigns for particular user demographics. Through the

implementation of these fundamental discoveries, Sri Lanka can endeavour to improve traffic safety and lower the number of motorcycle-related deaths.

In addition, Amarasingha (2016) has studied motorcycle crashes over five years and found important information about the variables influencing the risk and severity of crashes. It was discovered that drivers between the ages of 20 and 40 were responsible for the majority of motorcycle crashes and that only some motorcyclists had current licenses and were wearing safety helmets. Alcohol impairment raised the probability of crashes, and male drivers were linked to more serious collisions. Wearing a safety helmet has been proven to considerably reduce the severity of crashes, especially on rural and nighttime roads. Speeding and aggressive/negligent driving were found to be major driver contributing factors; these behaviours frequently corresponded with lower helmet wear. Roadway-related factors, such as broken pavement or signage, also contributed significantly to the frequency of crashes. Overall, the study emphasizes how complex motorcycle crashes are and how crucial it is to address a range of issues, such as driver behaviour, road conditions, and vehicle maintenance, in order to improve motorcycle safety.

Besides, Pieris (2016) found that the time of day, the driver's age, the lighting, human variables, and gender were all highly correlated with the seriousness of motorcycle crashes. Nevertheless, license age, rider gender, human variables, weather, and time of day were found to be the main risk factors impacting fatal crashes when examined together in a fitted binary model. These results highlight how crucial it is to comprehend and deal with these issues in order to increase motorcycle safety and lower the frequency of crashes.

## **2.3 Effects of motorcycles on signalized intersections**

### **2.3.1 Analysis of Motorcycle Impacts on Saturation Flow Rate**

One essential metric for determining intersection capacity and traffic signal timing is the saturation flow rate (Shao & Liu, 2012). There are several approaches to determining the intersection's saturation flow rate (Minh and Sano, 2003). One method is the headway method, which is used by TRB (1997) and Greenshields et al. (1947).

It calculates the headway between successive cars that are pulling out of a queue at the stop line and gets the saturation flow rate from the reciprocal of the mean headway. An alternative approach, the TRL method, as defined by TRRL (1963), divides the number of vehicles in a fully saturated green interval by its duration to calculate the saturation flow rate in terms of vehicle units, independent of the composition of the traffic. Furthermore, the regression technique, as introduced by Branston et al. (1978), Kimber et al. (1985), and Stoke et al. (1987), develops formulas that take into account saturated green time and vehicle counts in mixed traffic across different modes. Regression analysis works well to calculate average headway, saturation flow, and passenger car equivalents (PCU) for a variety of vehicle types other than passenger vehicles.

In addition, three different types of motorcycle riders' actions at signalized junctions were identified in a study conducted by Kariyana et al. (2021). To begin with, "Motorcycles ahead of the stop line" describes riders who intentionally try to position themselves close to other cars in front of the stop line while waiting for a red light. Second, "Motorcycles next to other vehicles" refers to the placement of motorcycles close to other vehicles, potentially in lanes of traffic or at their boundaries. Last but not least, "Motorcycle inside flow" refers to motorbikes that blend in with the flow of traffic, regardless of whether they are trailing or leading other vehicles. This classification offers important information for traffic management and safety considerations by illuminating the diverse behaviours displayed by motorcycle riders at signalized junctions.

### **2.3.2 The Effect of Motorcycles on Start-up Lost Time**

Start-up Lost Time is the additional time, expressed in seconds, that the first cars in a line at a signalized intersection spend beyond the saturation headway. This extra time is a result of having to accelerate after responding to the beginning of the green signal phase (Çalışkanelli et al., 2017). It is calculated by adding together the variance between each vehicle's observed headway and the saturated headway. (Minh & Sano, 2003)

Moreover, Minh & Sano (2003) looked into how motorcyclists affected traffic capacity, concentrating on saturation flow rates and motorcycle-passenger interactions at signalized crossings in Bangkok and Hanoi. High coefficient of determination values ( $R^2$ ) were obtained from regression analysis for the models that estimated the motorcycle equivalents of passenger cars and calculated saturation flow rates. Results indicated that passenger cars' passing number and headway were greatly reduced by motorbikes and that their start-up lost time at traffic signals increased. The percentage of motorcycles in Hanoi and Bangkok differed, however, the analytical results showed minimal variance. Strong connections were found between the motorcycle presence, lane width, and traffic flow factors, which were represented by two models. The study's overall findings highlight the significant influence motorcyclists have on traffic capacity and the necessity of taking this into account when designing and operating intersections in order to maximize overall traffic flow.

In addition, as per the study done by Singh et al. (2018) in Thailand, a unique practice allows motorcycles to ride on lane dividers, enabling them to advance to the front of stop lines during red lights. While this typically has minimal impact on start-up lost time in normal traffic conditions, it becomes significant during congestion. During congested periods, cycle times are extended, leading to longer red-light durations and more motorcycles accumulating at the front of queues. This accumulation exacerbates start-up lost time as motorcycles impede traffic flow.

## **2.4 Effects of motorcycles on road mid blocks**

### **2.4.1 The Effect of motorcycle driving behaviours**

Erratic driving behaviour and loose lane discipline among motorcycle drivers is a common sight in Sri Lanka (Weerasinghe, 2017). This can be caused by creating congestion and crashes in most of the situations. On the other hand, these driving patterns and loose disciplines can be caused by increasing the flowrate, but at the same time, it is caused by reducing the speed of the other vehicles. As a result of that the variation of the traffic flow and the speed due to the impact of motorcycles has become more complicated.

As per Minh and Sano, Motorcycles slow down other modes of transportation and increase traffic congestion in Hanoi, Vietnam, where two-wheelers account for more than 80% of all vehicles. This is because of the design and behaviour of motorcycles. According to Minh and Sano (2003), motorcycles possess the ability to perform zigzag manoeuvres, gradually advance to the front of a queue at an intersection and impede traffic flow by causing other vehicles to sluggishly start.

Studies have shown that motorcycles have unique driving patterns in urban traffic compared to other vehicles. Some of the common driving patterns observed in motorcycles include lane splitting, filtering, weaving, and swerving. (Asqool et al., 2021)

As per the study done by Asqool et al. (2021), Lane Splitting is the behaviour of riding between two lanes of vehicles that are either stopped or moving slowly in the same direction is known as lane splitting. This practice is quite common, among motorcyclists, in countries. The benefits of lane splitting include lower fuel consumption and tailpipe emissions since you spend less time stuck in slow-moving or stopped traffic. In addition, it can also reduce traffic congestion. However, it creates safety issues on the road. Moreover, it can also increase the risk of side-swipe collisions and requires a high level of skill and experience.

Moreover, Weaving is the movement of an MC in a zigzag pattern between lanes. Weaving is often used by motorcyclists to find gaps in traffic. In addition, it is regularly used by the riders to make themselves visible to other drivers. However, weaving can also raise the chance of collisions with other vehicles and it reduces the safety on the road (Yousaf & Wu, 2023).

In addition, Filtering is the practice of riding through traffic that is stopped or moving slowly to get to the front of the queue. Filtering is legal in many countries. Filtering can reduce travel time and improve the efficiency of the road network. However, it can also increase the likelihood of vehicle collisions, specifically if other motorists are not prepared for a motorcycle to filter in the traffic flow (Beanland et al., 2015),(Promraksa et al., 2022).

Swerving is the practice of making sudden lateral movements to avoid obstacles. These obstacles can be such as potholes, vehicles or debris in the road. Swerving can help motorcyclists avoid crashes with barriers. But if done unsafely, it can also enhance the risk of collisions with other vehicles and decrease safety on the road (Shuman et al., n.d.), (Federico et al., 2013).

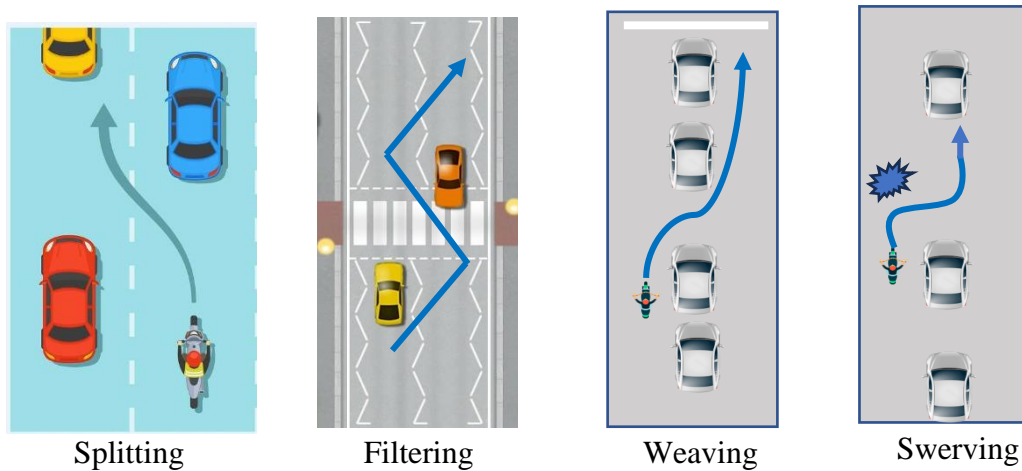


Figure 2. 2 Unique Driving Patterns of MCs

Izadi et al. (2021) conducted a study examining the impact of motorcycle mobility on different vehicle classes across six scenarios, utilizing various mobility models. These scenarios encompassed sublane, lane change, acceleration/deceleration and density models. Performance metrics such as travel time, average speed, fuel consumption and CO<sub>2</sub> emissions were employed to evaluate the effect of motorcycle mobility on diverse vehicle types, including motorcycles, cars, buses, and trucks. The findings revealed that sub-lane and lane change scenarios generally had a neutral or positive impact on traffic flow, enhancing metrics such as average speed, travel time, energy consumption, and environmental sustainability. However, acceleration/deceleration, incident, and density mobility models were observed to degrade vehicular traffic flow in terms of average speed and travel time.

Further, Matsuhashi et al. (2005) utilized microsimulation techniques to analyze traffic issues, particularly focusing on the impact of a high number of motorcycles on overall traffic flow. It was observed that the presence of a significant volume of motorcycles in the network significantly disrupts the flow of other vehicles, leading to a drastic reduction in their average speed.

## 2.4.2 The Effect of Motorcycles on Passenger Car Units (PCU)

Table 2.1 Comparison of PCU values

Vehicle Type	PCU Values				
	Sources				
	Jayaratne (2016)	Kumarage A. (2016)	RDA- Geometric Design Standards of Roads', 1998	Weerasin ghe (2015)	HCM 2000
Motorcycle	0.2	0.4	0.4	0.3	-
Car	1	1	1	1	1
Three-Wheeler	0.6	0.8	0.8	0.74	-
Van	1.2	1	-	1.39	-
Large Bus	4.1	1.8	2.4	4.89	1.1-2.5
Pick Up/ SUV	1.4	-	-	-	-
Mini Truck	1.2	-	-	-	-
Truck	3.2	3	3.8	4.21	1.1-2.5

According to Jayaratne.(2016), there is variability in the PCU values attributed to motorcycles across different sources. Table 2.1 presents a comparison of these values gathered from various local and foreign studies.

Shalini & Kumar, (2014) have illustrated that there exist multiple approaches for analyzing the PCU factors of vehicles. These methodologies encompass flow rate and density-based methods, headway-based methods, queue discharge flow-based methods, speed-based methods, delay-based methods, vehicle-hour-based methods, travel time-based methods, as well as the HCM Method.

Songviriyapanich & Suppattrakul (2005) made an effort to measure how motorcycles affected midblock traffic operations. Motorcycles' impact is assessed by analyzing alterations in headway between two consecutive passenger cars due to their presence, a crucial factor in calculating the Passenger Car Unit (PCU) for motorcycles. According to (Minh & Sano, 2003), the PCU of motorcycles is anticipated to vary based on the quantity of motorcycles positioned between passenger cars. To assess the passenger car equivalent (PCE) of motorcycles positioned between passenger cars,

three distinct approaches were employed. Approach 1 determined the PCE when there was one motorcycle situated between two consecutive passenger cars. Approach 2 calculated the average PCE between two motorcycles positioned between subsequent passenger cars. Approach 3 involved comparing the headway of a motorcycle to that of a passenger car to calculate the motorcycle's PCU. These approaches provided different perspectives on how motorcycles affect traffic flow and allowed for a comprehensive understanding of their impact on overall traffic capacity and congestion dynamics.

Moreover, according to Minh & Sano (2003), there is a steady trend of PCU declining as the percentage of motorcycles in traffic increases. Another discovery was that the motorcycle's PCU increases as the flow rate rises from 10-15 to 15-20 pcu/minute. Nevertheless, the motorcycle's PCU steadily drops with a flow rate beyond that threshold.

## **2.5 Usage of new technologies to study the MCs' behaviour**

According to Abdulwahid et al. (2022), recent advancements in technology have revolutionized the acquisition of comprehensive and nuanced data pertaining to driving behaviour, thereby necessitating innovative analytical approaches like driving behaviour profiles. Moreover, Global Positioning System (GPS) devices and in-vehicle sensors have notably addressed challenges associated with traditional data collection methods. As per the study, various technologies, including accelerometers, on-board diagnostics (OBD), GPS sensing, gyroscopes, and ProLaser-III with motorcycles, have been employed in research on road crashes, offering a holistic view of day-to-day driving activities.

However, according to Munigety et al. (2014), manual methods for data collection are capable of capturing macroscopic data such as traffic flow and volume counts but lack the capability to provide microscopic graphic data. GPS tracking of all vehicles is impractical due to the high number of devices required. Moreover, existing trajectory extraction tools like Autoscape and those developed by Traficon struggle in mixed traffic conditions due to the non-lane-based movement of vehicles. However, TRAZER, one of the capable tools for extracting microscopic graphic data in

heterogeneous conditions, is hampered by limitations including low accuracy, occlusion issues, and a restrictive capture length of only 50 meters, insufficient for comprehensive microscopic modelling.

Further, Munigety et al. (2014) explained that a new semiautomated Traffic Data Extractor (TDE) has been developed using the Visual Basic platform in response to these challenges. Moreover, TDE addresses the limitations of existing tools by enabling the extraction of accurate vehicle trajectory data, crucial for analyzing microscopic details such as headways and lane change durations. This tool extends its utility beyond heterogeneous traffic conditions, proving effective in homogeneous traffic scenarios as well. Additionally, the TDE allows for the extraction of trajectory data for multiple vehicles over a longer distance of 250 meters from the observation point with 0.1 seconds accuracy.

In another study, Munigety et al. (2017) employed a semiautomated Traffic Data Extractor (TDE) to extract vehicular trajectories, encompassing longitudinal and lateral positions, along with vehicle type, within a specified time frame. They adopted different time resolutions based on traffic flow conditions. A time resolution of 0.5 seconds was used for low and medium traffic flow conditions, while a resolution of 1 second was considered for heavy traffic flow conditions.

### **3 METHODOLOGY**

#### **3.1 Data Collection**

##### **3.1.1 Site Selection**

Selecting suitable sites for data collection in research is of utmost importance. The choice of sites directly influences the validity and reliability of the findings. Hence, various parameters representing local urban conditions have been taken into account when selecting the sites, outlined as follows:


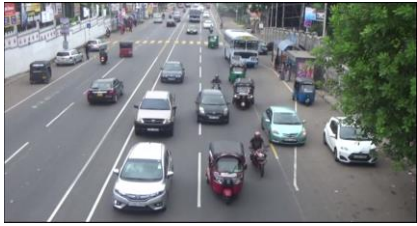


- Motorcycle volume
- Motorcycle positional patterns
- Passenger car volume
- Less influence from other factors- left/right turning, heavy vehicles, or pedestrians.



The sites were selected considering the aforesaid parameters for both intersections and mid-blocks. Mainly the sites are selected in major cities such as Colombo, Gampaha and Kandy considering the motorcycle volumes and passenger car volumes on the roads in order to represent the local urban conditions. In addition to that considering the objectives of the research, urban four-lane mid-blocks have been selected for the study.

The road segments spanning 80-100 meters in the middle of a block were chosen for analysis. The selection process prioritized the aforementioned factors to ensure appropriate road sections were selected.

A summary of the selected sites for the mid-blocks is shown in Table 3.1.


Table 3. 1 Details of the selected sites for the mid-block sections





Location Number	Road Name	City/Land Mark	Centre median separated	Number of Lanes/ Average Lane Width
MB 01	Colombo - Ratnapura - Wellawaya – Batticaloa (A 04) 	Pannipitiya  Overhead bridge near Pannipitiya Dharmapala College	No	4 Lanes / 3.5 m
MB 02	Colombo - Ratnapura - Wellawaya – Batticaloa (A 04) 	Pannipitiya  Overhead bridge near Pannipitiya Dharmapala College	No	4 Lanes / 3.5 m
MB 03	Getambe Kandy By Pass road (AB 42) 	Kandy  Overhead bridge near Kandy Courts Complex	Yes	4 Lanes / 3.5 m
MB 04	Getambe Kandy By Pass road (AB 42) 	Kandy  Overhead bridge near Heerassagala Junction	Yes	4 Lanes / 3.5 m

MB 05	Marine Drive 	Wellawatta  Near Mary's Drive road	No	4 Lanes / 3.3 m
MB 06	Colombo – Galle road (A01) 	Panadura  Near Egoda Uyana	Yes	4 Lanes / 3.5 m
MB 07	Battaramulla – Pannipitiya road (B 47) 	Palan Thuna  Near Palan Thuna Junction	Yes	4 Lanes / 3.5 m

A summary of the selected sites for the intersections is shown in Table 3.2.

Table 3. 2 Details of the selected sites for the Intersections

Junction Number	Junction	Intersecting Roads	Description
INT 01	Katugastota Junction 	Kandy – Jaffna (A09) Katugastota - Kurunegala – Puttalam (A10)	3-way Signalized junction

<p>INT 02</p>	<p>Nittambuwa Junction</p> 	<p>Colombo - Kandy (A01) Veyangoda - Ruwanwella (B445)</p>	<p>4-way Signalized Junction</p>
<p>INT 03</p>	<p>Yakkala Junction</p> 	<p>Colombo - Kandy (A01) Ja-Ela - Ekala - Gampaha - Yakkala (A33) Yakkala - Radawana (B479)</p>	<p>4-way Signalized Junction</p>
<p>INT 04</p>	<p>Miriswatta Junction</p> 	<p>Colombo - Kandy (A01) Miriswatte - Waturugama (B292)</p>	<p>3-way Signalized Junction</p>
<p>INT 05</p>	<p>Piliyandala Bypass road Junction</p> 	<p>Piliyandala - Maharagama (B367) Piliyandala By Pass (B639)</p>	<p>4-way Signalized Junction</p>

### 3.1.2 Data Collection method

In the study, both closed-circuit television (CCTV) cameras and mobile videography cameras were employed to record video footage. Additionally, certain essential data necessary for the analysis, such as road section widths and lengths, were gathered manually at the site. It's crucial to note that the effectiveness of video processing heavily relies on factors like camera angles and visibility. These aspects significantly impact the clarity and accuracy of the captured footage, ultimately influencing the reliability and comprehensiveness of the subsequent analysis. Therefore, precise attention to camera placement and environmental conditions was given to ensure the validity and usefulness of the collected data.

### 3.2 Data Extraction

Traffic data extractor software was utilized to extract the basic data from the captured videos. Traffic data extractor software is designed to process the recorded videos and extract specific data types for analysis (Figure 3.1). This software has been created by the Indian Institute of Technology Bombay (IIT) and it is a semi-automated freeware. The software package contains tools for vehicle trajectory extraction, speed extraction, vehicle counting and pedestrian data extraction from captured videos. Moreover, the software allows for precise time extraction with an accuracy of up to 0.01 seconds. The studies done by Munigety et al. in 2014 and 2017 have demonstrated the methodology and the accuracy of this software. The studies conducted by Munigety et al. in 2014 and 2017 have served to showcase both the methodology and the accuracy of the Traffic Data Extractor (TDE) software. Through these studies, the researchers demonstrated how TDE effectively captures and analyzes vehicular trajectory data, highlighting its ability to address challenges present in both heterogeneous and homogeneous traffic scenarios.



Figure 3. 1 Interface of Traffic Data Extractor Software

The software's Vehicle Trajectory Extractor function was utilized to obtain trajectory data and headway values for motorcycles. Additionally, the Vehicle Counting and Speed Extractor features were employed to gather information on vehicle compositions and speeds. The extraction procedure is semi-automated. A human operator must manually track vehicles by pointing and clicking on them with a mouse on a Windows-based graphical user interface. These mouse clicks are converted into actual coordinates by the Traffic Data Extractor (TDE), which then determines the positions of the vehicle. Four reference points that have been found in the video images and their matching coordinates in the real world help to facilitate this conversion. Vehicle tracking along the road segment is shown in Figure 3.3, where the graphical user interface of the software is displayed. The tracked vehicles are indicated with a green marker. Sample details of the selected road sections (Figure 3.2) are shown below,

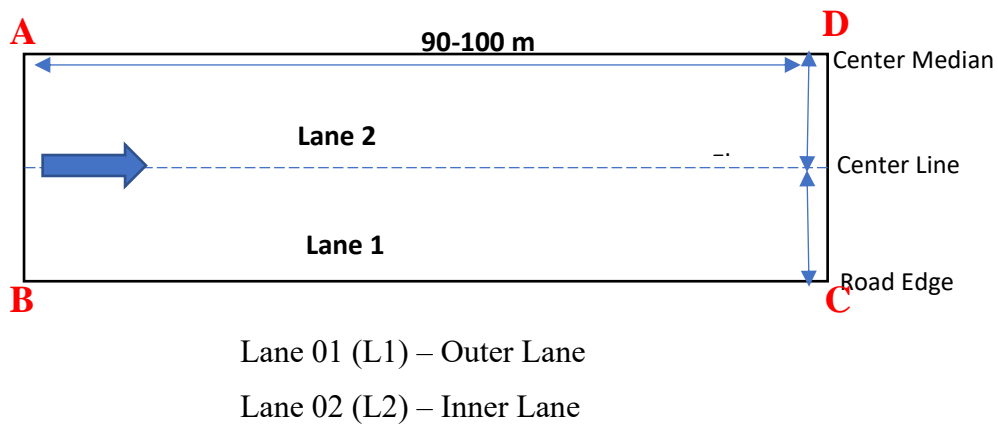


Figure 3. 2 Details of the selected road section

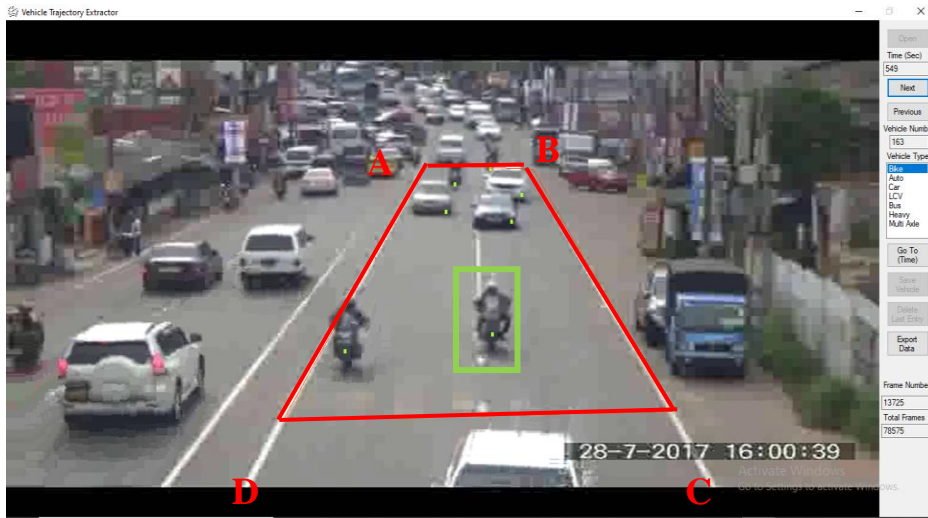


Figure 3.3 Interface of the trajectory analysis function

### 3.2.1 Calibration the TDE software

Before extracting data from the software, calibrating it to eliminate any errors is crucial. To perform this calibration, a road section on William Gopallawa Road was selected from the recorded videos. Initially, the road segment was marked in the TDE software, and the coordinates of the segment's start and end points were generated (Figure 3.4 and Table 3.3). These points should be easily identifiable both in the video and on the actual site. Using these coordinates, the lengths of each leg of the segment were calculated. Subsequently, the same section was physically marked on-site, and the lengths of each leg were measured using a measuring tape. The generated lengths from the software were then compared with the actual measured lengths, yielding the following results. Then, calculated the percentage error between the software-generated lengths and the actual lengths as shown in Table 3.4.

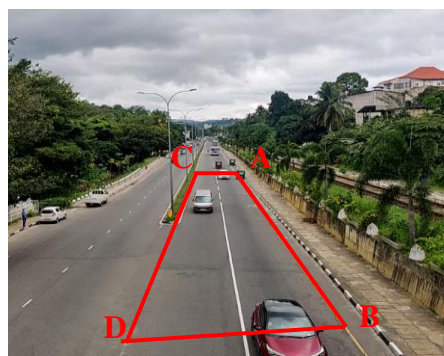


Figure 3.4 Selected road section for calibration

Table 3. 3 Generated coordinates from TDE software

	Generated Coordinates	
Point	X (m)	Y (m)
<b>A</b>	126.8090546	744.2446829
<b>B</b>	126.8090546	644.3369215
<b>C</b>	133.4090546	739.1453021
<b>D</b>	133.4090546	639.2375407

Table 3. 4 Percentage of error calculation

Leg	TDE Measurement	Physical Measurement	Percentage of Error
<b>AB</b>	99.907	100	0.1%
<b>CD</b>	99.907	100	0.1%
<b>AC</b>	6.6	6.6	0.0%
<b>AD</b>	6.6	6.6	0.0%

Therefore, considering the significantly low percentage of error values (less than 1%), no additional calibration is required for the extracted data.

### 3.3 Data Analysis

The analysis part plays a crucial role in uncovering key insights and understanding the relationship between motorcycle behaviour and traffic dynamics. The analysis part consists of two major aspects of this study.

1. Impact on urban mid-blocks
2. Impact on urban intersections

Figure 3.5 indicates the flowchart of the adopted research analysis.

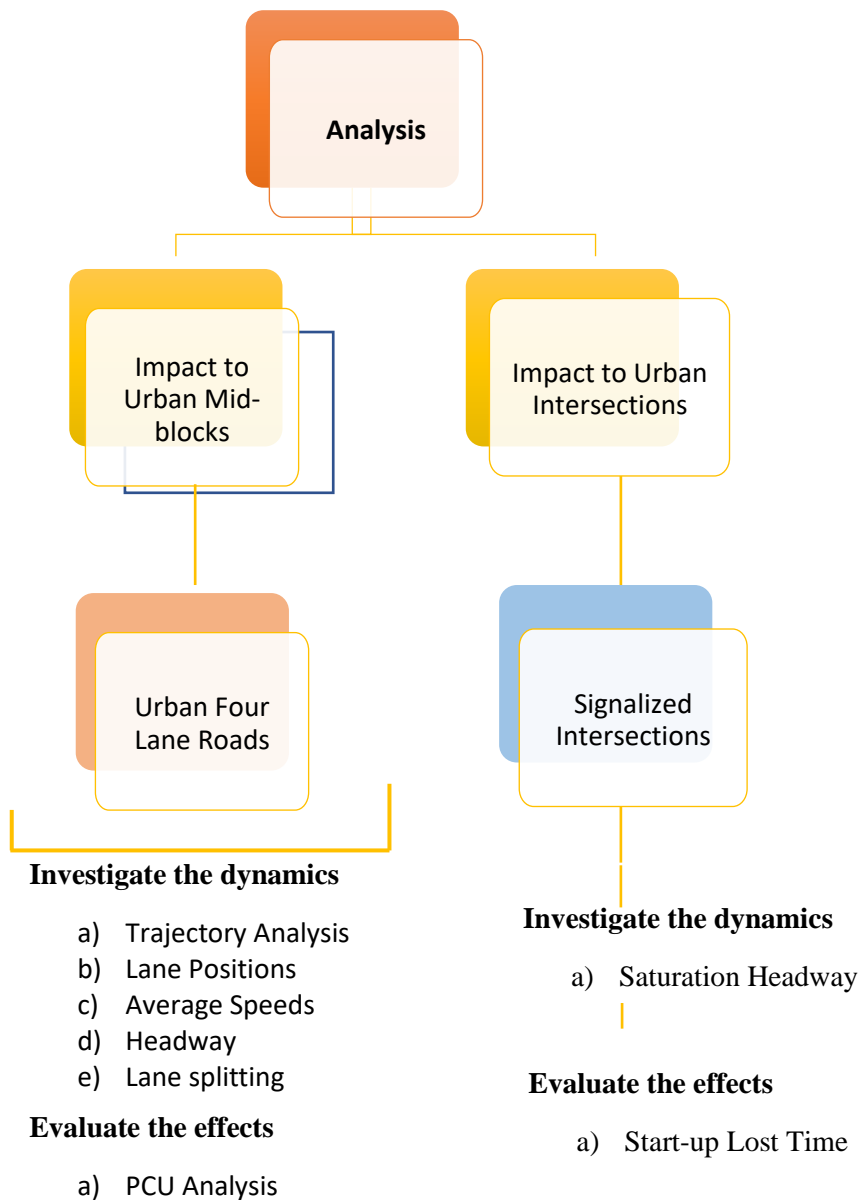


Figure 3.5 Research Analysis

### 3.3.1 Impact on urban mid-blocks

#### 3.3.1.1 Evaluating the dynamics of motorcycles

Evaluating the dynamics of motorcycles is important in identifying the impacts of the mid-blocks. The following driving characteristics are considered in the analysis,

a) Trajectory Analysis:

Trajectory analysis refers to the study of the paths followed by vehicles over time. In the context of transportation, trajectory analysis often involves tracking the movement of vehicles on roads or other transportation systems. This analysis can help understand patterns and behaviours, identify potential issues, and optimize transportation systems for efficiency and safety.

The trajectories of motorcycles are considered under two cases representing low and high flowrates.

1. Case 01: 0 – 1000 veh/hr/lane
2. Case 02: > 1000 veh/hr/lane

To quantify the trajectories, a metric measuring lateral change per meter has been introduced.

$$\text{Lateral Change} = \frac{\text{Initial Lateral Position} - \text{Final Lateral Position}}{\text{Length of the segment}}$$

b) Lane Positions:

Lane positions for motorcycles refer to the specific locations of motorcycles within their respective lanes on the road. Unlike cars, motorcycles have the advantage of being able to occupy different positions within a lane, such as riding in the centre, closer to one side, or on the far edge of the lane. Understanding and monitoring lane positions for motorcycles is essential for assessing rider behaviour, visibility to other motorists, and identifying potential risks and safety issues, such as lane splitting.

The lane positions of motorcycles are considered under three cases representing low, medium and high flowrates.

1. Low Flowrate : 0 – 500 veh/hr/lane
2. Medium Flowrate: 500 - 1000 veh/hr/lane
3. High Flowrate : > 1000 veh/hr/lane

c) Average Speeds:

The average speeds of motorcycles represent the average rate at which motorcycles travel over a specific distance and time. Monitoring the average speeds of motorcycles is important for studying traffic flow, evaluating the impact of motorcycles on overall congestion, and identifying areas where speed limits may need to be adjusted to accommodate motorcycle traffic safely. The correlation between MC speed and road traffic volume was investigated in this study.

d) Headway:

Headway is the time interval between two consecutive vehicles passing a specific point on a road. It is a fundamental measure used to analyze traffic flow and assess the spacing between vehicles. Maintaining an appropriate headway is crucial for motorcycle safety. Understanding the headway of motorcycles is important for evaluating traffic congestion, capacity, and safety, as it can indicate the level of traffic density and potential risks of collisions.

The headway of motorcycles for each lane is considered under the same three cases representing low, medium and high flowrates.

1. Low Flowrate : 0 – 500 veh/hr/lane
2. Medium Flowrate : 500 - 1000 veh/hr/lane
3. High Flowrate : > 1000 veh/hr/lane

e) Lane splitting:

Lane splitting for motorcycles involves the action of a motorcycle rider passing another vehicle on the road. Due to the smaller size and manoeuvrability of motorcycles, they can perform splitting in different situations where cars might not be able to do so. However, splitting can also be riskier for motorcycles, especially when visibility is limited. Understanding how motorcycles execute splitting manoeuvres helps assess rider safety practices and potential risks on the road. The lane-splitting of motorcycles for each lane is considered under the same three cases representing low, medium and high flowrates.

### 3.3.1.2 PCU Variation of MCs under different conditions

The PCU value is a numerical assignment designated to a device aimed at transforming a mixed vehicle traffic flow into an equivalent traffic stream comprising solely one type of vehicle. It provides a standardized measure to account for the impact of various vehicles on traffic flow and roadway capacity.

When it comes to motorcycles, defining their PCU values can be more complex. Motorcycles are smaller in size compared to passenger cars, and their manoeuvrability allows them to occupy less space on the road. However, when motorcycles are closely spaced or travelling in groups, that group can have an impact on traffic flow that is different to their individual impact.

In situations where motorcycles are travelling in clusters or groups, their PCU values may be adjusted to reflect their influence on traffic congestion. The rationale behind this is that motorcycles travelling in close proximity can affect the behaviour of other road users, such as passenger cars. The presence of a group of motorcycles may influence the lane-changing decisions of nearby cars or require additional space for overtaking.

Therefore, the PCU of motorcycles can be variable depending on the number of motorcycles in between passenger cars. This adjustment helps transportation planners and engineers accurately assess the effects of motorcycles on road networks and make informed decisions about infrastructure design, traffic management, and congestion mitigation.

Considering the placement of MCs in relation to passenger cars, three different approaches have been considered to calculate the PCU of MCs,

- I. In the scenario where there is only one motorcycle positioned between two consecutive passenger cars

$$PCU_{mc} = \frac{h_2}{h_1} - 1$$

- II. In the scenario where two motorcycles are situated between two consecutive passenger cars

$$PCU_{mc} = \frac{1}{2} \left( \frac{h_2}{h_1} - 1 \right)$$

III. In the scenario where there are two adjacent motorcycles,

$$PCU_{mc} = \frac{h_2}{h_1}$$

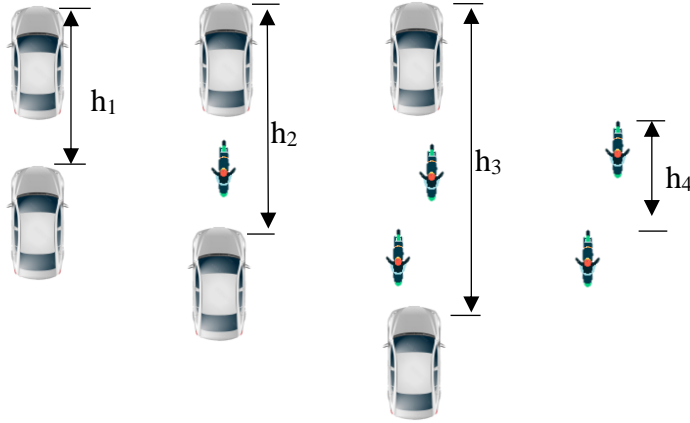
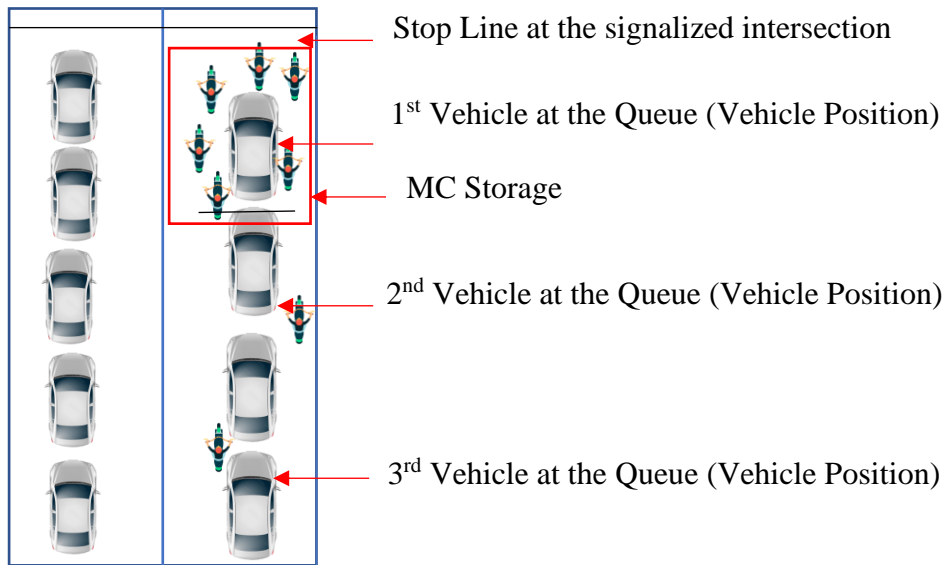


Figure 3. 6 Placement Details of the MCs

### 3.3.2 Impact on urban intersections

#### 3.3.2.1 Saturation headway analysis

Saturation headway refers to the minimum time gap required between consecutive vehicles passing through a given point, such as an intersection or a traffic signal, during peak traffic conditions. In this study, the impact of the motorcycles at the signal intersection has been considered under several conditions. Figure 3.7 shows the considered cases at the intersection.



Case 01:      Case 02:  
 With No      With MC  
 MC storage    storage in  
 in front of   front of the  
 the queue     queue

Figure 3. 7      Considered Cases at intersections

The storage of the MCs at a signalized junction refers to the count of motorcycles waiting behind or in front of the stop line when the traffic light is red. This can potentially obstruct the movement of the first vehicle in the queue when the traffic light changes to green.

Considering the behaviour of the motorcycles at a signalized junction, two scenarios have been considered for the analysis.

*Case 01: With no MC storage in front of the queue*

The variation of the average headways of the vehicles relevant to their Vehicle Position at the queue has been considered under the condition of no motorcycle storage. Then the saturation headway is observed using the average headways of the vehicles.

*Case 02: With MC storage in front of the queue*

The variation of the average headways of the vehicles relevant to their queue positions has been considered under the condition of motorcycle storage. Then the saturation headway is observed using the average headways of the vehicles.

The impact of motorcycle storage on achieving saturation headway is assessed based on the two scenarios outlined above.

By analyzing both scenarios, the associated delay of the attainment of saturation headway due to the presence of motorcycle storage in front of a queue is calculated using the following method,

$$\text{Delay of the attainment of saturation headway} = T_{\text{Case02}} - T_{\text{Case01}}$$

$T_{\text{Case01}}$  = Total time to achieve saturation flowrate in Case 01

$T_{\text{Case02}}$  = Total time to achieve saturation flowrate in Case 02

### 3.3.2.2 Start-up lost time

The variation of the start-up lost time of the vehicles is compared with the motorcycle storage at the queue. The start-up lost time is calculated as follows,

$$\text{Start – up lost time} = \sum_{k=1}^n (H1 - H2)$$

Where, H1 = Discharge Headway of the  $i^{\text{th}}$  Vehicle (seconds)

H2 = Saturation Headway (seconds)

N = Number of vehicles released before reaching saturation headway

## 4 RESULTS AND DISCUSSION

### 4.1 Urban Mid-Blocks

#### 4.1.1 Overview of motorcycle compositions

The following Table 4.1 shows the vehicle compositions in the considered cases.

Table 4. 1 Vehicle compositions in considered cases

	MC	TW	CAR	VAN/JEEP	MINI BUS	BUS	LT	MT	HT
MB 1	33.2%	14.5%	30.5%	7.3%	0.7%	7.1%	1.5%	5.1%	0.2%
MB 2	28.2%	18.4%	31.4%	8.5%	0.9%	7.6%	2.6%	2.2%	0.3%
MB 3	34.0%	15.9%	29.2%	9.1%	0.7%	5.2%	2.7%	2.7%	0.6%
MB 4	39.3%	16.7%	22.3%	7.9%	1.0%	4.7%	0.6%	5.6%	2.0%
MB 5	27.6%	20.6%	30.3%	10.9%	0.2%	4.2%	3.2%	2.0%	1.1%
MB 6	17.4%	26.9%	37.8%	14.6%	0.3%	0.7%	0.3%	1.4%	0.6%
Overall	30.1%	18.9%	30.0%	9.8%	0.6%	4.8%	1.9%	3.1%	0.8%

By considering the above cases, the overall motorcycle composition is shown in Figure 4.1.

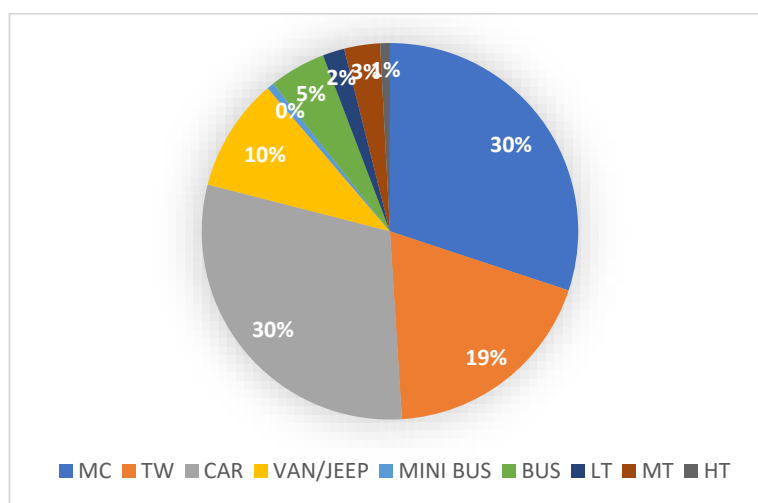


Figure 4. 1 Overall motorcycle compositions

The vehicle compositions in the selected 6 locations show that the motorcycle composition of each location varies between 17% and 39%. However, Motorcycles are the most prevalent vehicle types overall, making up approximately 30.1% of the vehicles, respectively. A summary of the motorcycle compositions is shown in Table 4.1 and Figure 4.1.

#### **4.1.2 Trajectories of Motorcycles**

The trajectories of motorcycles are considered under two cases representing low and high flowrates as mentioned in the methodology.

1. Case 01: 0 – 1000 veh/hr/lane
2. Case 02: > 1000 veh/hr/lane

The study highlights a significant diversity in the paths taken by motorcycles in various scenarios. Specifically, in Case 01, which is characterized by a low flowrate (lesser traffic density), motorcycles primarily travel in straight and predictable paths, displaying minimal lane-changing behaviour.

Conversely, in Case 02, where the flowrate is high (indicating greater traffic density), the trajectories of motorcycles become more dynamic and erratic. Motorcyclists tend to change lanes frequently to navigate through congested traffic, indicating a more active lane-changing behaviour in response to the higher flowrate.

This contrast in motorcycle behaviour between the low and high flowrate cases suggests that traffic density plays a crucial role in shaping the movement patterns of motorcycles. When the traffic is sparse, motorcycles tend to maintain a more stable and linear course, whereas, in heavy traffic conditions, they adopt a more turbulent path with increased lane-changing activity to accommodate the challenging traffic conditions. Figure 4.2 and Figure 4.3 show the trajectory variations in each condition.

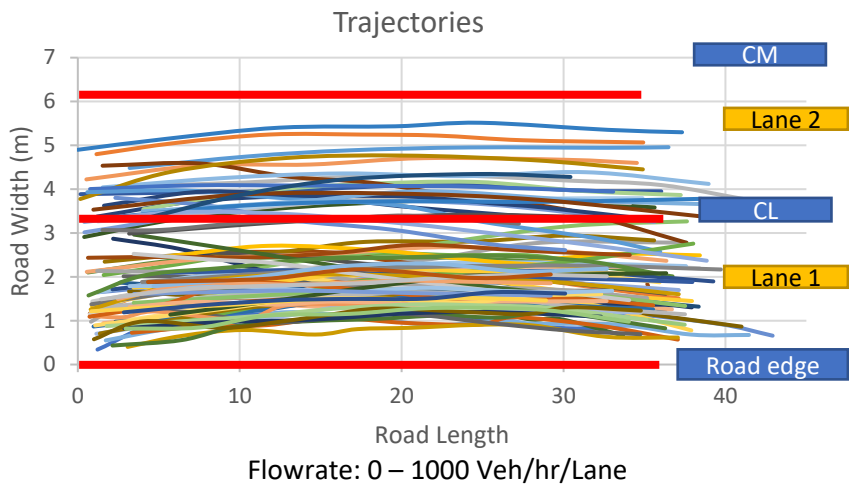


Figure 4. 2 Trajectories of MCs in flowrates between 0 – 1,000 Veh/hr/Lane

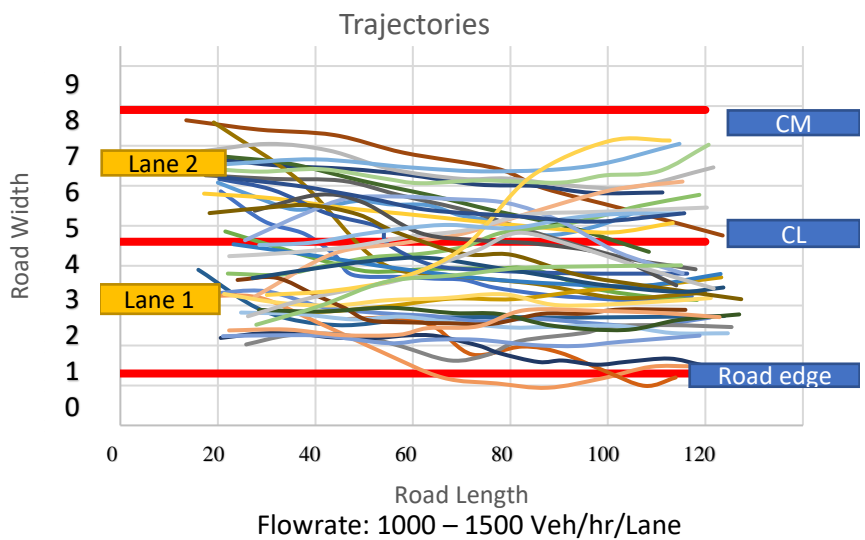


Figure 4. 3 Trajectories of MCs in flowrates exceeding 1,000 Veh/hr/Lane

To quantify the trajectories, a metric measuring lateral change per meter has been introduced. Table 4.2 illustrates the corresponding values for lateral change per meter.

Table 4. 2 Lateral change of MCs

Flow rate (Veh/hr/Lane)	Lateral Change Per meter (m/m)
0 - 1000	0.010
>1000	0.015

The findings reveal that the lateral change per meter is significantly lower in low traffic conditions compared to high flow rates.

### 4.1.3 Lane positions of motorcycles

Table 4.3 and Figure 4.4 show an analysis of the lane-changing behaviour of motorcycles in different flow conditions. In this analysis, L1 refers to the inner lane and L2 refers to the outer lane.

Table 4. 3 Lane changing behaviour of MCs

Flow vs. lane change behaviour		Lane Behavior			
		Changing Lane		Within Same Lane	
Flow (Veh/hr/lane)	Status	L1-L2	L2-L1	L1	L2
>1000	High	23%	13%	45%	20%
500-1000	Medium	9%	3%	58%	30%
0-500	Low	3%	3%	74%	19%

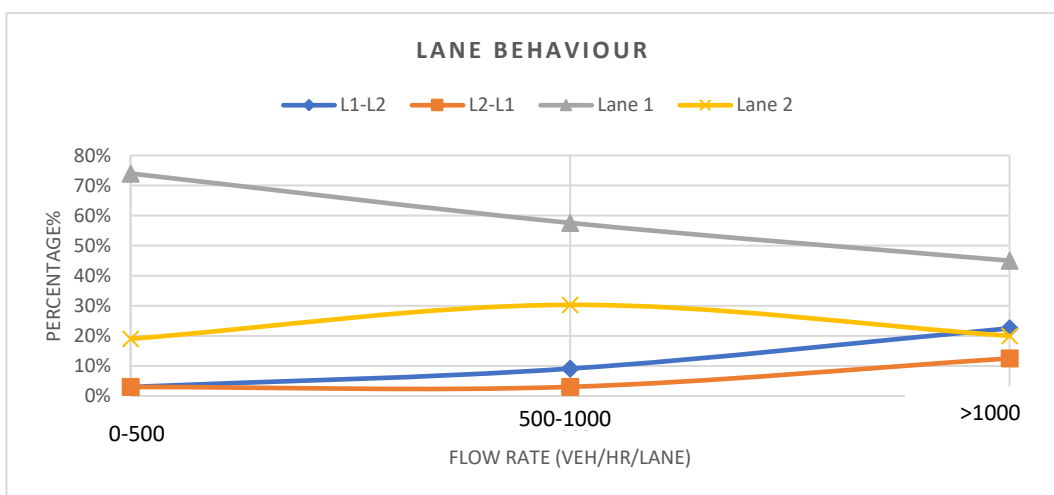


Figure 4. 4 Lane changing behaviour of MCs

The data analysis indicates a significant relationship between flow rate and lane-changing behaviour for motorcycles. As the flow rate increases, there is a noticeable rise in the frequency of lane-changing manoeuvres performed by motorcyclists. This suggests that when traffic density is higher, motorcyclists are more inclined to switch lanes to navigate through the congested roadways effectively. (Table 4.2 and Figure 4.4)

Moreover, the study highlights that a majority of motorcycles tend to prefer using the outer lane for their movement. It's essential to note that this lane preference and increased lane-changing behaviour are dynamic responses of motorcyclists to the changing traffic conditions. As the flow rate rises, motorcyclists may find it beneficial to switch lanes strategically to avoid congestion, overtake slower vehicles, or adapt to changing road conditions.

Overall, the findings underscore the importance of considering flow rate and lane usage patterns when studying motorcycle behaviour on roadways, as these factors significantly influence the dynamics of traffic movement and safety on the roads.

#### 4.1.4 Speed of motorcycles

Table 4.4 shows the Pearson correlation between flowrate and speed of motorcycles.

Table 4. 4 Pearson correlation between flowrate and speed of MCs

	<b>Flowrate</b>	<b>Speed of MCs</b>
Flowrate	1	-0.23736
Speed of MCs	-0.23736	1

To comprehend how motorcycle (MC) speed varies under various traffic conditions, the correlation between MC speed and road traffic volume was investigated. The results showed that there was a very weak relationship between MC speed and traffic volume.

Moreover, Figure 4.5 shows the regression analysis between motorcycle speeds and traffic volumes.

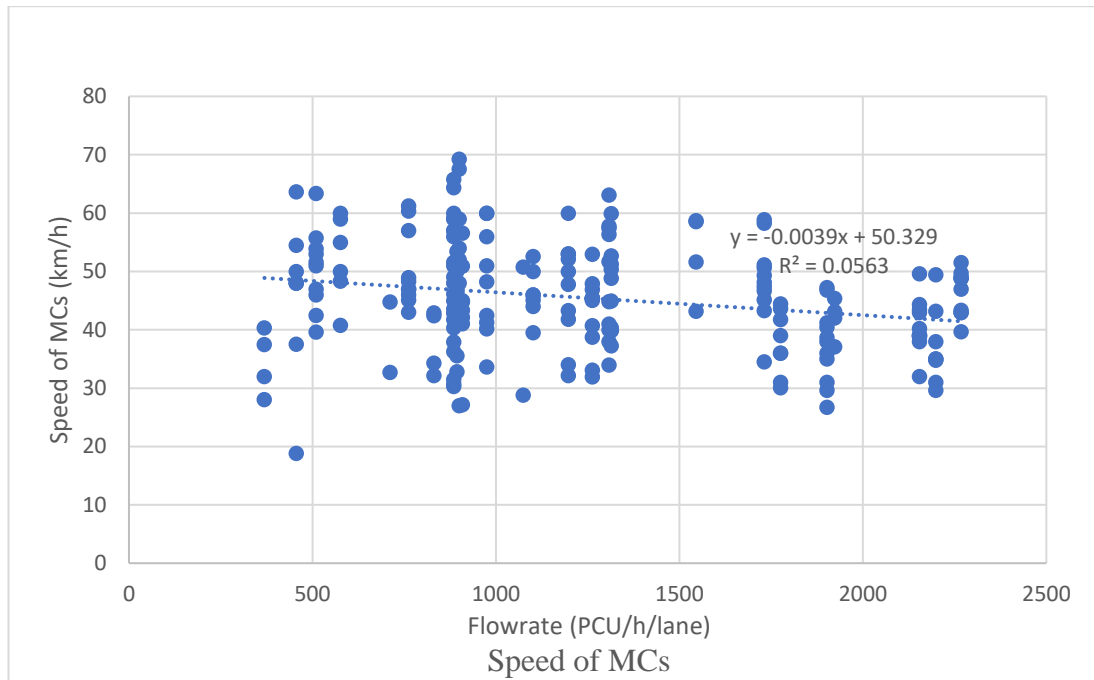


Figure 4.5 Speed Variation of MCs

An extension of the analysis to include regression analysis aimed to deepen the comprehension of the relationship between motorcycle (MCs) speed and traffic volumes. The outcomes demonstrated a very small R-squared value, once again signifying a notably weak correlation between MCs' speed and traffic volumes.

This weak relationship can be attributed to the distinctive behaviours of motorcycles, particularly practices like splitting and filtering. Motorcyclists often utilize these unique behavioural patterns to navigate through high traffic volumes, mitigating disruptions and preserving their preferred speed.

In summary, the analysis suggests that motorcycle speeds are not significantly influenced by the vehicle flow rate, primarily due to their distinctive behavioural patterns.

#### 4.1.5 Headways of motorcycles

Table 4.5 and Figure 4.6 indicate the analysis of the headway of motorcycles and the flow rate of vehicles.

Table 4. 5 Headway variation of MCs

Flow VS Headway of MCs				
Flow (veh/hr/lane)	Status	Headway(s)		
		Average	Lane 01	Lane 02
0-500	Low	2.45	2.85	1.80
500-1000	Medium	2.04	2.64	1.24
>1000	High	1.70	2.12	0.93

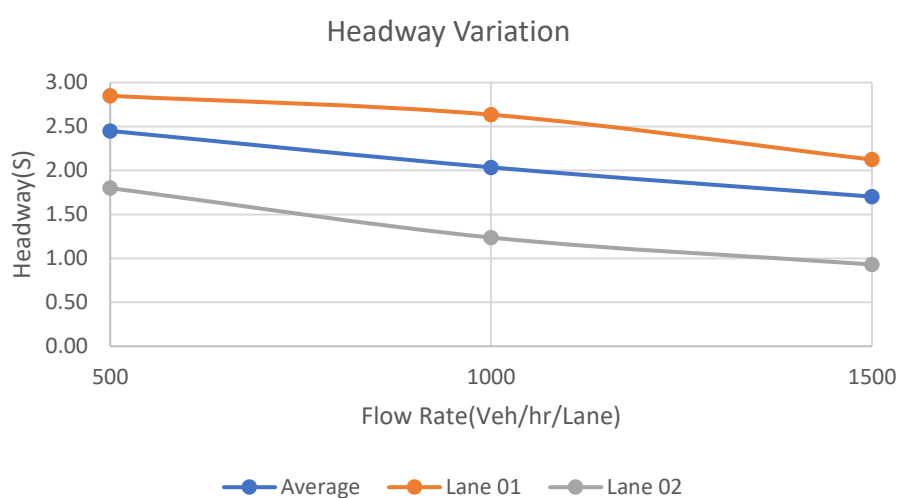


Figure 4. 6 Headway variation of MCs

The analysis indicates that there is a relationship between the headway of motorcycles and the flow rate of vehicles on the road. Specifically, as the flow rate of vehicles increases, the headway of motorcycles decreases. This suggests that when there are more vehicles on the road, motorcycles tend to have less space between them and the vehicle in front of them. This reduced headway can contribute to a higher risk of crashes and reduced manoeuvrability.

Furthermore, the analysis highlights a contrast between motorcycles in the outer lane and those in the inner lane in terms of headway. Motorcycles in the outer lane have shorter headways compared to motorcycles in the inner lane. This difference could be attributed to various factors, such as faster-moving traffic in the outer lane, more lane

changes or merging actions in the inner lane, or differing driving behaviours of motorcyclists in these two lanes.

In summary, the analysis suggests that there is an inverse relationship between vehicle flow rate and motorcycle headway, with higher flow rates leading to reduced headways. Additionally, motorcycles in the outer lane have shorter headways compared to those in the inner lane. Table 4.5 and Figure 4.6 show the headway variation of MCs.

#### 4.1.6 Lane splitting of Motorcycles

Table 4.6 and Figure 4.7 show an analysis of lane splitting behaviour of motorcycles under different flow conditions.

Table 4. 6 Lane splitting of MCs

Flow Vs Lane Splitting					
Flow ((veh/hr/lane)	Status	Lane 01		Lane 02	
		LHS	RHS	LHS	RHS
0-500	Low	3%	72%	24%	1%
500-1000	Medium	11%	38%	39%	12%
>1500	High	19%	31%	38%	13%

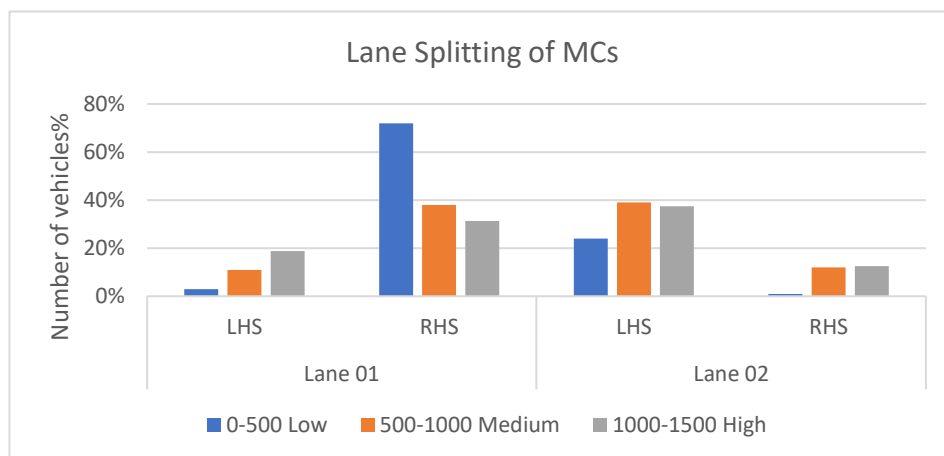


Figure 4. 7 Lane Splitting of MCs

The research findings highlight a compelling trend in motorcycle lane-splitting behaviour based on lane positioning and flow rates. The right-hand side-splitting of motorcycles in the outer lane is considerably high in the low flow rates. Interestingly, as flow rates increase, this right-hand side lane splitting diminishes. Remarkably, as flow rates rise, left-side splitting in the outer lane increases. (Table 4.6 and Figure 4.7)

In the meantime, left-hand side-splitting is predominant in the inner lane and with the increment of flowrate, both left-hand side and right-hand side-splitting are increased in the inner lane.

These findings present a significant connection between flow rate, lane choice, and splitting strategies, offering valuable insights into how motorcyclists adapt their behaviour to varying traffic conditions, which holds implications for road safety and traffic management strategies.

#### **4.1.7 PCU Variation of MCs under different conditions**

The following three approaches are considered in the analysis as explained in the methodology.

Condition 01: When there is only one motorcycle in between two successive passenger cars

Condition 02: When there are two motorcycles in between two successive passenger cars

Condition 03: When there are two adjacent motorcycles

Annex I shows the average headway values used for the PCU calculations.

Table 4.7 presents observed PCU values for three different conditions, each representing a distinct condition or scenario, under two specific traffic flow conditions relevant to motorcycles: MC Composition 0%-25% and MC Composition 25%-50%.

Table 4. 7 PCU Variation of MCs

Flow Rate (PCU/min)	Conditions			MC%
	C01	C02	C03	
0-10	0.40	0.41	0.48	0-25
	0.59	0.60	0.68	25-40
10-15	0.44	0.45	0.64	0-25
	0.67	0.57	0.76	25-40
15-20	0.44	0.44	0.63	0-25
	0.63	0.56	0.66	25-40
20-25	0.41	0.35	0.49	0-25
	0.50	0.39	0.63	25-40

For motorcycle compositions, Condition 01 indicates that under the condition of Motorcycle Composition 0%-25%, the observed PCU values vary between 0.40 and 0.44. This suggests that this condition involves moderate PCU values for less motorcycle composition scenarios. This implies the moderate impact of the motorcycles on the traffic under low motorcycle compositions. As the Motorcycle Composition increases to 25%-50%, the PCU values extend to a higher range (0.50 to 0.67), PCU values tend to rise in low-flow conditions and gradually decrease as traffic flow rates increase. This suggests that the influence of motorcycles on PCU reduces in high-flow conditions compared to low-flow conditions. (Figure 4.8)

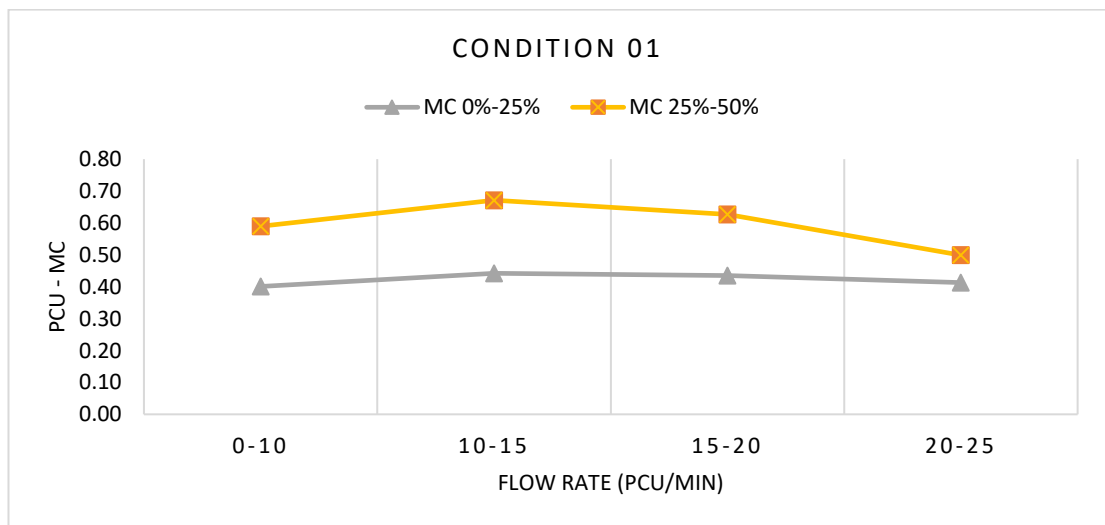


Figure 4. 8 PCU Variation in Condition 01

Condition 02 displays the same characteristics as approach 01. At motorcycle composition 0%-25%, the PCU range (0.35 to 0.45) implies low impact of Motorcycles, while the PCU range of 0.39 to 0.60 at Motorcycle Composition 25%-50% indicates the increment of impact of motorcycles to the traffic. Moreover, PCU values tend to rise in low-flow conditions and gradually decrease as traffic flow rates increase. (Figure 4.9)

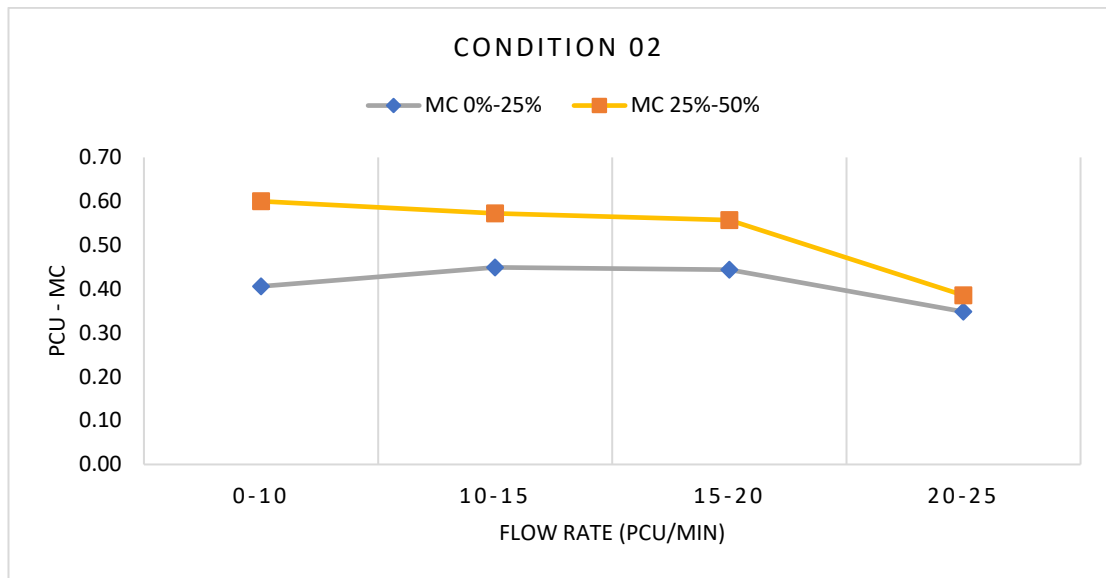


Figure 4.9 PCU Variation in Condition 02

In the context of motorcycle compositions, Condition 03 exhibits a pattern similar to Condition 01 and 02, with PCU values increasing as the flow rate shifts from Motorcycle Composition 0%-25% to Motorcycle Composition 25%-50%. At Motorcycle Composition 0%-25%, the PCU range changes from 0.48 to 0.63. Under Motorcycle Composition 25%-50%, the PCU range extends from 0.63 to 0.76, highlighting the potential for significant increment in PCU values during high motorcycle composition scenarios. In addition, as same as the previous conditions, PCU values tend to rise in low-flow conditions and gradually decrease as traffic flow rates increase. (Figure 4.10)

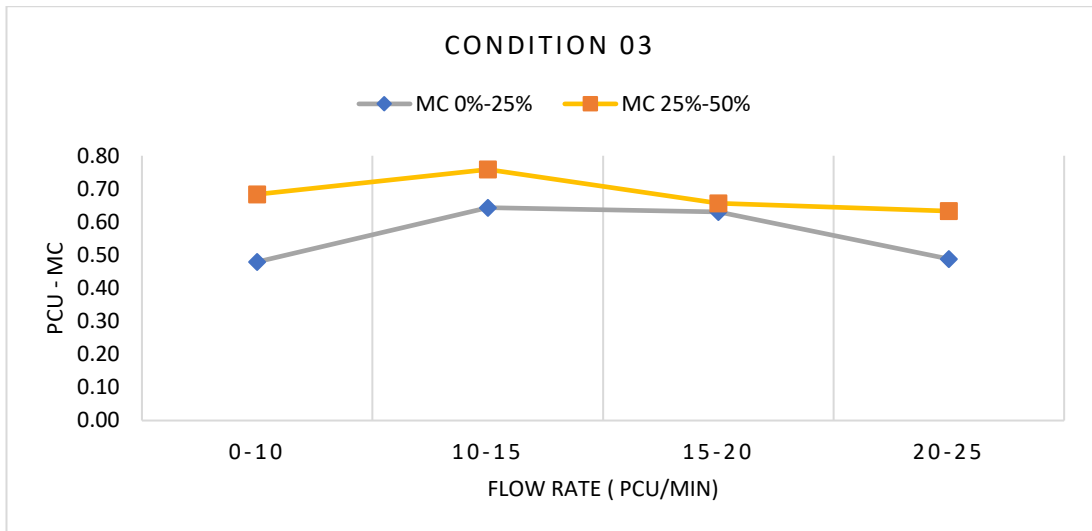


Figure 4. 10 PCU Variation in Condition 03

As a summary, Table 4.8 shows the observed PCU values under different conditions and different motorcycle composition scenarios.

Table 4. 8 Summary of PCU values for MCs

Observed PCU	MC 0%-25%	MC 25%-50%
Condition 01	0.40 – 0.44	0.50 – 0.67
Condition 02	0.35 – 0.45	0.39 - 0.60
Condition 03	0.48 – 0.63	0.63 – 0.76

## 4.2 Signalized Intersections

### 4.2.1 Saturation Headway Analysis

#### 4.2.1.1 Scenario with no motorcycle storage in front of the queue

Table 4.9 and Figure 4.11 show an analysis of the average headway variation of motorcycles in the scenario with no MC storage in front of the queue.

Table 4. 9 Average headway variation of MCs (No MC Storage)

Position in Queue	Average Headway	STDV	Number of Observations
1	2.90	0.76	30
2	2.63	0.70	30
3	2.47	0.92	30
4	2.42	0.99	30
5	2.45	0.95	29
6	2.14	0.61	29
7	2.24	0.54	29
8	2.13	1.18	28

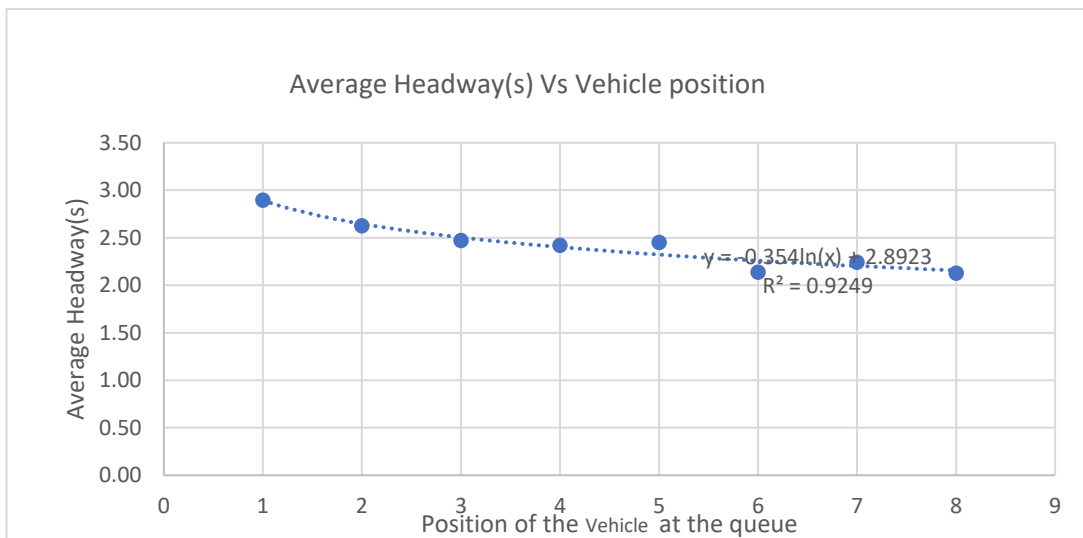


Figure 4. 11 Average headway variation of MCs (No MC Storage)

A high R-squared value confirms a robust connection between the average headway and the vehicle position at the queue. The observed headway values indicate that the saturation headway occurs at approximately the 6<sup>th</sup> position and the saturation headway is around 2.30 seconds. Furthermore, the average headway at the 1st position is approximately 2.9 seconds when there is no motorcycle storage in the queue.

#### 4.2.1.2 Scenario with motorcycle storage in front of the queue

Table 4.10 and Figure 4.12 show an analysis of the average headway variation of motorcycles in the scenario with MC storage in front of the queue.

Table 4. 10 Average headway variation of MCs (with MC Storage)

Position in Queue	Average Headway	STDV	Number of Observations
1	3.62	1.26	118
2	2.89	1.19	118
3	2.53	1.05	118
4	2.53	1.08	118
5	2.36	0.98	107
6	2.40	0.96	105
7	2.42	0.92	91
8	2.09	0.87	79
9	2.33	0.77	71
10	2.35	1.04	64

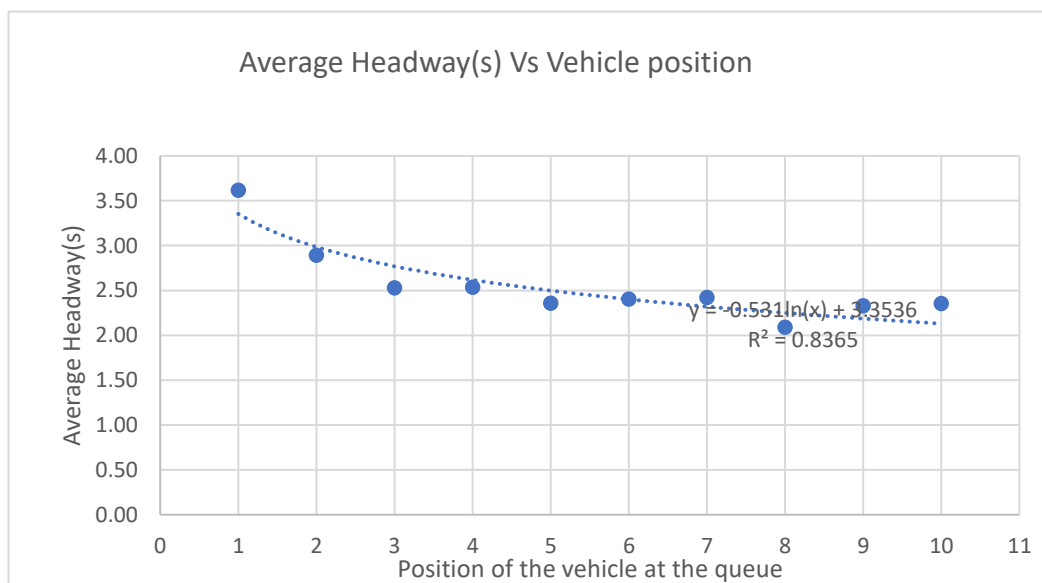


Figure 4. 12 Average headway variation of MCs (with MC Storage)

The queue reaches the saturation headway condition nearly around the 8<sup>th</sup> position, resulting in a saturation headway of 2.3 seconds. A high R-squared value confirms a robust connection between the average headway and queue position. Furthermore, the results show that the presence of motorcycle storage in the queue has caused a delay in achieving the saturation headway when compared to the scenario without motorcycle storage.

Upon analysis of both scenarios, it was evident that the presence of motorcycles (MCs) in the queue has a notable impact on achieving saturation headway, resulting in an associated delay of approximately 5.7 seconds.

#### 4.2.2 Start-up lost time

Based on the results obtained from the Pearson correlation test conducted using SPSS Software, a strong positive correlation was observed between Start-Up lost time and the storage of motorcycles (MCs) in the queue. Table 4.11 shows the Pearson correlation between Start-up lost time and MC storage.

Table 4. 11 Pearson Correlation between Start-up lost time and MCs storage

		Startup Lost Time	MCs Storage
Pearson Correlation	Startup Lost Time	1.000	0.717
	MCs Storage	0.717	1.000
Sig. (1-tailed)	Startup Lost Time	.	.000
	MCs Storage	.000	.
N	Startup Lost Time	108	108
	MCs Storage	108	108

Figure 4.13 shows an analysis of start-up lost time variation with MCs storage.

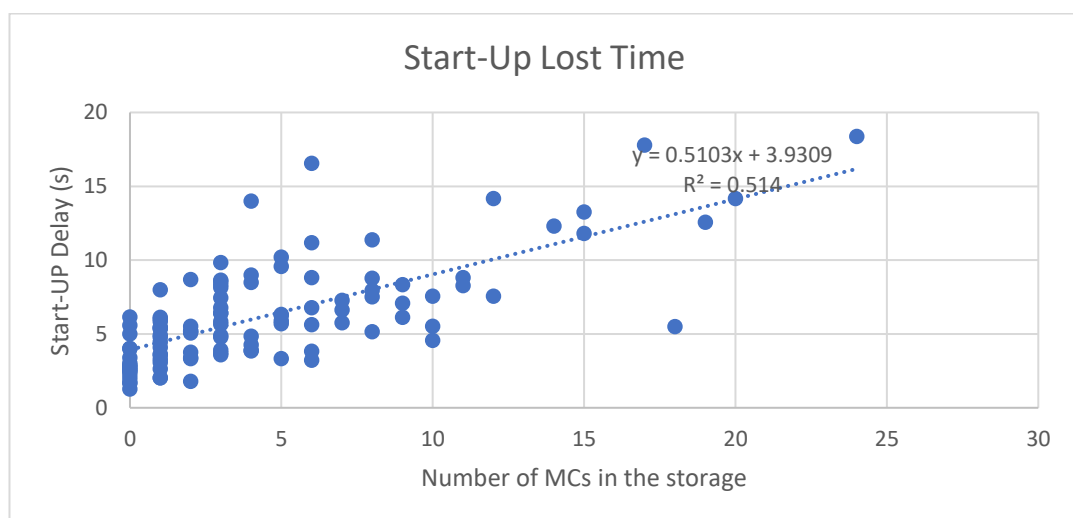


Figure 4. 13 Start-up Lost Time variation with MCs storage

According to the analysis, it was determined that, on average, the presence of each motorcycle in the queue at a signalized intersection contributed an additional 0.5103 seconds to the Start-up Lost Time. Conversely, in situations where no motorcycles are waiting in the queue, the Start-up Lost Time was observed to be approximately 3.9 seconds.

## 5 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusion

In many South Asian countries, including Sri Lanka, the traffic landscape is characterized by heterogeneous conditions and distinct driving behaviours. Motorcycles represent a significant portion of urban traffic. Despite their high manoeuvrability, motorcycles pose considerable impacts on traffic, safety, and the environment. Therefore, closely monitoring and regulating motorcycle behaviour is imperative to understand and mitigate their impact on urban traffic flow. Despite the prevalence of motorcycles in road traffic across many Asian cities, there remains a scarcity of empirical studies on the characteristics of this mode of transportation in the region.

This study focused on evaluating the influence of motorcycles on urban traffic flow in Sri Lanka, with the aim of proposing effective mitigation measures. Data collection utilized cameras at mid-block road sections and signalized intersections, employing both manual and semiautomated software-based methods for accurate data extraction. Various data types including headway, vehicle types, and vehicle counts were analyzed. The research aimed to delve into the dynamics of motorcycles under different traffic and roadway conditions, examining aspects such as trajectory, lane position, speed, headway, and lane splitting. Additionally, the study sought to assess the impact of motorcycles on urban traffic by exploring variations in Passenger Car Units (PCU) under diverse traffic and road conditions. Moreover, the study spanned to evaluate the saturation headway and startup lost time at the urban intersections to evaluate the effects of motorcycle behaviours.

In conclusion, the presence and behaviour of motorcycles on urban roads in the studied context have been shown to have significant effects on traffic flow. The composition of motorcycles on the considered roads varies between 17% and 40%, emphasizing their significant presence in the urban traffic landscape.

Notably, the study has discovered evident behavioural patterns of motorcycles under varying traffic conditions. In low flow rates, motorcycles tend to follow linear

trajectories and exhibit minimal lane-changing behaviour. However, as traffic flow increases, motorcycles adopt turbulent trajectories with a higher tendency for lane changes. Moreover, the findings indicate that the lateral change per meter of motorcycles (MCs) is notably lower in low traffic conditions when contrasted with high flow rates. Additionally, the results emphasize motorcycle speeds are not significantly influenced by the vehicle flow rate, primarily due to their distinctive behavioural patterns. Additionally, the study has demonstrated that motorcycle headway with successive vehicles decreases as flow rates rise, indicating the importance of considering this parameter in traffic management strategies. High-flow scenarios also witness significant left-hand side (LHS) overtaking in the outer lane and right-hand side (RHS) overtaking in the inner lane.

Motorcycle composition notably affects the variations in Passenger Car Units (PCU) under varying traffic conditions, and the positioning of motorcycles within traffic further influences PCU values. PCU values for motorcycles change depending on their placement in relation to passenger cars and the motorcycle composition in the traffic flow.

These PCU values will assist designers in enhancing their designs by utilizing the most appropriate PCU factors for motorcycles, taking into consideration the specific characteristics of the road and traffic. Additionally, these values can be applied in any location where comparable conditions exist.

Furthermore, the study has identified a crucial delay factor at signalized intersections, where achieving saturation headway is hindered by the presence of motorcycles in queues. The presence of motorcycles (MCs) in the queue notably impacts the achievement of saturation headway, resulting in an associated delay of around 5.7 seconds. A robust positive correlation exists between Start-Up Lost Time and the presence of motorcycles stored in these queues. Moreover, each motorcycle has contributed 0.5103 seconds to the Start-Up Lost Time and in the absence of motorcycle storage, the Start-Up Lost Time is approximately 3.9 seconds.

In summary, these findings elaborate on the complex dynamics of motorcycles in urban traffic and the necessity for tailored traffic management strategies that consider

their behaviour, speed control measures, overtaking patterns, and positioning within traffic. Addressing these aspects is vital for optimizing traffic flow, enhancing road safety, and minimizing disruptions caused by motorcycles on urban roads.

## **5.2 Strengths of the adopted research methodology**

The adopted research method for this research boasts several positive aspects that enhance its comprehensiveness and reliability. Firstly, the method involves the utilization of cameras, facilitating the collection of comprehensive data regarding motorcycle behaviour within urban traffic settings. This extensive dataset is helpful in gaining a comprehensive understanding of how motorcycles interact with other vehicles in these environments.

Moreover, the research method places a strong importance on accuracy through the combined use of manual and software-based data extraction techniques. This precision ensures that the data analysis process is reliable and can yield trustworthy insights into the influence of motorcycles on traffic.

Another prominent strength of the research method lies in its ability to explore various features of motorcycle behaviour. It examines factors such as trajectory, lane position, speed, headway, and overtaking manoeuvres, offering a complete view of how motorcycles navigate urban traffic. Moreover, this research has taken into account different traffic flow conditions, spanning from low to high flow rates. This consideration enables a thorough examination of how motorcycle driving patterns change in response to changing traffic scenarios.

The research method also explores the impact of motorcycles on Passenger Car Unit (PCU) variations, taking into account both motorcycle composition and positioning within traffic. This analysis provides critical insights into the broader implications of motorcycle presence on traffic efficiency.

Furthermore, the study explores queue dynamics and intersection behaviour at signalized junctions, particularly focusing on the effects of motorcycles on saturation headway and start-up lost time at signalized intersections. This aspect of the research

is essential for understanding the details of traffic management in urban areas with a substantial motorcycle presence.

Ultimately, the research method employs a quantitative approach, assigning specific time values such as the contribution of each motorcycle to Start-Up Lost Time. This quantitative analysis enhances the precision and practicality of the findings, leading to the formulation of actionable recommendations for improving traffic management and safety in urban environments characterized by significant motorcycle activity.

### **5.3 Limitations of the adopted research method and suggestions**

It is critical to recognize the limitations of the research conducted and consider potential improvements in this research.

In this analysis, the interaction between motorcycles and passenger cars was exclusively considered in the Passenger Car Unit (PCU) calculations. For future research, it would be beneficial to expand the scope of PCU calculations to include interactions between motorcycles and other types of vehicles.

At the intersections, the impact of slow-moving vehicles, heavy vehicles, and three-wheelers was not specifically considered. These scenarios were omitted to focus solely on analyzing the impact of motorcycles. However, it is recommended that future research takes into account the influence of these additional vehicle types on motorcycle behavior for a more comprehensive analysis.

This analysis focuses solely on the impact of motorcycles on urban traffic. However, the effects of motorcycles in rural areas may differ significantly from those in urban contexts. Therefore, it is recommended to extend this analysis to rural conditions to thoroughly identify and understand the impacts of motorcycle driving patterns in these areas.

In this analysis, 4-lane roads were considered to identify the unique driving patterns of motorcycles in an urban context. However, the behavior of motorcycles on urban 2-lane roads, where space restrictions and limitations are more pronounced, may differ significantly. Therefore, it is recommended that future studies analyze motorcycle behavior on 2-lane urban roads separately.

Generally, relying on cameras and GPS devices, for data collection may have limitations when it comes to coverage in busy or complex urban traffic situations. To overcome this limitation, consideration of incorporating additional data sources, such as traffic sensors or mobile app data, to complement camera and GPS data can be adopted. This can provide a more comprehensive view of motorcycle behaviour.

Additionally, manual and software-based data extraction can be time-consuming and resource-intensive, especially for large datasets. Therefore, exploring advanced data processing and machine learning techniques for more efficient and automated data extraction can be helpful to streamline the analysis process.

#### **5.4 Recommendations for future work**

Recognizing the significance of left-hand side (LHS) and right-hand side (RHS) overtaking in high-flow scenarios is crucial. Road safety campaigns should educate both motorcycle riders and other road users about responsible overtaking practices to minimize disruptions and improve traffic flow.

The motorcycle composition and the positioning of motorcycles within traffic significantly impact Passenger Car Unit (PCU) variations. The results of this study will enable the establishment of precise Passenger Car Unit (PCU) factors for motorcycles, which are relevant to various traffic conditions and compositions of motorcycles. This will assist designers in enhancing their designs by employing the most appropriate PCU factors for motorcycles, taking into account specific road and traffic characteristics.

With the results and methodology adopted in this study, road designers can perform advanced analyses by incorporating additional critical parameters. This will enable them to evaluate the necessity of dedicated motorcycle lanes, optimize signal lights to mitigate delays caused by motorcycles, and implement measures to control motorcycle behaviors.

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**APPENDIX – I: SAMPLE DATA FOR AVERAGE TIME  
HEADWAY VALUES UNDER DIFFERENT APPROACHES**

<b>H1</b>	<b>H2</b>	<b>H3</b>	<b>H4</b>	<b>MC%</b>	<b>Flow rate</b>
2.87	2.80			8%	6.3
				18%	8.1
1.65		3.47	0.43	20%	10.0
1.24	1.76		0.96	24%	9.2
2.08	1.80		1.36	24%	9.2
1.73	4.37			25%	4.9
	5.04			27%	6.4
1.15	1.30		1.87	27%	10.0
1.28	1.92		0.79	28%	9.0
			2.47	29%	6.2
1.76	3.04		1.12	29%	9.7
1.55	2.74		3.00	34%	9.2
	4.84		1.43	36%	7.0
1.94	2.62		1.37	36%	7.5
2.04		2.14	2.01	38%	8.5
2.43				40%	5.7
2.12	2.96		0.70	41%	9.4
2.00			4.45	43%	7.8
1.13		5.94	1.80	43%	9.7
1.48	3.80		2.69	45%	8.1
1.27				46%	7.6
				47%	9.6
1.10	1.75		1.90	48%	8.4
	1.22			48%	9.3
2.75			3.64	50%	6.7
2.19	2.40		1.52	50%	8.8
1.82			2.45	53%	8.5
2.84			1.91	59%	5.5
2.08	2.17	2.40	0.37	59%	7.0
		6.61	2.08	59%	8.1
			1.72	67%	3.0
2.07	5.87		3.27	30%	8.5
3.84	4.60		4.42	32%	10.0

1.74				7%	14.1
1.73	2.00			7%	14.1
1.89				7%	13.8
1.47			3.07	8%	14.8
1.53				10%	10.6
1.75	2.74			13%	13.0
2.04			2.90	14%	12.4
2.10				14%	13.4
3.62				14%	14.4
				17%	10.3
1.80	2.09			17%	13.8
1.38			3.90	17%	14.2
1.46	1.60		2.47	17%	14.3
2.34	8.18		0.92	18%	12.8
2.07	2.60			18%	13.4
1.85	1.96		2.88	19%	11.2
7.63				20%	11.9
2.52	2.50			20%	12.9
1.24	4.26			20%	12.9
1.70	1.72		0.90	20%	12.9
	3.95		0.93	21%	13.8
1.79	2.38		5.81	21%	14.1
1.96			1.06	22%	14.4
				22%	14.5
1.44				22%	14.5
1.33	5.27			23%	13.4
2.52	4.26		4.32	23%	14.4
2.64	1.92		4.32	23%	14.4
3.50				25%	10.8
2.19			1.00	25%	12.1
			3.50	26%	14.6
2.64				26%	14.4
2.52				26%	14.4
1.77	2.24		1.37	27%	13.8
1.74	2.50		2.12	27%	14.8
2.07	3.30		4.67	28%	11.2
1.90	2.50		3.88	29%	14.3
	2.30			30%	13.6

## APPENDIX – II: SAMPLE DATA FOR TRAJECTORY DATA OF MOTORCYCLES

Vehicle No.	Time (s)	Vehicle Type	X (m)	Y (m)
1	0.03	Boundary	59.21682	10.0463
1	0.03	Boundary	106.2166	10.0463
1	0.03	Boundary	57.7482	16.0463
1	0.03	Boundary	104.748	16.0463
1	0.00	Boundary	104.2446	16.12681
1	0.50	Boundary	105.7121	9.920823
1	1.00	Boundary	59.35394	10.0355
1	1.50	Boundary	57.91084	15.98518
2	30.00	Bike	34.39917	0.903662
2	30.50	Bike	29.79854	0.835086
2	31.00	Bike	21.9655	1.163033
2	31.50	Bike	16.79755	1.127586
2	32.00	Bike	11.52705	1.15123
2	32.50	Bike	5.042271	0.934445
2	33.00	Bike	1.213719	0.341698
3	56.00	Bike	37.11443	1.5094
3	56.50	Bike	30.71911	1.816996
3	57.00	Bike	25.23269	2.097162
3	57.50	Bike	21.32526	2.019417
3	58.00	Bike	16.00136	1.950989
3	58.50	Bike	10.25475	1.974047
3	59.00	Bike	4.914693	1.692898
3	59.50	Bike	0.876026	1.167561
4	73.00	Bike	37.59688	2.778311
4	73.50	Bike	28.63321	2.778937
4	74.00	Bike	21.30542	2.383751
4	74.50	Bike	12.91987	2.164618
4	75.00	Bike	5.288196	1.888305
4	75.50	Bike	0.810001	0.976827
5	74.50	Bike	38.42446	2.490396
5	75.00	Bike	33.03165	2.516635
5	75.50	Bike	25.22765	2.280859
5	76.00	Bike	18.93381	2.239821
5	76.50	Bike	12.36478	2.105695
5	77.00	Bike	5.843035	1.848456
5	77.50	Bike	0.880105	1.324258

6	74.50	Bike	36.48483	4.957033
6	75.00	Bike	32.74623	4.944048
6	75.50	Bike	24.1943	4.951587
6	76.00	Bike	16.77929	4.885567
6	76.50	Bike	10.47472	4.745484
6	77.00	Bike	3.198957	4.483235
7	84.00	Bike	32.68017	2.187167
7	84.50	Bike	28.35127	2.476858
7	85.00	Bike	23.37748	2.493222
7	85.50	Bike	19.43435	2.537728
7	86.00	Bike	15.1231	2.481854
7	86.50	Bike	10.6575	2.538579
7	87.00	Bike	6.027942	2.278262
7	87.50	Bike	1.594006	2.041621
8	85.50	Bike	33.75658	3.240083
8	86.00	Bike	28.06484	3.37067
8	86.50	Bike	20.65594	3.584862
8	87.00	Bike	13.81895	3.822783
8	87.50	Bike	7.112291	3.714367
8	88.00	Bike	1.182588	3.375528
9	86.50	Bike	35.17484	1.836539
9	87.00	Bike	35.16918	1.69946
9	87.50	Bike	25.47577	2.077377
9	88.00	Bike	19.09582	2.379494
9	88.50	Bike	15.80454	2.556167
9	89.00	Bike	8.276484	2.570453
11	95.00	Bike	33.69949	1.408023
11	95.50	Bike	28.07784	1.709069
11	96.00	Bike	26.48853	1.431171
11	96.50	Bike	21.1387	1.873309
11	97.00	Bike	18.46614	1.739968
11	97.50	Bike	14.53775	1.768578
11	98.00	Bike	10.54838	1.889548
11	98.50	Bike	6.873666	2.000976
11	99.00	Bike	2.825372	2.012768
12	98.50	Bike	35.59798	2.830546
12	99.00	Bike	30.11089	2.940576
12	99.50	Bike	24.49939	2.807213
12	100.00	Bike	17.73519	2.79706
12	100.50	Bike	12.422	2.566819
12	101.00	Bike	6.934482	2.51543
12	101.50	Bike	1.654904	2.345893

**APPENDIX –III: SAMPLE HEADWAY DATA SET AT  
KATUGASTOTA INTERSECTION**

<b>Cycle</b>	<b>storage</b>	<b>in queue</b>	<b>green</b>	<b>time</b>	<b>type</b>	<b>Headway</b>
<b>1</b>	1	4	21.00831	25.4626	c	4.454294
				29.55125	c	4.088643
				36.06648	c	6.515235
				38.92521	c	2.858726
				44.37673	t	5.451524
<b>2</b>	14	10	125	133.5956	b	8.595568
				137.385	t	3.789474
				139.9778	b	2.592798
				145.3629	b	5.385042
				148.3878	l	3.024931
				151.1801	t	2.792244
				154.4709	c	3.290859
				158.3601	c	3.889197
				160.9529	b	2.592798
				165.2078	j	4.254848
				167.6343	c	2.426593
				169.3961	b	1.761773
				171.2244	c	3.590028
				172.9529	c	1.728532
				175.1136	c	2.160665
177.0083	l	1.894737				
177.9723	t	0.963989				
<b>3</b>	4	2	163.8116	169.795	l	5.98338
				172.3878	c	2.592798
				176.8753	c	4.487535
				178.6704	t	1.795014
				180.6	c	1.92964
				182.5928	c	1.992798
				185.1191	c	2.526316
				190.3047	c	5.185596
				192.2659	c	1.961219
				195.8892	t	3.623269
				197.8837	v	1.99446
				201.0748	t	3.191136
				203.2022	t	2.127424

				205.4626	v	2.260388
<b>4</b>	5	10	408.5651	412.7202	c	4.155125
				415.4127	t	2.692521
				417.108	c	1.695291
				420	t	2.891967
				424.3546	b	4.354571
				429.5402	c	5.185596
				433.3961	c	3.855956
				435.3241	c	1.927978
				437.0194	t	1.695291
				440.3435	b	3.3241
				444.5651	c	4.221607
				446.2936	t	1.728532
				447.9224	t	1.628809
				449.4183	t	1.495845
				452.9751	v	3.556787
				455.1357	c	2.160665
<b>5</b>	1	2	22.27147	25.19668	c	2.925208
				29.38504	c	4.188366
				36	c	6.614958
				38.69252	c	2.692521
				44.27701	t	5.584488
<b>6</b>	6	8	688.6205	695.4349	b	6.814404
				699.2576	t	3.822715
				700.6537	t	1.396122
				706.338	c	5.684211
				708.5319	t	2.193906
				711.2244	l	2.692521
				713.2853	v	2.060942
				716.8753	b	3.590028
				719.9335	t	3.058172
				722.3601	c	2.426593
				725.0859	c	2.725762
				727.1468	t	2.060942
				728.9751	c	1.828255
				730.5706	t	1.595568
				732.4321	c	1.861496
				734.8255	c	2.393352
				737.5512	c	2.725762
				739.9114	t	2.360111

				741.7729	v	1.861496
				744.9972	t	3.224377
				747.3906	v	2.393352
				750.1496	t	2.759003
				752.144	c	1.99446
<b>7</b>	<b>0</b>	<b>5</b>	<b>728.8421</b>	<b>730.8366</b>	<b>c</b>	<b>1.99446</b>
				736.2216	c	5.385042
				739.9114	c	3.689751
				742.5042	c	2.592798
				746.1939	v	3.689751
				750.1828	l	3.98892
				754.1	c	3.917175
				756.5983	t	2.498338
<b>8</b>	<b>6</b>	<b>3</b>	<b>971.6343</b>	<b>974.9252</b>	<b>l</b>	<b>3.290859</b>
				980.5762		5.65097
				982.0388	t	1.462604
				983.0693	c	1.030471
				984.7978	c	1.728532
				986.7922	t	1.99446
				989.1191	c	2.32687
				991.5457	c	2.426593
				994.4044	t	2.858726
<b>9</b>	<b>20</b>		<b>1252.753</b>	<b>1256.742</b>	<b>c</b>	<b>3.98892</b>
				1261.596	b	4.853186
				1268.842	c	7.246537
				1271.069	t	2.227147
				1272.997	l	1.927978
				1275.49	c	2.493075
				1276.787	t	1.296399
				1282.039	c	5.252078
				1284.199	c	2.160665
				1286.693	c	2.493075
				1288.554	t	1.861496
				1291.18	l	2.626039
				1293.175	t	1.99446
				1294.571	t	1.396122