SPEED DATA ANALYSIS OF NATIONAL HIGHWAY (N5) AND MOTORWAY (M1) OF PAKISTAN

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A thesis submitted in partial fulfillment of the

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In

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By

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Submitted To:

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<u>DEDICATED</u>

To my Parents and Husband….

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LIST OF ABBREVIATIONS

HCM	Highway Capacity Manual
FHWA	Federal Highway Administration
NHA	National Highway Authority
FWO	Frontier Works Organization
SPI	Speed Performance Index
RCI	Roadway Congestion Index
PCU	Passenger Car Unit
NB	Northbound
SB	Southbound
M1	Islamabad Peshawar Motorway
N5	National Highway/ GT Road
v/c	Volume to Capacity ratio
Kmph	Kilometer per hour
vph	Vehicle per hour
LTV	Light Traffic Vehicle
HTV	Heavy Traffic Vehicle

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ABSTRACT

The supply component of any transportation system hinges on the provision of facilities (roadways, parking spaces, etc.), services (interchanges, tolls), policies, and regulations that create movement opportunities. As far as facilities are concerned, roadway infrastructure becomes an important part of the road for the development of any country. A traffic stream consists of multiple vehicle types making it a heterogeneous platoon of vehicles. The difference in driving behavior on motorways and highways alters the traffic stream characteristics. For analyzing the characteristics, traffic flow parameters to evaluate the condition of traffic on any road network are speed, flow, and density.

This research is conducted to assess the macroscopic flow parameters together with evaluating the spatial, temporal, and climatic impacts on speed for motorways and highways in Pakistan. Motorways and Highways are major constituents of the road infrastructure of a country. For this research, Motorway M1 and National Highway N5 are selected. M1 is in Punjab and KPK provinces and becomes the central link to Afghanistan and Central Asia. This research provides a detailed study on the Speed relationship with Flow, Congestion Index, and Speed Performance Index. Moreover, in this research, a comparison of average speed at different traffic flow conditions is made for N5 and M1. In a heterogeneous traffic platoon, with varying operating speeds a comparative study is conducted on the traffic speeds of each vehicle class. This research is further extended to assess the time of day and weather impact on travel speed for each vehicle class. The Speed Prediction models are also developed for Motorways based on Flow and demand. Evaluation of road traffic conditions can be more objective by calculating the road traffic congestion index which contributes to traffic planning and management. The traffic congestion index reflects the congestion state of possibility which can be sensed by travelers. It can be calculated using several traffic flow parameters based on fuzzy mathematics. The relationship of the congestion index with traffic flow parameters is developed for both motorways and national highways.

Keywords: Macroscopic Flow parameters, Heterogeneous traffic, Congestion index, Speed performance index, M1, N5, Fuzzy Mathematics.

CHAPTER 1

1. INTRODUCTION

1.1. General

Speed is one of the key entities to measuring the characteristics of a traffic stream. Speed is a critical transportation parameter to assess travel time, safety, comfort, convenience, and economics. Travel speed depends on several factors like maximum permissible speed, driver behavior, climatic conditions, light effect and geometric design of highways, etc. Road transportation is the backbone of Pakistan's transport system, accounting for 90 percent of national passenger traffic and 96 percent of freight movement. Over the past ten years, road traffic – both passenger and freight – has grown much faster than the country's economic growth. The 10,849 km long National Highway and Motorway network contribute 4.2 percent of the total road network. They carry 90 percent of Pakistan's total traffic.

Motorways of Pakistan are a network of multiple-lane, high-speed, controlled-access highways, which are owned, maintained, and operated federally by Pakistan's National Highway Authority and Frontier Works Organization (FWO). At present, 2567 km of motorways are operational. Motorways are a part of Pakistan's "National Trade Corridor Project" and "China-Pakistan Belt Road Initiative," from Khunjerab Pass near the Chinese border to Gwadar in Balochistan. The map of the Motorways of Pakistan is mentioned below in Figure 1.1.

Figure 1-1 Motorways Network of Pakistan

M1 is a motorway link that connects Islamabad and Peshawar, Length of this motorway is 155 km of which 88km is in Khyber Pakhtunkhwa and 67km in Punjab. Motorway M1 is the central link to Afghanistan and Central Asia. The M1 has 14 interchanges at Airport link road, Islamabad, AWT/ Sanjiani/ Paswal, Burma Bhatar, Burhan (Hassanabadal/ Kamra), and Hazara Express (E-35), Ghazi, Chachh, Sawabi, Rashakai, Charsadda, the Peshawar Northern Bypass, and Peshawar Ring Road. At Brahma Bahtar Interchange, the Brahma Bahtar-Yarik Motorway has commenced towards Dera Ismail Khan. The figure of the Network Map of the M1 motorway with interchanges is given below in Figure 1.2.

Figure 1-2 Network Map of M1 motorway (Islamabad - Peshawar Motorway)

The N-5 or National Highway 5 is an 1819 km national highway in Pakistan, which extends from Karachi in Sindh to Torkham in Khyber Pakhtunkhwa. The N-5 is the longest national highway in Pakistan and serves as an important north-south road artery. The Route Map of N5 is given below in Figure 1.3.

When it comes to the term traffic flows, reference to vehicle type can be easily classified into Homogenous and heterogeneous. Homogeneous traffic is composed of vehicles of the same types whereas heterogeneous traffic consists of motorcycles, passenger cars, auto-rickshaws, light commercial vehicles, and heavy vehicles (Buses and trucks) (Sarkar et al., 2020a).

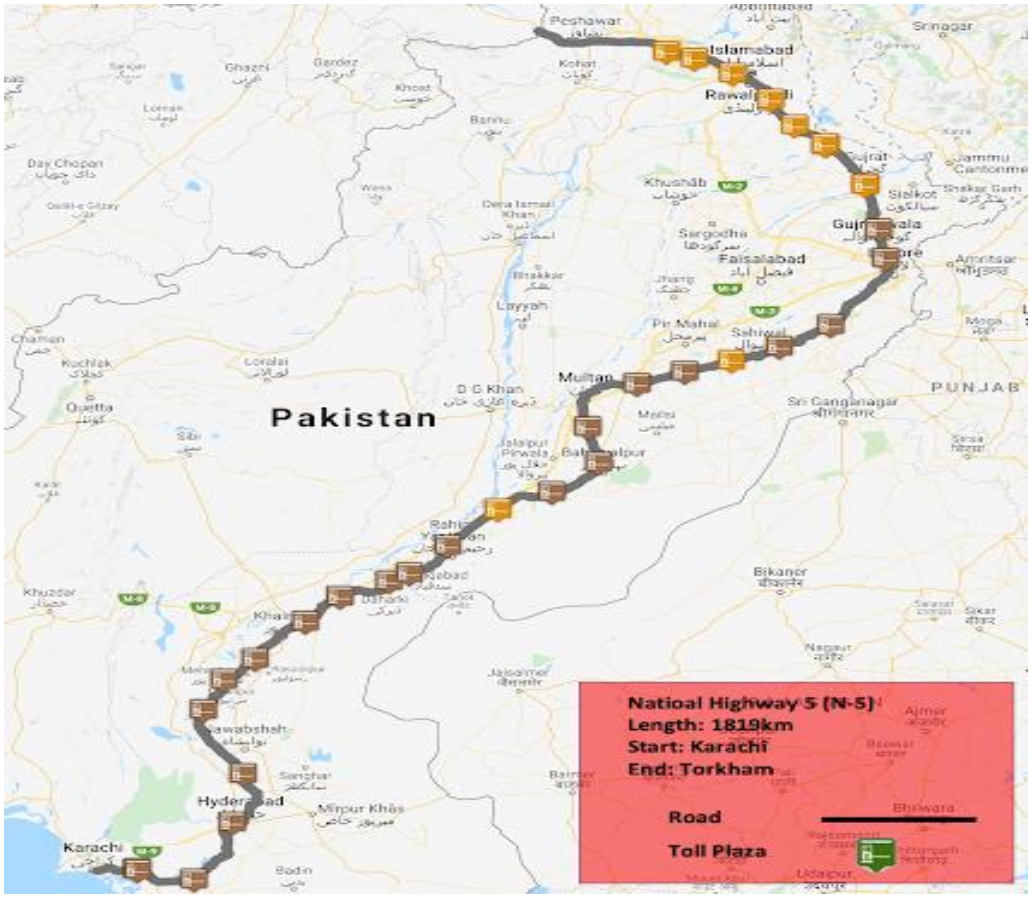


Figure 1-3 Map of N5

In the developing world, in countries like Pakistan, and some developed counties, traffic is comprised of various kinds of vehicles making up mixed traffic or heterogeneous traffic. These vehicles vary widely in terms of behavioral, static, and dynamic characteristics.

In access-controlled facilities like motorways or freeways, the Traffic stream consists of Homogenous vehicle types like (Cars, Buses, Hiace, Trucks, etc.). While in facilities like multilane highways, the traffic stream consists of various vehicle types including motorcycles, carts, etc. Since the early 1950s (Tanner, 1952), it has been recognized that factors like weather conditions and spatial and temporal factors affect driver behavior and traffic flow characteristics. Like an increase in traffic volume impacts the free flow speeds, climatic changes impact the speed of the vehicle. Weather phenomena exert significant impacts on traffic flow-related parameters, such as free-flow speed and capacity (Akin, Sisiopiku, et al. 2011). In their study, Salomen and Puttonen (1982) found that darkness results in a reduction of operating speed by 5 km/h. In terms of capacity, Jones and Goolsby (1969, 1970) indicated a 14% reduction during rain; however, no information was provided on the severity of the rain conditions. The rain severity has an important impact on such reduction as reported by Kleitsch and Cleveland (1971). Evaluation of road traffic conditions can be more objective by calculating the road traffic congestion index which contributes to traffic planning and management. The traffic congestion index reflects the congestion state of possibility which can be sensed by travelers. It can be calculated using several traffic flow parameters based on fuzzy mathematics.

1.2. Problem Statement

Traffic speed analysis is a vital parameter in the planning and management of highways and freeways. For a well-planned and efficient transportation infrastructure, traffic flow characteristics should be evaluated properly. In developing countries like Pakistan with a good infrastructure of freeways and Highways, such analyses are important to improve the traffic condition and geometric parameters of highways and freeways.

1.3. Research Objectives

The main research objectives are mentioned below:

i. Speed Relationship with Flow/Congestion Index/Speed Performance Index/Travel Efficiency/Volume/Volume to Capacity Ratio(Saturation Degree)
ii. Average Operating Speed on National Highway Vs. Speed on Motorways for each vehicle class
iii. Comparison between Average Speed on National Highways and Motorways at similar traffic demand
iv. Speed analysis for Day and Night
v. Speed Analysis with Weather condition

1.4. Scope of Research

The scope of this research will be to assess the impact of spatial, temporal, and climatic impacts on travel speed for motorways and highways of Pakistan. Motorways and Highways are major constituents of the road infrastructure of a country. For this research, Motorway M1 and National highway N5 were selected. This research can be used to optimize parameters like road geometry, driving behavior, traffic management, etc.

1.5. Organization of Report

This Thesis Contains a Total of Five Chapters, a brief introduction is given as follows.

- Chapter 1 presents the background of the study, problem statement, and objectives of the research. The remainder of the study is organized as follows.
- Chapter 2 consists of the literature review on the theory of traffic flow relationships on uninterrupted flow facilities, the Impact of weather conditions on highways speed, Fuzzy Mathematics to calculate the Roadway Congestion index, and Speed Performance index.
- Chapter 3 provides in detail the methodology used in the study and a description of the study areas. Traffic data collection and reduction processes in different study areas are discussed in detail and data on traffic are gathered to be analyzed.
- In Chapter 4, traffic speed data is analyzed and curves are developed between different traffic flow parameters.
- Chapter 5 consists of the conclusion and discussion provided to improve traffic conditions.

CHAPTER 2

2. LITERATURE REVIEW

2.1. General

The supply component of any transportation system hinges on the provision of facilities (roadways, parking spaces, etc.), services (interchanges, tolls), policies, and regulations that create movement opportunities. As far as facilities are concerned roadway infrastructure becomes an important part of the road to development for any country. A traffic stream consists of multiple vehicle types making it a heterogeneous platoon of vehicles. Moreover, the difference in driving behavior on freeways and highways alters the traffic stream characteristics. For analyzing the characteristics & to evaluate the condition of traffic of any road network major traffic flow parameters are speed, flow, and density.

Many researchers evaluated the relationships between different traffic flow parameters to determine the current traffic stream conditions and predict the flows for the future in congested network models and uninterrupted flows.

Evaluation of traffic flow conditions on a road network requires a thorough study of the spatial & temporal dimensions and relevant components of travel demand. The basic purpose of this research will be to assess the macroscopic flow parameters together with evaluate the spatial, temporal, and climatic impacts of these parameters on motorways and highways of Pakistan. Motorways and Highways are major constituents of the road infrastructure of a country. For this research, we choose Motorway M1 and National highway N5. M1 is a link between Peshawar and Islamabad with a span of approximately 155km. The whole stretch of M1 consists of six lanes, three lanes in each direction separated by a raised center median. A speed limit of M1 is 120km/hr. While N-5 is the longest highway in Pakistan. The length of N-5 is 1819km starting from Karachi in Sindh and ending at Torkhum in Khyber Pakhtunkhawa. M1 is access controlled facility with a total of 14 interchanges and N5 is easily accessible in various locations.

Speed is one of the basic parameters used for describing the characteristics of traffic flow and it is an important transportation parameter because it relates to safety, travel time, quality of travel (in terms of traffic density on a road), and the regulation and control of traffic operations. Generally, speed studies have a significant impact on the level of service (LOS) of highway facilities in terms of travel speed and time.

In developed countries and some developing countries including Pakistan, many studies have been done and well documented on speed-flow-density models and relationships on freeways and multilane highways.

Speed-flow-density relationships are the most useful tools in the highway design and planning process. They are useful in predicting the roadway capacity, determining the adequate level of service of traffic flow, and determining travel time for a given roadway. Traffic flow theory is one of the disciplines of transportation engineering which uses mathematical analysis and modeling to explain road traffic flow mechanisms.

The theory of traffic flow uses mainly three interrelated parameters for which relationships are worthy to be understood. To establish these relationships, it is essential to understand those parameters for which the steady-state flow fundamental relationship is shown in the following equation.

$$\mathbf{Q} = \upsilon_{\mathbf{s}} . \mathbf{K}$$

Where,

Q = Flow (Veh /h)

u_s = Macroscopic speed (Km/h)

K = Density (Veh/km)

Different terms used in the analysis of traffic flow are defined in the following part as described in the Highway Capacity Manual, TRB (Manual 2000). These terms are arranged into two categories according to the relative approach which is to be used, as shown in the following Figure 2.1.

Macroscopic Approach

When traffic is studied at the macroscopic level, the following traffic characteristics are considered:

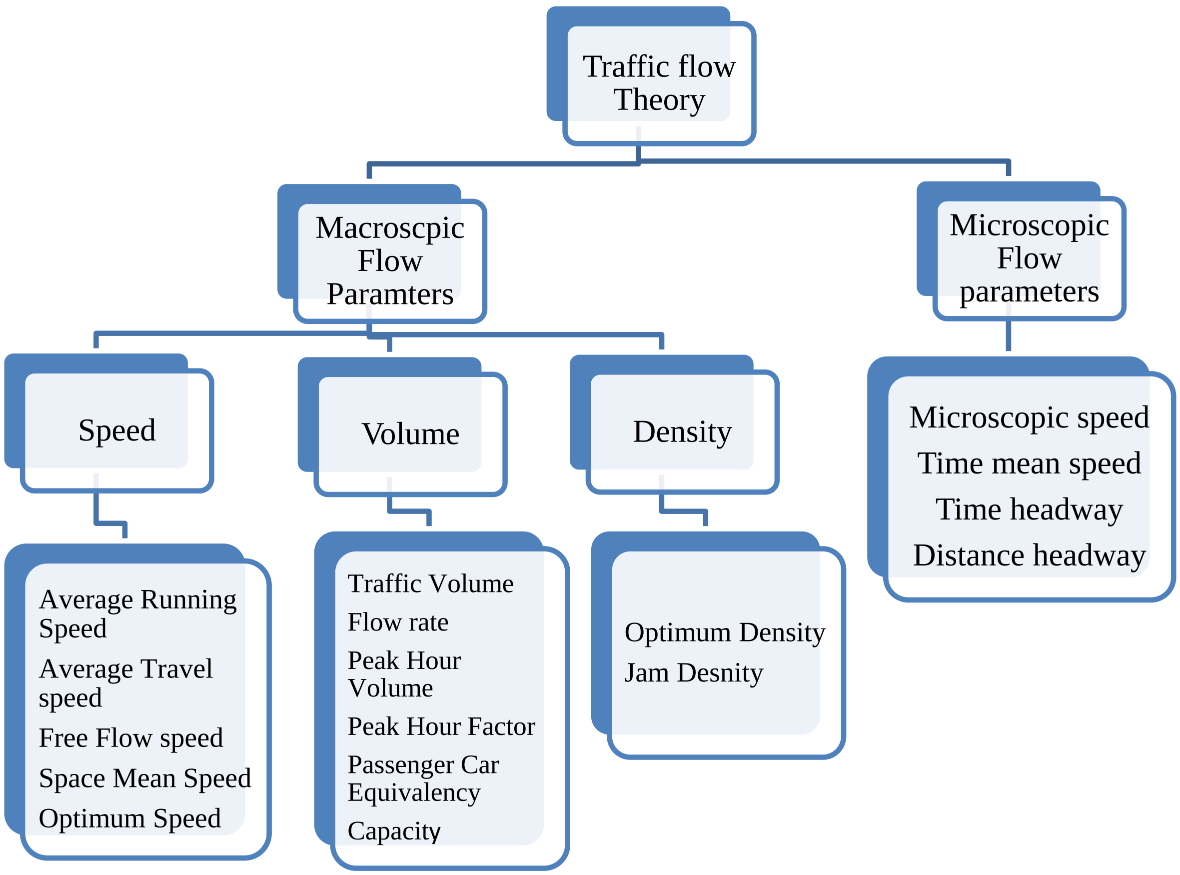


Figure 2-1 Traffic Flow Theory

Speed

Speed can be defined as the rate at which vehicles move along a given roadway and it is expressed as distance per unit of time.

In the analysis of the traffic stream, the following speed parameters can be considered depending on the purpose of the study.

Average Running Speed

Average running is a speed computed when vehicles are only in motion and are obtained by dividing the length traveled by the time a platoon of vehicles uses to travel a given length.

Average Travel Speed

Average travel speed is the speed calculated by dividing the distance traveled by the average travel time required for a stream of the vehicle with not excluding the time the vehicles were stopped.

Free Flow Speed

Free-flow speed is defined as the average speed of vehicles traveling over a roadway, measured under low volume traffic conditions that are when density and flow rate on a particular section of the roadway are both zero. In this case, the drivers are free to drive at their desired speed and are not embedded by the presence of others.

Space Mean Speed

Space mean speed also termed macroscopic speed is defined as a speed of a traffic stream measured on basis of the average travel time of vehicles traveling over a given length. This speed draws this name from the fact that the average travel time weights the average to the time each vehicle spends in a given roadway. The following formulae are used to compute the space mean speed.

$$\mu_s = \frac{n}{\sum \frac{1}{\mu_i}}$$

Where:

μ_s = Space mean speed (km/h)

n = Number of vehicles (vehicles)

μ_i = The time it takes the individual vehicle i to travel a given highway section (sec).

Optimum Speed

Optimum speed is defined as the speed which occurs when the level of traffic flow is at capacity.

Volume:

Traffic Volume

Is the total number of vehicles passing a point on a roadway within a given time. Volumes are expressed in terms of annual, daily, hourly, or sub-hourly periods. The following terms are used to characterize traffic volume (flow) on a given portion of the road.

Flow Rate

Flow rate is defined as a rate at which vehicles pass over a given point of the roadway during the sub-hourly time, usually 15 minutes. And it is expressed as the number of vehicles per unit of time mostly an hour or second.

Peak Hour Flow

Peak hour flow is defined as the highest traffic flow which is obtained during any successive 60 minutes. This flow is mostly considered in capacity and other traffic studies since it provides the most critical period which can affect the operation of a given highway thereby capacity.

Peak Hour Factor

The peak hour factor is the ratio of total hourly volume to the maximum rate of flow within the hour. The peak hour factor can be computed by the following equation.

$$\text{Peak hour Factor} = \frac{\text{Hourly Volume}}{\text{Peak Flow rate(within the hour)}}$$

Capacity

Capacity can be defined as the maximum rate of flow that can be achieved on a given roadway facility under prevailing roadway, traffic and control conditions.

Passenger Car Equivalency

It can be defined as the equivalent value which is representative of several passenger cars that would use the same amount of capacity of a given highway as heavy vehicles under the prevailing conditions.

Density

Density is defined as an average number of vehicles occupying a given length of a roadway at a particular instant. It is expressed as a vehicle per kilometer.

Density is an important parameter for uninterrupted flow facilities since it characterizes the quality of traffic operations of a given facility, also describing the proximity between vehicles and reflecting the freedom to maneuver within the traffic stream.

Following density parameters have great importance in defining a relationship between traffic characteristics:

i. **Optimum density** can be defined as a density that corresponds to the maximum flow.

ii. **Jam density** is defined as the maximum density that may be found on any road. This density is obtainable for stopped vehicles on a given road, that is, when the flow rate is zero.

Microscopic Analysis

In the microscopic analysis of traffic stream, the following terms are used to characterize and study the state of the traffic flow.

Microscopic speed also called spot speed is defined as a rate of motion at which an individual vehicle travels a certain distance over time. It can be computed by the following formula.

$$\mu_i = \frac{dx}{dt}$$

Where,

μ_i= Microscopic speed of vehicle i

dx = Short distance travelled

dt = Short time interval

Time mean speed:

It is defined as the arithmetic mean of the speeds of vehicles passing a point on a highway during an interval of time. The time-mean speed is computed by the following formula.

$$\mu_t = \frac{1}{n}\sum \mu_i$$

Where,

μ_t = time mean speed (km/h)

μ_i= speed of the ith vehicle (km/h)

Time Headway

Time headway is defined as a difference between the time when the front of a vehicle arrives at a point on a highway and the time when the front of the next following vehicle arrives at the same point. It is expressed in seconds. (Roess, Prassas, et al. 2004)

Distance Headway

Distance headway can be defined as the longitudinal distance between the front bumper of the lead vehicle and the front bumper of the following vehicle. This distance includes the length of the lead vehicle and the gap distance between the lead and the following vehicles. Space headway is expressed in meters.

Speed flow relationships have been established for different free-flow speeds on urban freeways. However, there have been few research efforts relating real-time traffic flow parameters and weather conditions for different levels of heavy vehicle traffic (Twagirimana 2013).

The above-mentioned parameters are important to assess the macroscopic and microscopic properties of highways and motorways. Speed flow density relationships are important to check the level of service and capacities of highways and freeways.

Speed-flow relationships have been established for different free-flow speeds on urban freeways and highways. However, there have been few research efforts relating real-time traffic flow parameters and weather conditions for different levels of heavy vehicle traffic. This study aims at establishing relationships between speed, flow, and density relationships in freeway sections using Metro counters as a function of weather conditions.

2.2. Impacts of Weather on Traffic Flow Characteristics of Urban Freeways in Istanbul(Akin, Sisiopiku, et al. 2011)

In this study, speed-flow relationships have been conducted for different free-flow speeds on urban freeways. Relationships between speed and volume have been established in freeway sections using Remote Traffic Microwave Sensor (RTMS) data from two highway corridors in Istanbul metropolitan area as a function of weather conditions.

Empirical relationships between traffic speed and volume are analyzed by weather conditions (clear, rain, fog/mist/haze, or snow), and surface conditions (dry, wet, or icy). The findings from the analysis show that rain reduced the average vehicular speeds by 8 to 12% and the capacity by 7-8%. Moreover, wet surface conditions resulted in a reduction of average speeds by 6 to 7%. (Rakha, Farzaneh, et al. 2007)

This study used weather, surface condition data, and detector data captured by RTMS in 2009 along two main highway corridors to develop relationships among traffic flow parameters i.e. speed, density, volume, etc. Moreover, these include road classification (6 or 8-lane freeway sections with 90 or 120 km/h speed limits respectively).

The findings from this study were compared with the HCM 2000 values and recommendations were offered for future potential improvements.

Using data from both corridors, a linear regression model was fitted to relate the speed to large and small vehicle volumes, density, and weather parameters such as weather temperature and surface temperature as follows

$$\log_{10}(V) = 0.486 + 0.087 \cdot \log_{10}(LV) + 0.769 \cdot \log_{10}(SV) - 0.925 \cdot \log_{10}(K) + 0.026 \cdot \log_{10}(WT) + 0.026 \cdot \log_{10}(ST)$$

V: Speed in kmph,

LV: Large vehicle volume in vph,

SV: Small vehicle volume in vph,

K: Density in vpkm,

WT: Weather temperature in degrees of Celcius,

ST: Surface temperature in degrees of Celcius,

The model yielded an $R2$= 0.895 (adjusted; F=16008.150, p=0.000<0.01) and all the independent variables are statistically significant at 0.01 level (all p<0.01).(Lamm, Choueiri, et al. 1990)

The results show that rain reduced the average speed (kmph) by 12 and 8% in the 1st and 2nd corridors, respectively. This is a speed reduction of about 7 to 8 km/h. Light snow resulted in 65-66% less traffic volume which, in turn, led to a speed increase by 4 and 5%. Fog, mist, or haze did not have significant impacts on the average speeds.

Differences in all three flow measures concerning various weather conditions were statistically significant at the 0.05 level

In the highway capacity manual (HCM 2000) “base conditions assume good weather, good pavement conditions, users familiar with the facility, and no impediments to traffic flow”. Similarly, the HCM 2000 specifies that “the base conditions under which the full capacity of a basic freeway segment is achieved are good weather, good visibility, and no incidents or accidents” (HCM. 2000). The HCM 2000 suggests that free-flow speed (FFS) is reduced by 10 km/h in light rain and by 19 km/h in heavy rain. The capacity reduction in wet and rainy conditions is not specified. In this study, capacity reduction due to rainy conditions accounted for 7 to 8% for the two study highway sections and observed speed reductions due to rain ranged from 8-12% (or 7-8 km/h)(Manual 2000)

The following conclusions were reached by the results of the study:

1. The relationships among flow parameters (V-K-Q) as observed from the analysis of empirical data at the study sites are in general agreement with the ones documented in the literature.
2. Inclement weather appeared to have an impact on speeds and flow rates on both roadway sections studied. Rain reduced the average vehicular speed by 8 to 12% and light snow resulted in 65 to 66% traffic volume reduction. Rainy conditions also led to a 7-8% capacity reduction.
3. The impact of light snow, fog, or haze on average speed as well as FFS on both bridge sections was minimal.
4. Wet surface conditions resulted in a reduction of average speeds by 6 to 7%.

2.3. A Traffic Congestion Assessment Method for Urban Road Networks Based On Speed Performance Index (He, Yan et al. 2016)

This study has been conducted to examine traffic congestion in urban road networks. Fort his speed performance index (SPI) was taken on to evaluate the conditions of the existing road’s congestion, then road segment & network congestion indexes were introduced that compute the congestion levels of the urban road network. For this congestion analysis data on the urban Beijing expressway (consisting of 5 loops & 15 urban connecting lines) was collected from Jan to Nov 2012.

Based on these analyses the proposed congestion indexes of traffic congestion can well assess the conditions of urban road networks. Moreover, this assessment study provides an accurate and clear understanding of the traffic network's operation status to traffic control & management agencies.

In this study vehicle speed is an important indicator to evaluate the traffic state of the road.

For this Beijing, Traffic Management Bureau has presented the speed performance index as the evaluation measure/indicator for the traffic state of the urban road network.

The speed performance index is the ratio of the average speed of a vehicle over the maximum permissible speed.

$$R_V = \frac{V}{V_{max}} * 100$$

Where,

Rv: denotes the speed performance index;

V: denotes the average travel speed, km/h;

Vmax: denotes the maximum permissible road speed, km/h.

Following are the evaluation criteria of (SPI) on the expressway.

- (0-25) Heavy Congestion which means average speed is low and road traffic state poor.
- (25-50) Mild Congestion which means average speed is lower and road traffic state is a bit weak.
- (50-75) Smooth which means the average speed is higher and road traffic state is better.
- (75-100) Very smooth which means the average speed is high and road traffic state is very good.

To calculate the degree of road segment congestion, this study picks up the average road segment state and the duration of non-congestion state in the observation period to define the road segment congestion index. The non-congestion state includes two traffic states, one is smooth, and the other is very smooth, namely the speed performance index is larger than 50 (km/h). The value of the road segment congestion index *Ri* lies between 0 and 1, the smaller the value of *Ri*, which means the more congestion of the road segment. (Zhang and Ren 2009)

$$R_V = \frac{R_v}{100} * R_{NC}$$

Where, $$RNC = T_{NC}/T_t$$

R_i indicates the road segment congestion index.

R_v indicates the average speed performance index.

R_{NC} indicates the proportion of non-congestion states.

t_{NC} indicates the duration of the non-congestion state, minute.

T_t indicates the length of the observation period, minute.

Based on a large number of data, this study analyzes the characteristics of the Beijing expressway network. The following figure represents the frequency corresponding to the different speed performances, and line segments represent the cumulative probability density of speed performance. The result shows that the proportion of speed performance which over 90 is more than 50%, and 78.8% of the data in which the speed performance index is larger than 75. Before the value of 75, the cumulative probability density function of Speed performance increases slowly, whereas it increases rapidly after the value of 75. (Quiroga 2000)

In this study speed performance index was selected as the road network state evaluation indicator, and divided the traffic state into four categories i.e. heavy congestion, mild congestion, smooth, and very smooth. Based on the traffic state, the study proposed the road network congestion index. With this index degree of congestion, the road segment is determined. (Shunping, Hongqin, et al. 2011)

The finding from this study shows overall, 78.8% of the Beijing expressway network is very smooth all year round. The morning peak has the congestion delay situation in the way that road network congestion continues till 10:00. According to road segment congestion assessment and road network congestion assessment, the Beijing expressway network during the morning peak is much better than during the evening peak, and the season is also an important factor for urban road network congestion. The Beijing expressway network congestion has a seasonal pattern that the road congestion concentrates mainly on the Second and Third Ring Road throughout the year, but spreads to the Fourth and Fifth

Ring Road in autumn and winter, which can be seen from the road segment congestion assessment. The road network congestion is the worst in autumn, followed by summer and it is more severer on weekdays than on weekends.

2.4. Research on Road Traffic Congestion Index Based on Comprehensive Parameters: Taking Dalian City as an Example(Wang, Guo, et al. 2018)

This study was carried out for the state of traffic flow. The traffic congestion index measures the travel density of major urban roads and also reflects the state of traffic flow. The traffic congestion index can be used to evaluate the operation status of roads, plan and organize road traffic for traffic managers, and to make reasonable decisions for commuters to travel.

Traffic congestion parameters include average travel speed, road saturation degree travel efficiency, low-speed proportion, total delay, average stopping number, and total length. Traffic congestion can be divided into road congestion and intersection congestion but in this study, our main research is focused on road congestion. Four main indicators are as follows

According to road traffic congestion, the average speed of vehicles can be divided into five levels. The larger the speed level is the more serious road congestion is. The road saturation degree is the ratio of the survey traffic volume to road capacity. It can reflect the relationship between transportation demand and transportation supply, also indicates the service level of road

$$\boldsymbol{S = V/C}$$

Where,

S is the road saturation degree.

V is the field traffic volume on the road (veh/h)

C is the field capacity on the road (veh/h).

$$\boldsymbol{R = T_D/T_T}$$

Where,

R is the low-speed proportion, $\mathbf{T_D}$ is the travel time at a lower speed, and $\mathbf{T_T}$ is the total travel time. The low-speed proportion varies from 0 to 1. When R=0 the road traffic operation is in a state of free flow and there is no delay on the contrary when R approaches 1 it indicates the worst state and low speed occupies most of the time. (ZHANG, HUANG, et al. 2008)

In this study, Shugang Road data had been collected and used. Shugang Road is an urban expressway consisting of four lanes in Dalian city China connecting Dalian Port and Xinan road in China. There is no traffic signal lamp on the 7.5-km-long road section, so stable vehicle flow can be observed. By surveying a section of Shugang Road from 7:00 to 19:00 two cameras were used to record license plate numbers of the entry lane in two road cross-sections. The start time and end time can be recorded for the sections. So, the travel time of vehicles, the flow rate, and the speed can be calculated.

In this study, three calculation methods for the road congestion index were proposed. Based on fuzzy mathematics theory, some membership functions of evaluation indexes were designed. Their calculation results were compared mutually. It had been concluded that using saturation calculations by the corresponding service level of the traffic congestion index does not well reflect the traffic situation. Using comprehensive parameters can calculate the congestion index of the third method. Both of them are roughly similar and in line with the actual traffic phenomenon.(Xinmiao and Communications 2007)

In this study, the situation of urban road traffic congestion in Dalian city is analyzed, and the characteristics of traffic congestion in Dalian are revealed. Through the analysis of several kinds of traffic state evaluation index based on fuzzy mathematics, the membership degree function of traffic congestion index is proposed using analysis and evaluation of the single and composite index, at the same time compared with each method. C_1 congestion index based on travel speed, C_2 is congestion index of saturation degree and C_3 is traffic congestion index based on fuzzy mathematics. The three methods are calculated based on the field data of the Shugang Road in Dalian City. According to the results, it can be seen that the crowding phenomenon existed, congestion was serious during the morning rush hour, the traffic flow running speed was slow, and it took travelers much delay.

2.5. Spot Speed Survey & Analysis – A Case Study on Jalandhar-Ludhiana Road, National Highway-1, India(Naidu 2018)

This study aimed at measuring the speed characteristics of pre-established areas under natural conditions. Spot speed studies were carried out to assess the movement of rates of the vehicle at a specific region on the roadway.

In this study of spot speed analysis survey has been carried out to determine the speed characteristics parameters which include average speed, variance, standard deviation, median speed, modal speed, and percentile speed of various classes of vehicles to find out and analyzed the accidental data of the region. In this study, a safe speed limit and reason of happening accidents on the national highway have been found which provide road safety measures on the national highway of India. (Singh, Zaman, et al. 2011)

For this analysis comparable method of reasoning has been adopted which includes two ways to deal with the vehicle speed at spot areas. One is a singular vehicle choice strategy and the other one is all inspecting vehicle techniques. The data is collected because of arbitrarily inspecting singular vehicle speed over a short time. The region selected for this region is Chaheru to Ludhiana road. Chaheru is a town in Punjab & Ludhiana is the biggest city in north Delhi.

An analysis of spot speed data frequency distribution & cumulative frequency curve of cars buses and trucks is prepared to show the effect of speed on various classes of vehicles.

For Buses

1. Upper Speed = 85th Percentile Speed= 80 Kmph
2. Design Speed = 98thPercentile Speed= 85 Kmph
3. Median Speed = 50th Percentile Speed=70 Kmph
4. Lower Speed =15th Percentile speed = 60 Kmph

Similarly, frequency distribution and cumulative frequency distribution curves will be plotted for cars and trucks to show the effect of speed. (Fitzpatrick 2003)

It has been concluded from the above analysis that speed is one of the major & most important parts that should be considered in the layout of the geometric design of the road. The result shows the effects of speed on the geometric design of roads and differences in road geometrical framework would significantly impact the speed of the vehicles. The vehicles found in the lower 15 percent are considered to be traveling unreasonably direct and those seen over the 85th percentile are thought to outperform a secured and reasonable speed. 85th percentile could be a govern in setting up the speed limit as this speed is seen as protected and reasonable under conditions states of the road.

2.6. Spot Speed Study of Vehicular Traffic on Major Highways in Makurdi Town(Adeke and Atoo 2018)

This study was carried out for spot speeds of vehicular traffic on four highways namely Otukpo, Gboko, Lafia, and Iorchia in Makurdi town Nigeria. Manual traffic count was carried out to make sure traffic volume per hour per lane on each lane of the selected sampled road segments. Spot speeds of vehicles traveling in both directions of the highways were randomly measured using a Brushel speed gun at different locations for 12 hours (6:00 am – 6:00 pm) daily. Data analysis using statistical techniques revealed that vehicles traveled at an average speed of 51 km/h, 53 km/h, 63 km/h, and 50 km/h on four highways respectively.

Therefore, a speed limit ranging between 50-55km/h was proposed for highways in Makurdi town for safe travel. The study also revealed that highways in Makurdi town operated at a design speed below design specifications of 80–100 km/h required by the Nigeria Highway Design Manual except for the Lafia road which has a design speed of 80km/h. Speed calming devices, high traffic volume, geometrical layout or highway capacity, and possibly pavement condition were identified as factors affecting the speed of vehicles on highways. Road widening to improve capacity, traffic volume to satisfy design speed, and the use of warning signs for the speed limit to assure travel safety were recommended. The table shows traffic volume characteristics & statistical parameters of highways. (Derry, Afukaar, et al. 2007)

The study shows that the Lafia road has the highest average spot speed of 63.64 km/h, followed by Gboko, Otukpoand Iorchia roads having 52.88 km/h, 50.68 km/h, and 49.89 km/h respectively. The high average vehicular traffic spot speed on Lafia road is attributed to its relatively low traffic volume and possibly better pavement condition as observed during the fieldwork. The route has a relatively high standard deviation of 15 km/h which shows the significant spread of data points over the range of data obtained. Its relatively high percentage composition of heavy trucks also has a significant impact on travel speed characteristics on the highway. The spread of data points on the other highways is within a relatively closer range (about 6 – 8 km/h) with an average spot speed measuring between 50 – 53 km/h, these highways majorly serve township travels. In addition, the Gboko road is characterized by traffic calming bumps sited at intervals of approximately 200 meters apart covering a total length of 3 km which reduces the vehicle's travel speed significantly for safety reasons.

This study also revealed that approximately 50% of vehicles in Makurdi town travel at a pace ranging between 46 – 57 km/h, except the Lafia road where 32% of the vehicles travel within the range of travel pace. This variation is attributed to the fact that speed characteristics of vehicles traveling on Lafia road are described by a multimodal pattern caused by a homogenous traffic stream having different travel speeds or shockwave flow trends since it serves both intercity travel demand and interstate traffic flow which consists majorly trucks conveying agricultural produce (such as timber, oranges, yams), cement and crude petroleum produce to the northern part of Nigeria. (Igene and Ogirigbo)

Based on the results of this study, the following conclusions were made. The average speed of vehicular traffic on highways in Makurdi town lies between 50 – 53 km/h except for the Lafia road which recorded an average spot speed of 64 km/h approximately. This discrepancy was attributed to its homogenous traffic composition with higher percentage composition of heavy vehicles and very fast-moving vehicles. The modal speed of vehicular traffic on Makurdi highways falls within the range of 46 – 50 km/h except for the Lafia road which recorded a modal speed ranging between 56 – 60 km/h due to its peculiar characteristics. Though the national speed limit of 50 km/h as set down by the Federal Road Safety Commission for Nigeria towns and cities was below the 85th percentile vehicular speed on highways in Makurdi town. A general speed limit within the range of 50 - 55 km/h is reasonable and guarantees the safety of motorists and pedestrians traveling on highways in Makurdi town.

CHAPTER 3

3. METHODOLOGY

3.1. BACKGROUND

A systematic methodology is developed to achieve the research objectives. Figure 3.1 shows the sequential tasks for this research.

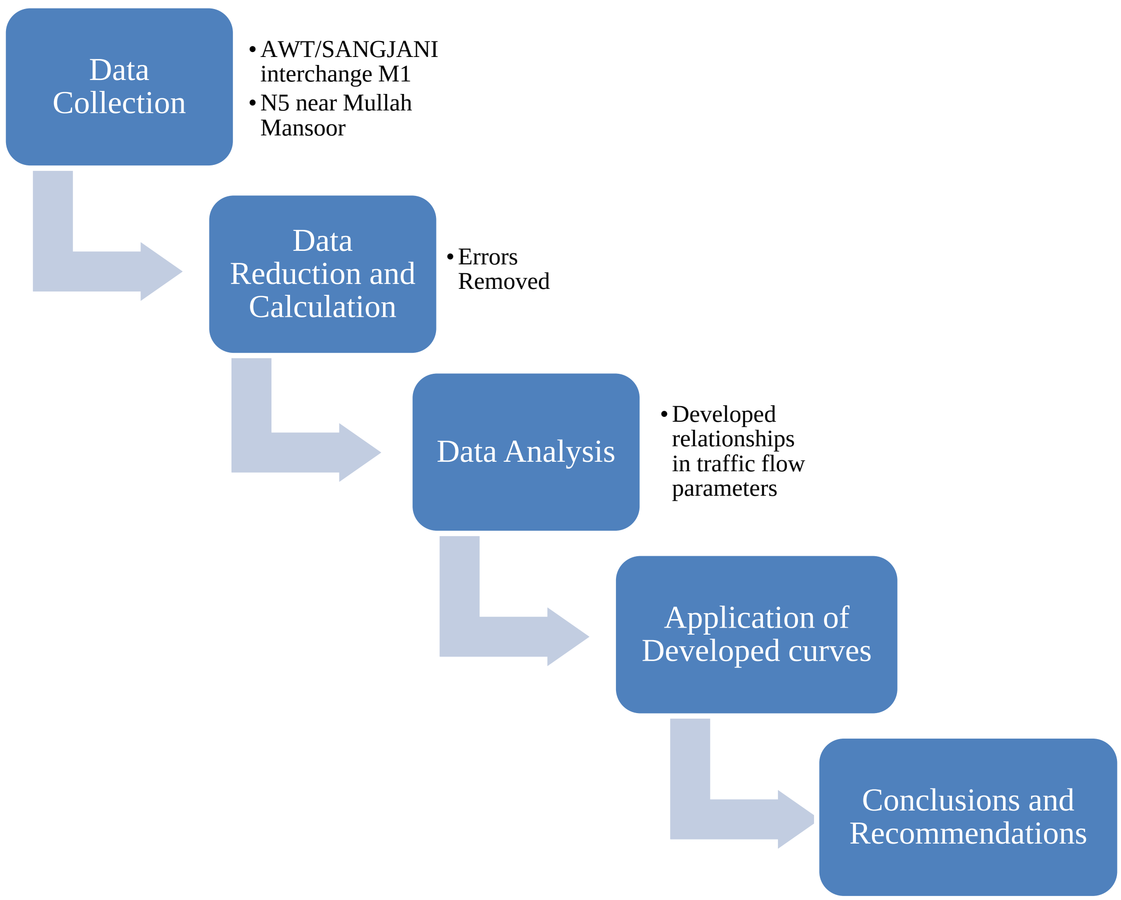


Figure 3-1 Research Methodology

3.2. Site Selection

To establish acceptable and accurate speed relationships and to meet the objectives of the study, certain considerations are deliberated while selecting the study. The main consideration was the availability of all conditions of traffic namely free-flow, moderate and heavy traffic conditions. This criterion was deemed very important for site selection, to obtain traffic data that shall produce speed relationships pertained to cover a full range of traffic conditions, varying from free-flow to congestion sequence. In addition to the above conditions, it was also necessary to determine a suitable time and enough time for the collection of data, with the purpose to provide more reliable results from which conclusions drawn can apply to other roads with similar conditions. To this end, numerous study sites were proposed but only two of the proposed sites were found to satisfy these conditions one on N5 near Mullah Mansoor the second site was on M1 near AWT/Sangjani interchange, Data of four months were collected.

According to many studies, several other factors are likely to influence driver behavior on multilane highways and motorways. These factors must be taken into account during the selection of the study sections to reflect the true traffic behavior under prevailing conditions. These other factors can be classified as follows:

- **Road geometric conditions**

These conditions include various factors such as the lane widths, shoulder width, and lateral clearance, design speed, speed limit, lane and shoulder conditions, horizontal and vertical alignments, and adjacent land use.

- **Traffic conditions**

These include factors like traffic composition (mix), directional distribution, parking, and the presence of pedestrians.

- **Environmental conditions**

These include factors like weather conditions, season, visibility, light effect, and so on.

On M1 near Sangjani/AWT interchange, Metro Counter was used to collect data.

Figure 3-2 Research site on M1

Several housing schemes are around this location (D18, D17, AWT, WAPDA Town, etc.). So this location data is a good sample to represent the traffic condition on M1.

On N5- GT Road, a Location near Mullah Mansoor was selected that lies in Attock Region.

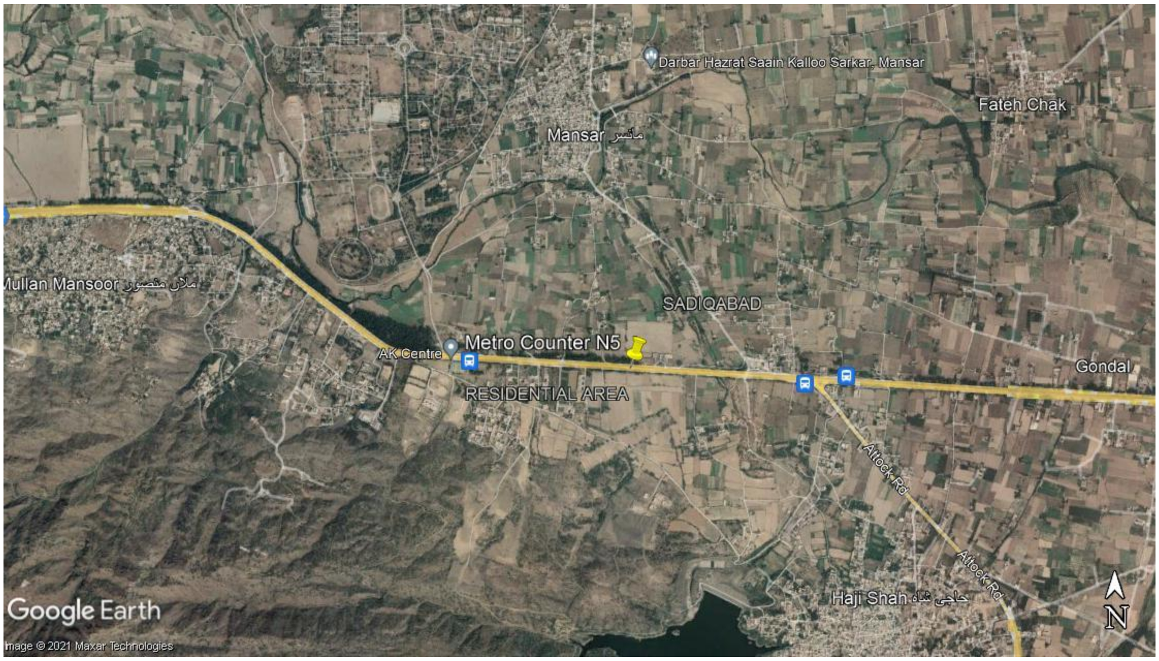


Figure 3-3 Research site on N5

3.3. Data Required

Average spot speeds of individual vehicles and Vehicle categories were collected on the Field using the Metro counter. Data for four-month were collected for a complete representation of the entire year. Further, A Reconnaissance Survey was conducted on-site to record any further changes or obstructions.

Details of data collection are described below;

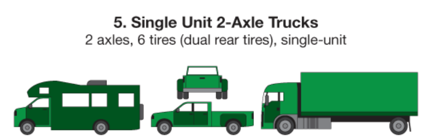
3.2.1. Vehicle Specification

Classification of the vehicles plays an important part in traffic modeling depending on their analysis requirements.

Motorways are access-controlled entities while highways are easily accessible so the types of vehicles using these facilities vary.

Tables 3-1 and 3-2s show the type of vehicles (i.e., Passenger Car, 2 Axle Truck) and their dimensions that are the part of Heterogeneous Traffic system in Pakistan and how they vary from motorway to national highway. The vehicle's dimension is the size of the vehicle which contributes to the causes of congestion. Vehicle dimensions are determined to calculate the space occupied by each vehicle when they flow with the traffic or are static in areas of congestion. Vehicular dimensions were taken as standard dimensions provided by the companies of each vehicle. Only those vehicles are taken that run on the route of interest. (Design and Guide 1997)

Table 3-1 Vehicle Configuration on M1 (Islamabad- Peshawar Motorway)

<table>
<tr><th>Sr. No</th><th>Vehicle Type</th><th>Dimension:
Length x Width x Height
(feet)</th><th>Images</th></tr>
<tr><td>1</td><td>Car</td><td>15.16' x 5.82' x 4.84'</td><td></td></tr>
<tr><td>2</td><td>Hi ace Coach</td><td>15.88' x 6.17' x 6.91'</td><td></td></tr>
<tr><td>3</td><td>Bus</td><td>39.37’x 8.20' x 12.14'</td><td></td></tr>
<tr><td>4</td><td>2 Axle Truck</td><td>30.0’x8.0’x11.0-13.5’</td><td>
</td></tr>
<tr><td>5</td><td>3 Axle Truck</td><td>39.5’x8.0’x11.0-13.5’</td><td>
</td></tr>
</table>

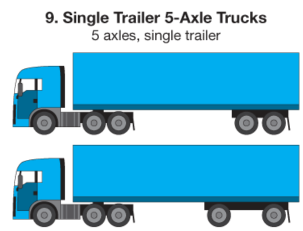
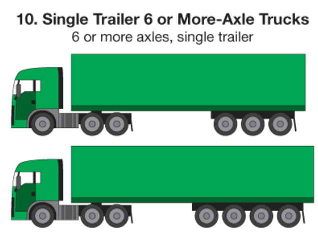
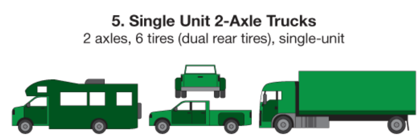
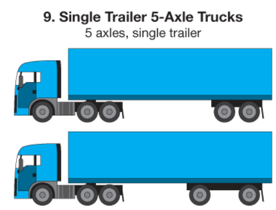
Sr. No	Vehicle Type	Dimension: Length x Width x Height (feet)	Images
6	4 Axle Truck	45’x8.0’x45’	
7	5 Axle Truck	69’x8.5’x13.5’	
8	6 Axle Truck	73.5’x8.5’x13.5’	

Table 3-2 Vehicle Configuration on N5 (GT Road)

Sr. No	Vehicle Type	Dimension: Length x Width x Height (feet)	Images
1	Motorbike	6.63' x 2.58' x 3.62'	
2	Car	15.16' x 5.82' x 4.84'	

Sr. No	Vehicle Type	Dimension: Length x Width x Height (feet)	Images
3	Hi ace Coach	15.88' x 6.17' x 6.91'	
4	Bus	39.37'x 8.20' x 12.14'	
5	Hi ace Coach	15.88' x 6.17' x 6.91'	
6	2 Axle Truck	30.0’x8.0’x11.0-13.5’	
7	3 Axle Truck	39.5’x8.0’x11.0-13.5’	
8	4 Axle Truck	45’x8.0’x45’	

Sr. No	Vehicle Type	Dimension: Length x Width x Height (feet)	Images
9	5 Axle Truck	69’x8.5’x13.5’	
10	6 Axle Truck	73.5’x8.5’x13.5’	

3.2.2. Spot Speed of Vehicles using Metro Counters and Classifier:

The Spot Speed of each vehicle was collected using the metro counter. Metro counter gives the detail of each vehicle crossing the point with its axle configuration and based on load. North bound and south bound direction traffic speed was assessed. MetroCount’s inductive loop system (MC5810) is a simple and affordable setup that is connected to loops already embedded on the road. In Metro Counter Road Tubes were installed for vehicle classification survey. RoadPod® VL 5810 offers a set of diagnostic tools bundled in the MTE software and used for long-term data collection. This is designed for a count, recording just binned volumes from up to 4 lanes. For more detailed data, the MC5810 also provides accurate information on volume, speed, and class, covering up to 2 lanes of traffic. (Goyal, Sharma, et al. 2016)

Figure 3-4. Metro Counter

Table 3-3. Traffic Data collection Locations

List of Traffic Survey Locations		
	Traffic Directions	**Description**
M-1 (Islamabad Peshawar Motorway)	NB Lane 1	Towards Peshawar
	NB Lane 2	
	SB Lane 1	Towards Islamabad
	SB Lane 2	
N-5 (GT Road)	NB Lane 1	Towards Peshawar
	NB Lane 2	
	SB Lane 1	Towards Islamabad
	SB Lane 2	

Figure 3-5 Data Collection site on N-1 with directions

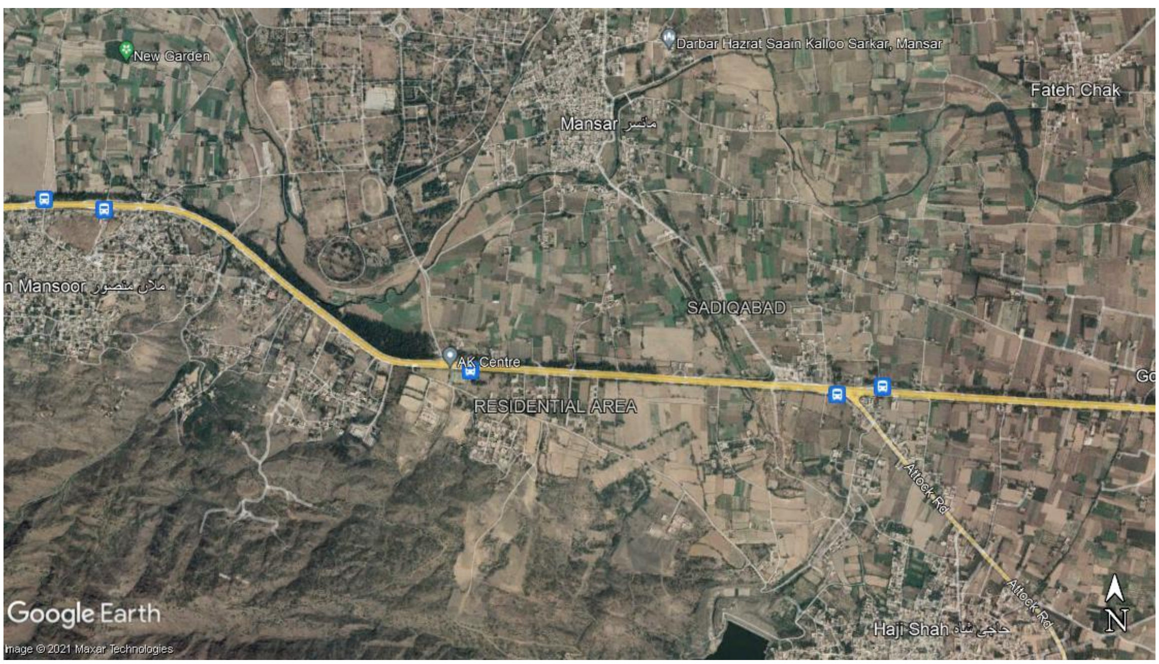


Figure 3-6. Data Collection site on N-5 with direction

Vehicle configuration data with spot speeds are mentioned below in the Tables.

Table 3-4. Traffic Survey on M-1

DATE	TIME	VEHICLE TYPE	SPEED
11/24/2019	8:25:14 AM	Car	96.59
11/24/2019	8:25:17 AM	Car	114.86
11/24/2019	8:25:23 AM	Car	110.56
11/24/2019	8:25:25 AM	Car	98.34
11/24/2019	8:25:33 AM	Car	106.92
11/24/2019	8:25:46 AM	Car	114.80
11/24/2019	8:26:38 AM	Car	116.44
11/24/2019	8:26:40 AM	Car	115.51
11/24/2019	8:28:10 AM	Car	93.84
11/24/2019	8:28:11 AM	Car	91.86
11/24/2019	8:28:23 AM	Car	111.41
11/24/2019	8:28:25 AM	Car	108.59
11/24/2019	8:28:26 AM	Car	117.30
11/24/2019	8:28:53 AM	Car	108.79
11/24/2019	8:28:58 AM	Car	125.90
11/24/2019	8:29:26 AM	Car	108.56
11/24/2019	8:29:43 AM	Car	124.78
11/24/2019	8:29:49 AM	Car	108.21
11/24/2019	8:30:20 AM	Car	141.56
11/24/2019	8:30:52 AM	Car	114.64
11/24/2019	8:30:55 AM	Car	121.65

Northbound_Lane-1 | Northbound_Lanes-2 | Southbound_Lane-1 | Southbound_Lanes-2 | Southbound_Lanes

Table 3-5. Traffic Survey on N-5

DATE	TIME	VEHICLE TYPE	SPEED
11/24/2019	3:34:08 PM	Car	51.68
11/24/2019	3:34:28 PM	Car	47.69
11/24/2019	3:34:32 PM	Car	43.40
11/24/2019	3:34:34 PM	Motorcycle	53.00
11/24/2019	3:35:06 PM	Car	43.56
11/24/2019	3:35:27 PM	3-Axle Truck	38.95
11/24/2019	3:35:49 PM	Motorcycle	48.69
11/24/2019	3:35:51 PM	Car	48.80
11/24/2019	3:36:15 PM	Car	64.84
11/24/2019	3:36:28 PM	Car	72.92
11/24/2019	3:36:38 PM	4-Axle Truck	40.72
11/24/2019	3:36:45 PM	Car	45.19
11/24/2019	3:37:07 PM	Motorcycle	23.96
11/24/2019	3:37:21 PM	4-Axle Truck	45.17
11/24/2019	3:37:45 PM	Motorcycle	44.24
11/24/2019	3:37:51 PM	Motorcycle	46.19
11/24/2019	3:37:57 PM	Motorcycle	64.07
11/24/2019	3:38:02 PM	Motorcycle	42.79
11/24/2019	3:38:10 PM	3-Axle Truck	44.80
11/24/2019	3:38:16 PM	2-Axle Truck	48.11
11/24/2019	3:38:18 PM	Car	43.15

Northbound_Lane-1 | Northbound_Lanes-2 | Southbound_Lane-1 | Southbound_Lanes-2

3.2.3. Rainfall Data:

From Climatic Data Processing Center, PMD rainfall was collected. PMD has two stations for weather data collection near New Islamabad International Airport and Near Attock which are very close to our research site. November 2019 to February 2020 rainfall data was collected. Rain fall data was used to assess the impact of change in pavement condition (Dry, Wet) on Traffic Speed. In the winter season generally Fog, Smog, and Rain impact the traffic speed, especially on motorways. Where the speed limit is up to 120kmph. Rain fall data collected from PMD is given below in Figure 3.7:

3.2.4. Maximum Permissible Speeds on Motorway and National Highway:

Motorways are controlled access facilities with very efficient mobility, comfort, and convenience. Maximum permissible speed on such facilities depends on certain factors like Geometric design, stopping sight distance, Vehicle characteristics, etc. For LTV (Light Transport Vehicle) maximum permissible speed on M1 is 120 kmph while for HTV (Heavy Transport Vehicle) speed limit is 110 kmph.

For National Highway N5 which passes between rural and urban areas both so its speed limit varies from location to location. In urban areas speed limit is generally up to 80kmph. But in this study area maximum permissible speed for LTV is 100kmph and for HTV speed limit is 80kmph.

Station : Islamabad-New Int. Airport

Year : 2020 Precipitation, Past 24 hrs.(mm)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	15.2	14.6	0.0	14.7	0.0	9.7	46.1	0.0	0.0	0.0
2	0.0	0.0	0.0	2.8	0.1	0.0	0.0	0.0	73.1	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	14.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	115.8	0.0	0.0	0.0
5	0.0	0.0	14.0	0.0	3.2	0.0	5.1	0.0	31.4	0.0	0.0	0.0
6	0.0	0.0	13.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	6.9	0.0	23.0	0.0	0.0	6.9	0.0	0.0	1.9	0.0	0.0	0.0
8	0.0	0.0	7.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
9	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
10	0.0	0.0	0.0	6.6	1.8	0.0	0.0	16.6	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7	0.0	0.0	0.0	0.0
12	0.0	0.0	28.4	0.0	15.6	0.0	1.2	5.7	0.0	0.0	0.0	7.8
13	14.2	0.0	5.2	0.0	0.0	0.1	1.0	21.5	0.0	0.0	0.0	0.0
14	55.0	0.0	0.0	0.0	0.0	0.0	0.0	56.8	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	1.2	36.3	0.0	0.0	0.0	0.1	0.0	13.1	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	22.1	0.0	0.0	0.0	23.9	0.0
17	0.0	0.0	0.0	0.1	0.0	0.0	0.0	11.6	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	24.9	0.0	0.0	0.2	32.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.8	0.0	0.0	0.0	0.0
20	0.0	7.0	0.0	0.0	0.0	1.4	0.0	13.3	0.0	0.0	0.7	0.0
21	0.7	7.4	3.1	0.0	0.0	0.0	1.5	0.9	0.0	0.0	0.0	0.0
22	1.1	0.0	0.0	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	18.4	0.0	0.0	14.8	0.0	0.0	0.0	0.0	1.0	0.0
25	0.0	0.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0
26	0.0	0.0	7.8	0.0	0.0	0.0	27.9	30.6	0.8	0.0	13.0	0.0
27	0.0	0.0	2.8	0.0	0.0	1.2	0.0	5.9	0.0	0.0	0.0	0.0
28	1.0	29.3	76.7	10.7	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.8
29	56.1	17.1	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0

Figure 3-7. Rainfall Data near New Islamabad International Airport.

Station : ATTOCK

Year : 2019 Precipitation, Past 24 hrs.(mm)

1	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0
2	----	----	----	----	----	----	----	----	0.0	0.0	2.0	0.0
3	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0
4	----	----	----	----	----	----	----	----	0.0	2.0	0.0	0.0
5	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0
6	----	----	----	----	----	----	----	----	0.2	0.0	12.4	0.0
7	----	----	----	----	----	----	----	----	7.0	0.0	0.0	0.0
8	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0
9	----	----	----	----	----	----	----	----	0.0	0.0	0.0	0.0

NOTE:

UTC=GMT: GREENWICH MEAN TIME, ----: DATA NOT AVAILABLE,

-Data should be acknowledged.

-Data should not be supplied to any other user within/outside Pakistan without prior permission of the office.

DATA REQUESTED BY:
Ms. Ayesha Shabbir, MS Student,
School of Civil & Environmental Engnr. (SCEE), -NUST, Islamabad

DATA PROCESSED AT:
Computerized Data Processing Center;
PAK. METEOROLOGICAL DEPTT.,
University Road Karachi-75270

(NAEEM AKHTAR)
Asstt. Meteorologist
For Director, CDPC

Figure 3-8. Rainfall Data near Attock

3.2.5. Capacity and LOS:

The level of service is an important parameter to assess the operational condition of the highway or freeway. To determine LOS various factors are used like volume to capacity ratio, average travel speed, maximum service flow rates, etc. Here in this research Volume to capacity ratio is calculated to assess the condition of the roadway section, then its relationship with speed is also checked. According to the latest version of the Highway Capacity Manual (HCM 1994), The capacity is estimated as the number of lanes multiplied by 2,200 vehicles per hour per lane four four-lane freeway segments, and 2,300 vehicles per hour per lane for segments with six or more lanes. The maximum ideal lane capacity for a multilane highway segment is 2,200 vehicles per hour. The Criteria to determine the LOS of the freeway and Multilane highways are given below in Table 3.6 and Table 3.7 respectively(Brilon and Practice 1994)

Table 3-6 Criteria to determine LOS on Motorways

Speed(mph)	70mph	65mph	60mph
LOS	Maximum v/c	Maximum v/c	Maximum v/c
A	0.318	0.295	0.272
B	0.509	0.473	0.436
C	0.747	0.704	0.655
D	0.916	0.887	0.829
E	1.00	1.00	1.00
F	Variable	Variable	Variable

Table 3-7 Criteria to determine LOS on Multilane Highways

Speed(mph)	60mph	55mph	50mph
LOS	Maximum v/c	Maximum v/c	Maximum v/c
A	0.33	0.31	0.3
B	0.55	0.52	0.5
C	0.75	0.72	0.7
D	0.89	0.86	0.84
E	1.00	1.00	1.00
F	Variable	Variable	Variable

3.3. Data Analysis

Date, Time (Hrs: Mins: Second), Vehicle Category, and Speed data were collected using Metro Counter. Data was arranged to perform analysis. All errors were removed. Data were organized by every hour. Entire data for four months from November 2019 to February 2020 was arranged as mentioned in the table below:

Table 3-8 Hourly Analysis of Data Set

Date	From	To
11/24/2019	8:00:00 AM	9:00:00 AM
11/24/2019	9:00:00 AM	10:00:00 AM
11/24/2019	10:00:00 AM	11:00:00 AM
11/24/2019	11:00:00 AM	12:00:00 PM
11/24/2019	12:00:00 PM	1:00:00 PM
11/24/2019	1:00:00 PM	2:00:00 PM
11/24/2019	2:00:00 PM	3:00:00 PM
11/24/2019	3:00:00 PM	4:00:00 PM
11/24/2019	4:00:00 PM	5:00:00 PM
11/24/2019	5:00:00 PM	6:00:00 PM
11/24/2019	6:00:00 PM	7:00:00 PM
11/24/2019	7:00:00 PM	8:00:00 PM
11/24/2019	8:00:00 PM	9:00:00 PM
11/24/2019	9:00:00 PM	10:00:00 PM
11/24/2019	10:00:00 PM	11:00:00 PM
11/24/2019	11:00:00 PM	12:00:00 AM
11/25/2019	12:00:00 AM	1:00:00 AM
11/25/2019	1:00:00 AM	2:00:00 AM
11/25/2019	2:00:00 AM	3:00:00 AM
11/25/2019	3:00:00 AM	4:00:00 AM
11/25/2019	4:00:00 AM	5:00:00 AM
11/25/2019	5:00:00 AM	6:00:00 AM
11/25/2019	6:00:00 AM	7:00:00 AM
11/25/2019	7:00:00 AM	8:00:00 AM
11/25/2019	8:00:00 AM	9:00:00 AM

Date	From	To
11/25/2019	9:00:00 AM	10:00:00 AM
11/25/2019	10:00:00 AM	11:00:00 AM
11/25/2019	11:00:00 AM	12:00:00 PM
11/25/2019	12:00:00 PM	1:00:00 PM
11/25/2019	1:00:00 PM	2:00:00 PM
11/25/2019	2:00:00 PM	3:00:00 PM
11/25/2019	3:00:00 PM	4:00:00 PM
11/25/2019	4:00:00 PM	5:00:00 PM

3.3.1. Vehicle Classes on M1 and N5:

Vehicles of the same categories were combined in the sets naming LTV, HTV, and PT for Motorway M1 while LTV, HTV, and Motorcycle for Highway N5. In LTV category Cars were included. Buses, 2 axle Trucks, 3 axle Trucks, 4 axle Trucks, 5 axle Trucks, and 6 axle Trucks were included in HTV. In PT, Buses and Hi ace were considered.

3.3.2. Average Speeds of Vehicles:

Average Speeds, for each class of vehicles, were using a pivot table. The tables below show Speeds for each vehicle class. Speed being the distance divided by travel time was determined for the vehicles running on the desired route. This section shows the speeds of different vehicles which were moving on the road. The tables below show the Average speed field data collected for various vehicle types (LTV, HTV, PT, and Motorcycle).

Table 3-9 M1 North Bound Lane 1

Vehicle Type	Average Speed(kmph)
Bus	109.54
Car	108.52
Hiace	120.55
Truck	85.87

In M1 North bound lane 2 average travel speeds are less than that of Lane 1. Table 3-10 shows the average travel speed in North bound lane 2 of M1.

Table 3-10 M1 North Bound Lane 2

Vehicle Type	**Average Speed(kmph)**
Bus	92.69
Car	88.06
Hiace	81.11
Truck	70.54

Table 3-11 and 3-12 shows the average travel speeds by each vehicle class in South Bound Lane 1 and South Bound Lane 2 of M1.

Table 3-11 M1 South Bound Lane 1

Vehicle Type	**Average Speed(kmph)**
Bus	101.9
Car	104.48
Hiace	117.8
Truck	91.65

Table 3-12 M1 South Bond Lane 2

Vehicle Type	Average Speed(kmph)
Bus	88.05
Car	87.53
Hiace	71.26
Truck	57.14

Figures 3-9 show the comparison between the average travel speed of different vehicle classes in both lanes of the north and south-bound Islamabad- Peshawar Motorway (M-1).

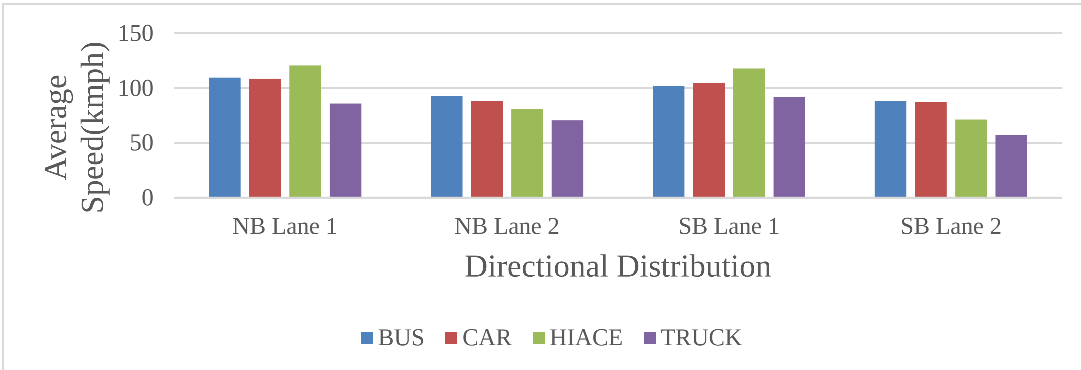


Figure 3-9 Average speeds Vehicles with directions (M1)

Similarly, the average vehicle speed on N5 by each vehicle configuration is given below in Tables 3-13, 3-14, 3-15, and 3-16;

Table 3-13 N-5 North Bond Lane 1

Vehicle Type	Average Speed(kmph)
Bus	56.75
Car	57.57
Hiace	50.87
Motorcycle	48.97
Truck	47.42

Table 3-14 N-5 North Bond Lane 2

Vehicle Type	**Average Speed(kmph)**
Bus	64.48
Car	75.91
Hiace	60.2
Motorcycle	63.84

Truck	52.48

Table 3-15 N5 South Bound Lane 1

Vehicle Type	Average Speed(kmph)
Bus	48
Car	52.87
Hiace	45.24
Motorcycle	44.2
Truck	40.18

Table 3-16 N-5 South Bound Lane 2

Vehicle Type	Average Speed(kmph)
Bus	57.93
Car	71.18
Hiace	68.09
Motorcycle	60.88
Truck	50.03

Figure 3-10 shows the average vehicle speed by each vehicle category according to directional distribution;

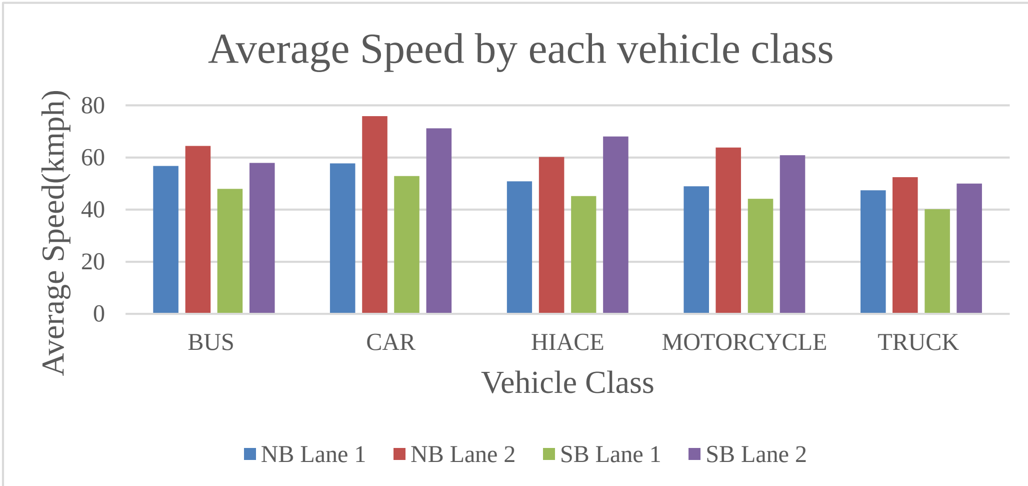


Figure 3-10 Average Speed vehicles with directions

3.3.3. Speed Performance Index (%):

To quantify the congestion level, numerous congestion measures have been developed considering different performance criteria. Criteria to measure congestion level following measures can be categorized into five categories: (i) speed, (ii) travel time, (iii) delay, (iv) level of services (LOS), and (v) congestion indices. Moreover, some measures are used by the DOT-FHWA to quantify the congestion level annually.

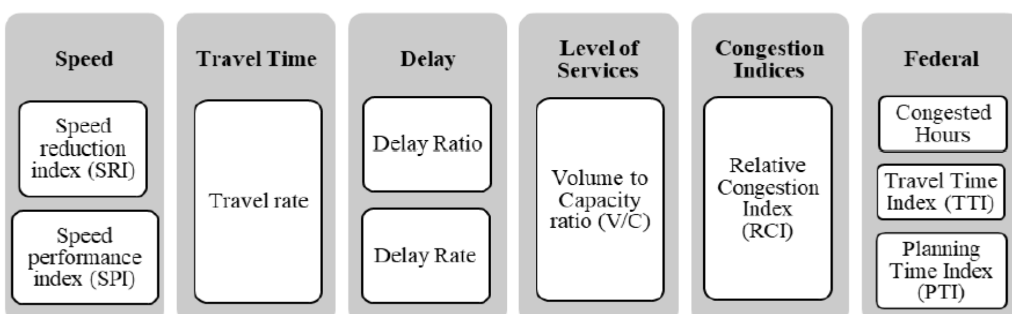


Figure 3-11 Congestion measures in different categories

SPI is developed to evaluate urban road traffic conditions. The value of SPI (ranging from 0 to 100) can be defined by the ratio between vehicle speed and the maximum permissible speed, as shown in Equation (2). To measure the traffic state on the road with this index, the traffic state level can be classified with three threshold values (25, 50, and 75). The classification criterion of the urban road traffic state is shown in Table 1.

$$SPI = \left({}^{Vavg}/_{Vmax} \right) * 100 \qquad (2)$$

Where; SPI denotes the speed performance index, $V_{avg.}$ Indicates the average travel speed, and V_{max} denotes the maximum permissible road speed. Table 3-17 categorizes traffic conditions based on speed performance index value.

Speed Performance Index	Traffic State Level	Description of Traffic State
(0,25)	Heavy congestion	Low average speed, poor road traffic state
(25,50)	Mild congestion	Lower average speed, road traffic state bit weak
(50,75)	Smooth	Higher the average speed, road traffic state better
(75,100)	Very smooth	High average speed, road traffic state good

Table 3-17 Speed Performance Index with traffic state

3.3.4. Congestion Index

The degree of road segment congestion, denoted by Ri, can be measured by using the normal Road segment state and the duration of the non-congestion state in the observation period. The non-congestion state includes the traffic state where the speed performance index (SPI) is higher than 50. The R_i index value ranges between 0 and 1, and the smaller the value of R_i, the less congested the road segment is. (He, Yan et al. 2016)

$$R_i = \frac{SPI(avg)}{100} * R_{NC}$$

By Calculating the Monthly congestion Index, the Traffic condition of the road throughout the month including weekdays and weekends can be assessed easily. Monthly and Weekly Roadway Congestion Index was calculated. Figures 3-12 show the congestion index value on M1 Northbound lane 1 in November which shows the maximum value of congestion on weekends.

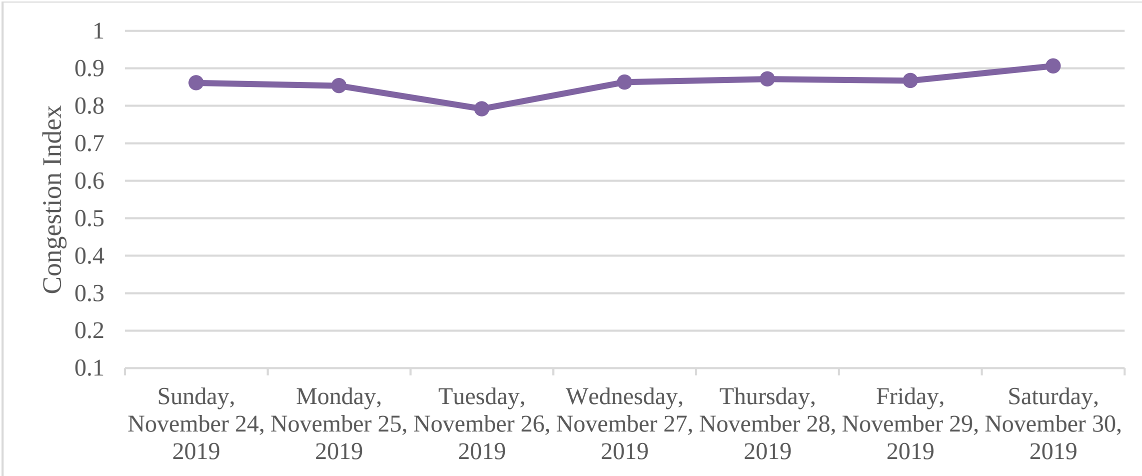


Figure 3-12 Roadway Congestion index M1 NB Lane 1 (November 2019)

Figure 3-13 shows the congestion index value in M1 northbound lane 1 in December.

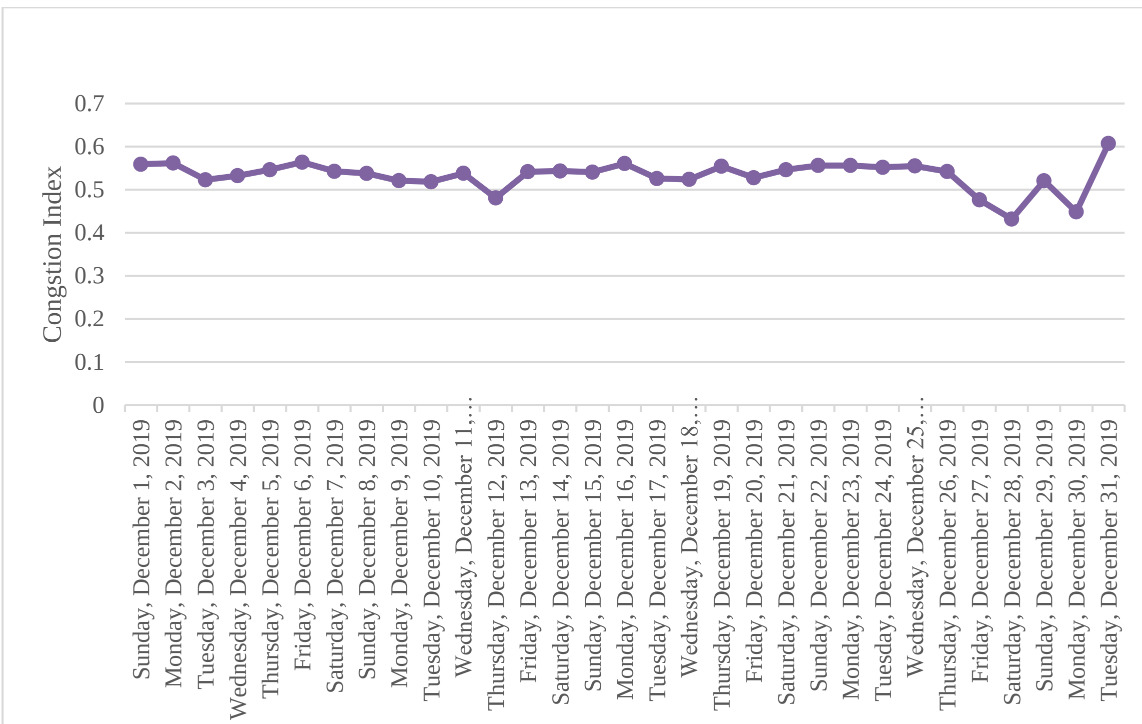


Figure 3-13 Roadway Congestion index M1 NB Lane 1 (December 2019)

Figures 3-14 show the congestion index value in January of northbound lane 1 which shows that the congestion index value peaks on weekends.

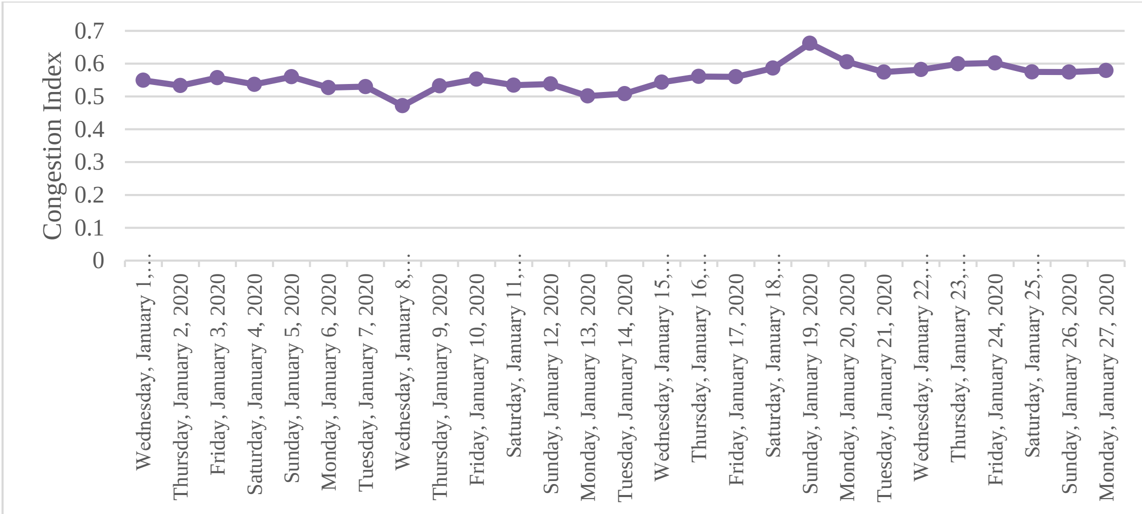


Figure 3-14 Roadway Congestion index M1 NB Lane 1 (January 2020)

Figures 3-15 show that the congestion index value is maximum on Saturday, February 1 which is 0.7.

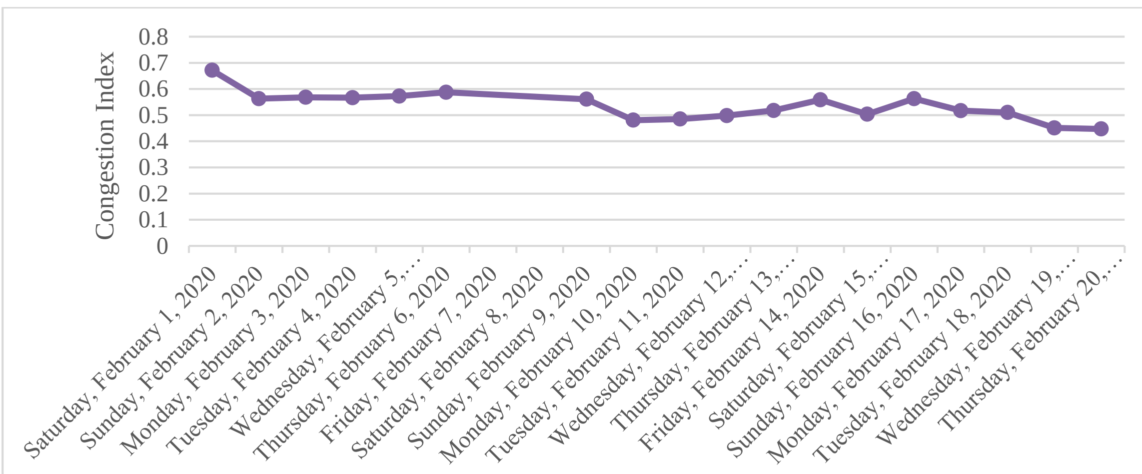


Figure 3-15 Roadway Congestion index M1 NB Lane 1 (February 2020)

Figures 3-16, 3-17, 3-18, and 3-19 show the congestion index value of M1 northbound lane 2 for November, December, January, and February. In November, the congestion index value is maximum in mid of week Wednesday. In December value of the congestion index is maximum on weekends. Whereas a very less value of congestion index is observed on 6 January, Monday, and on 14 February, Friday.

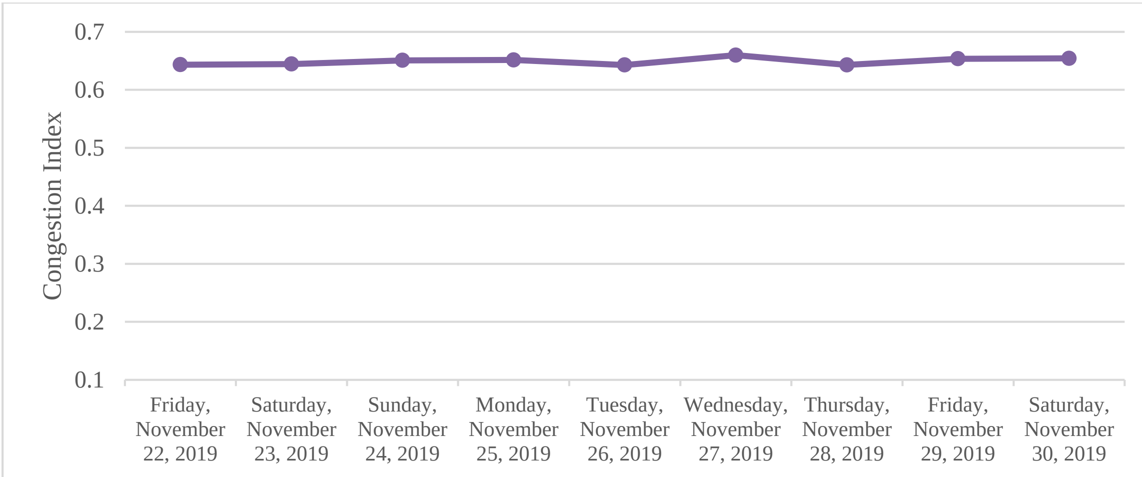


Figure 3-17 Roadway Congestion index M1 NB Lane 2 (November 2019)

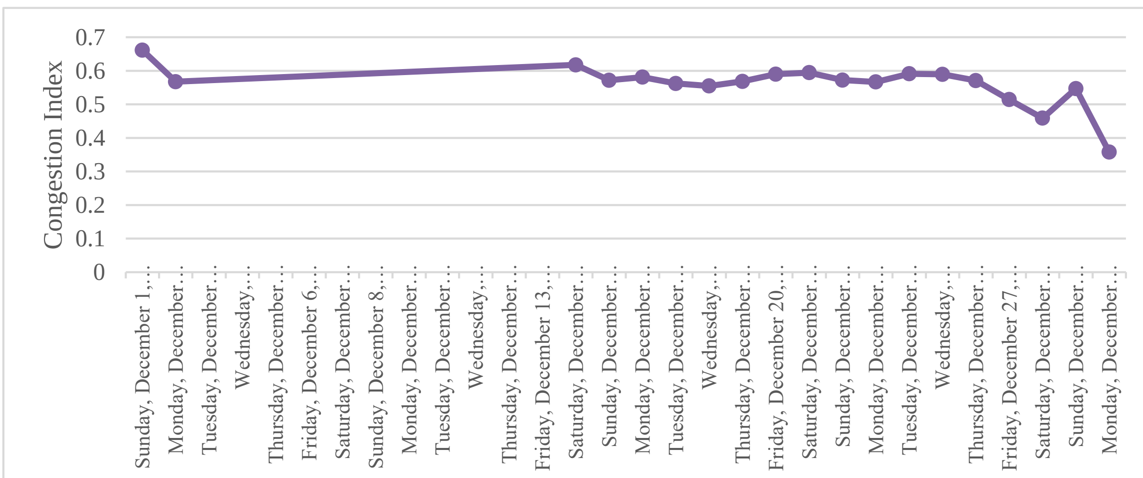


Figure 3-16 Roadway Congestion index M1 NB Lane 2 (December 2019)

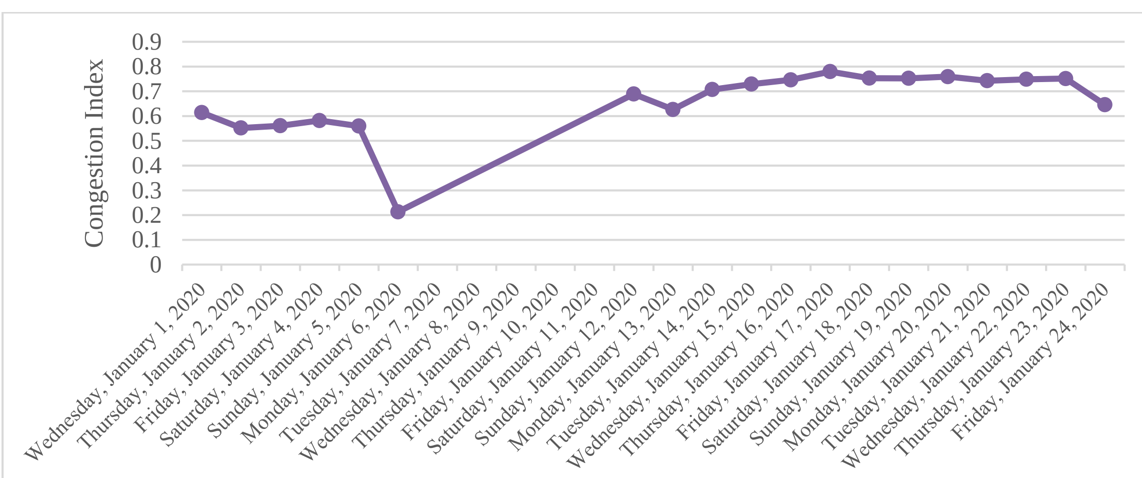


Figure 3-18 Roadway Congestion index M1 NB Lane 2 (January 2020)

Roadway congestion index value is almost the same for February except on February 15, when slightly less traffic volume is assessed. The decline in traffic volume is dependent on multiple factors like weather conditions etc.

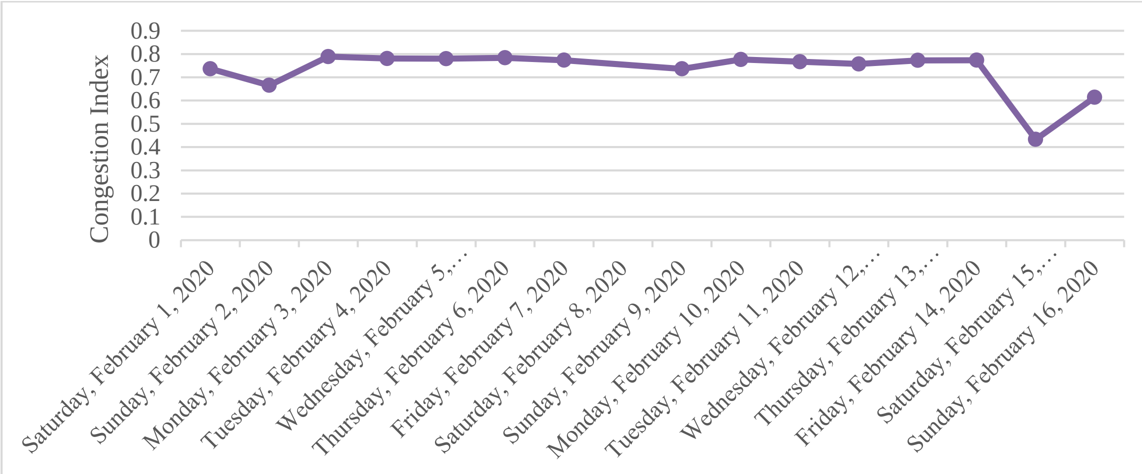


Figure 3-19 Roadway Congestion index M1 NB Lane 2 (February 2020)

Figures 3-20, 3-21, 3-22, and 3-23 show the congestion index value of M1 southbound lane 1 for November, December, January, and February. In November congestion index value is minimum on Tuesday. In December value of the congestion index is maximum on weekends. Whereas the maximum value of the congestion index is seen on Friday and Sunday in January and February respectively.

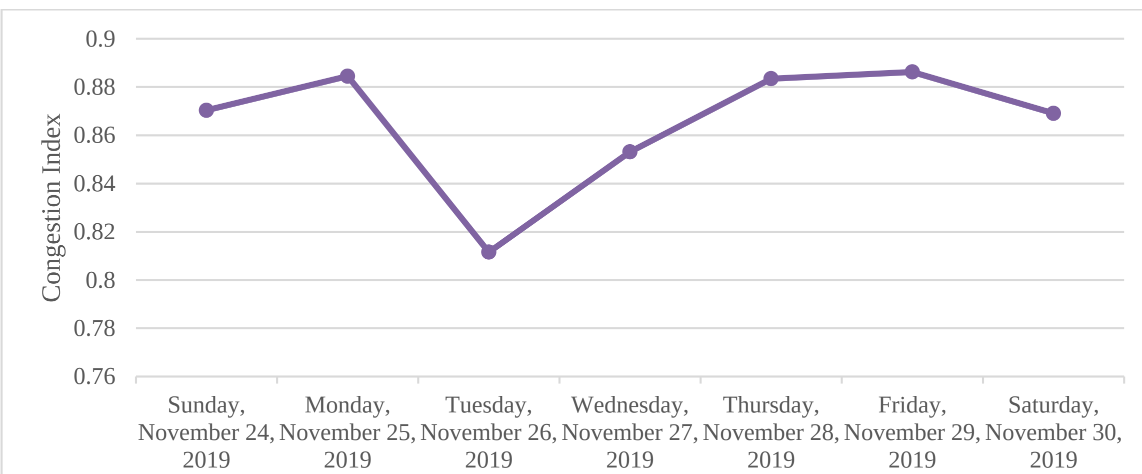


Figure 3-20 Roadway Congestion index M1 SB Lane 1 (November 2019)

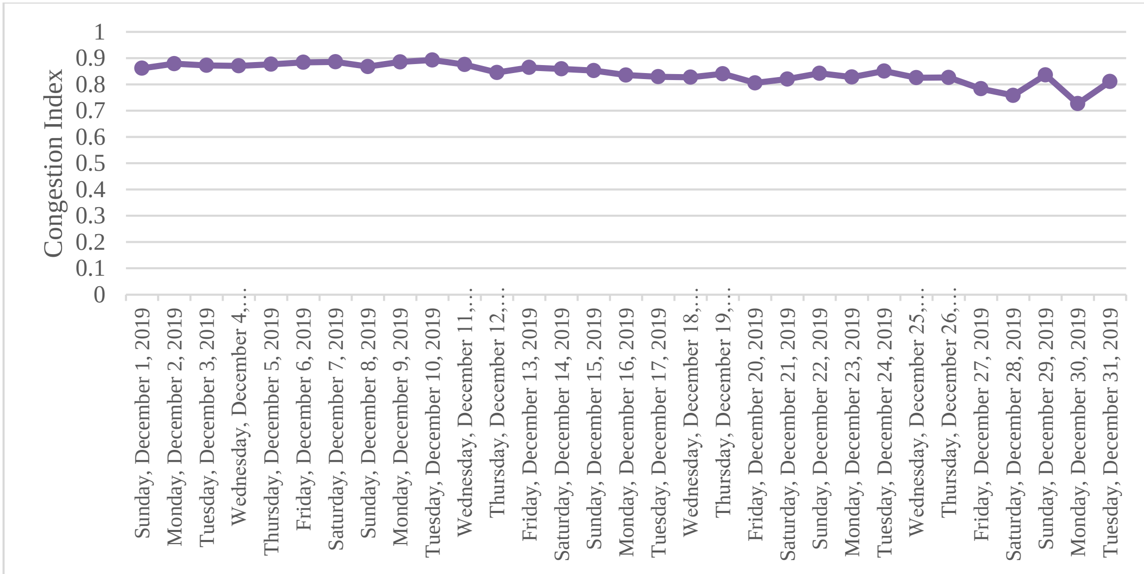


Figure 3-21 Roadway Congestion index M1 SB Lane 1 (December 2019)

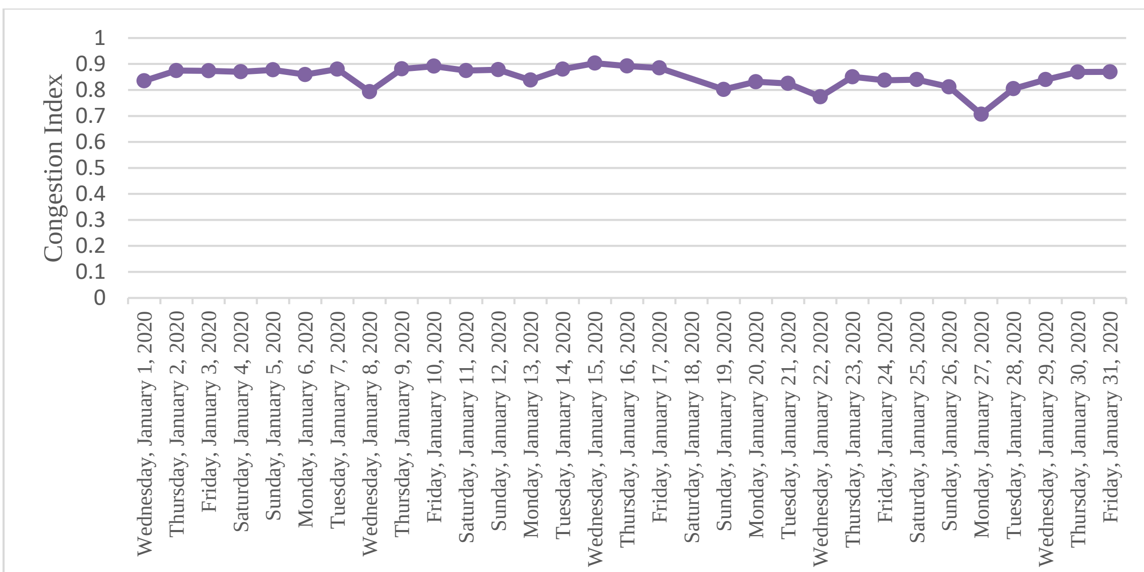


Figure 3-22 Roadway Congestion index M1 SB Lane 1 (January 2020)

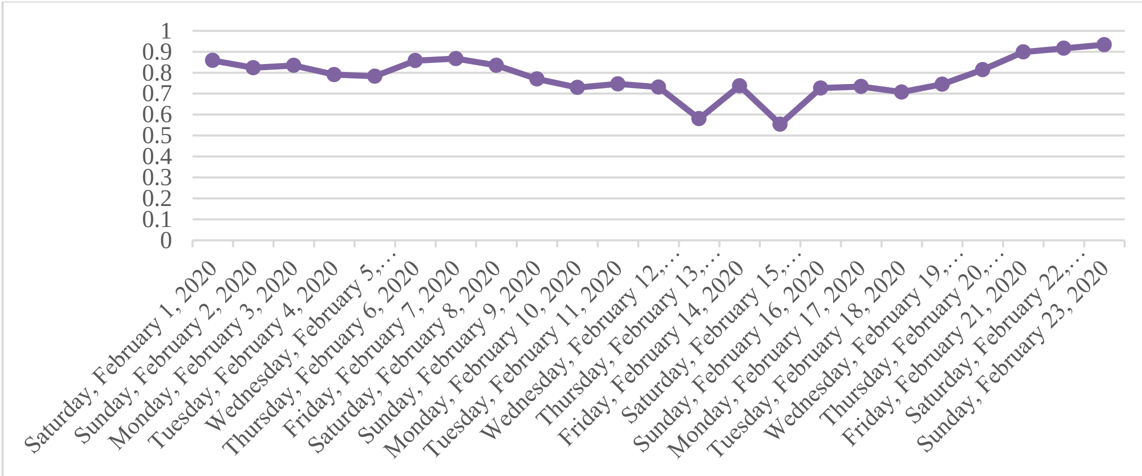


Figure 3-23 Roadway Congestion index M1 SB Lane 1 (February 2020)

Figures 3-24, 3-25, 3-26, and 3-27 show the congestion index value of M1 southbound lane 2 for November, December, January, and February. In November congestion index value is minimum on Tuesday. In December value of the congestion index is maximum on weekends. Whereas the maximum value of the congestion index is seen on Friday and Sunday in January and February respectively.

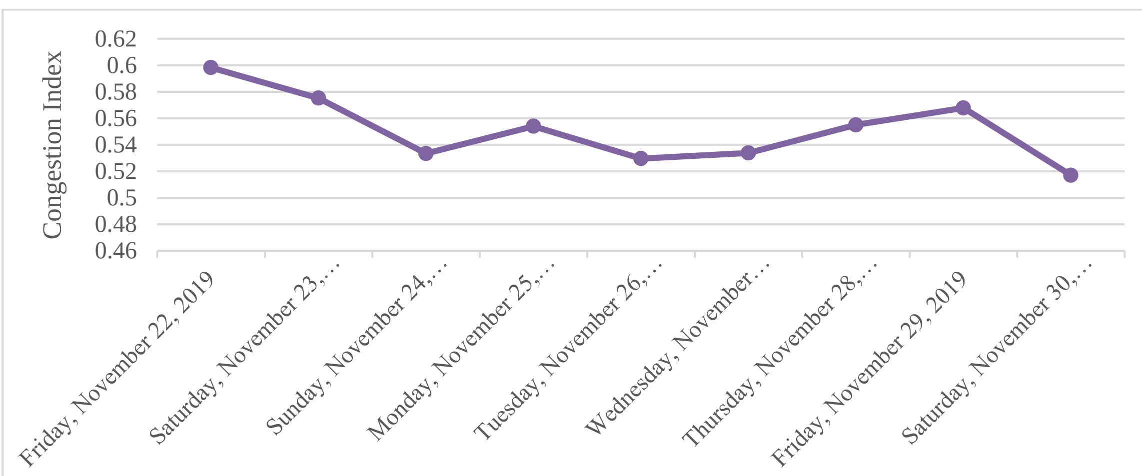


Figure 3-24 Roadway Congestion index M1 SB Lane 2 (November 2019)

The congestion index value ranges between 0.4 and 0.6 in December. The almost same trend is seen except few days. The following figure shows that traffic flow conditions in smooth in December.

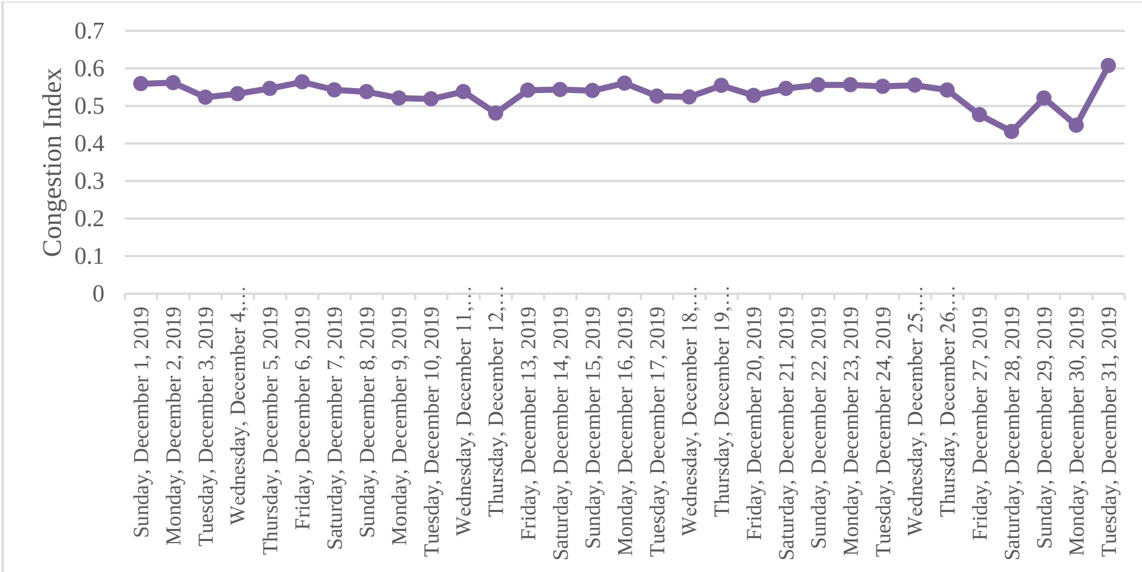


Figure 3-25 Roadway Congestion index M1 SB Lane 2 (December 2019)

For January, an increase in traffic volume is observed. Traffic volume is at its peak on Saturday, January 18.

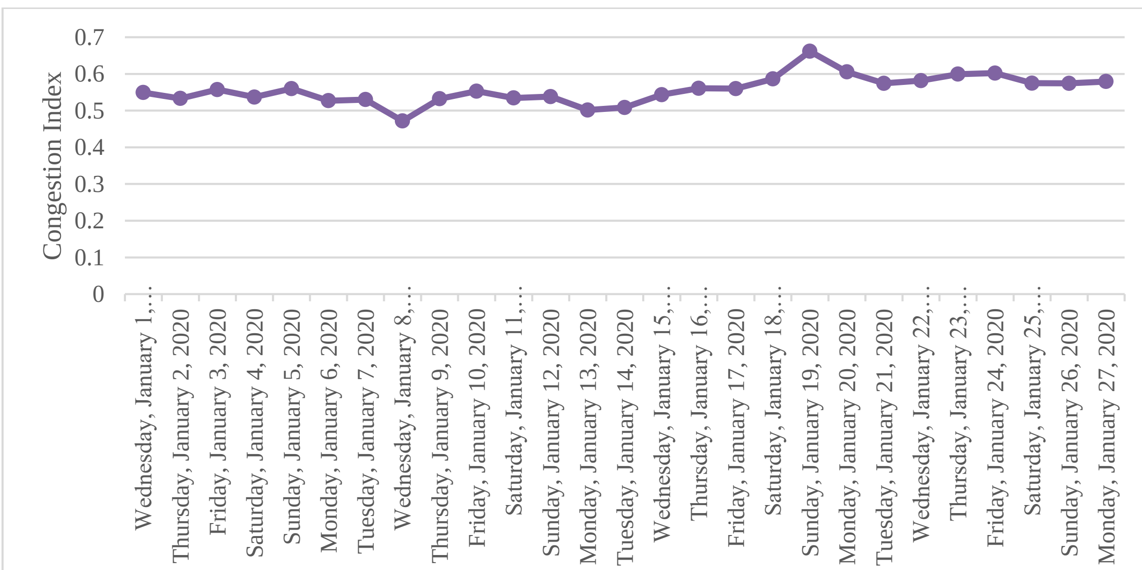


Figure 3-26 Roadway Congestion index M1 SB Lane 2 (January 2020)

The congestion index value decreases as February progresses. The value ranges between 0.4 and 0.7 in February.

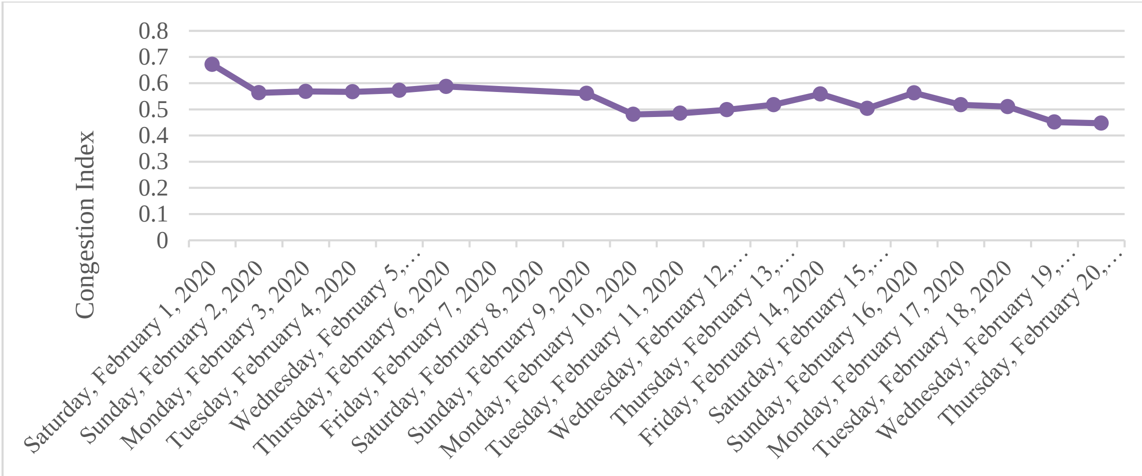


Figure 3-27 Roadway Congestion index M1 SB Lane 2 (February 2020)

Similarly to know about traffic conditions on National Highway, Congestion Index was calculated for each month. The congestion index value is less than 1 for all directions in the case of N5 which means traffic flow is smooth without any congestion. Figures 3-8 show the traffic congestion state for November in N5 northbound lane 1. The congestion index value is 0.6 at end of this month.

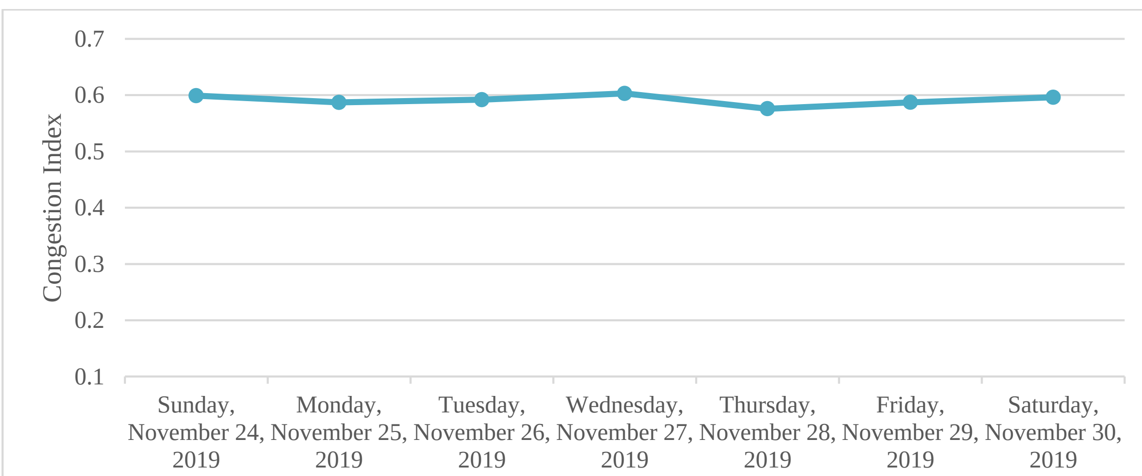


Figure 3-28 Roadway Congestion index N5 NB Lane 1 (November 2019)

Figure 3-29 shows that the congestion index value is between 0.5 and 0.7 at this value of the congestion index traffic flow is smooth without any delay. In the first half of the month traffic flow is almost the same each day but in the last half of the month fluctuation between roadway congestion indexes is observed.

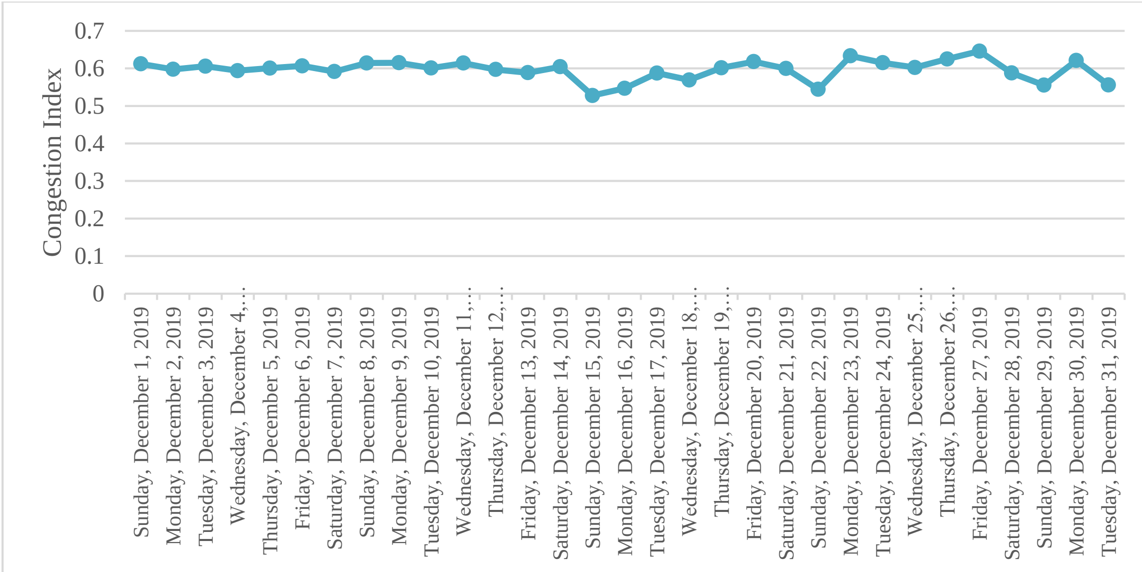


Figure 3-29 Roadway Congestion index N5 NB Lane 1 (December 2019)

A congestion index value of less than 0.5 depicts that traffic flow is very smooth. Figure 3-30 shows traffic congestion index values in northbound lane 1 of N5 for the month of January which indicates that traffic flow is smooth. The congestion index value is less than 0.5 on one day which represents that traffic flow is very smooth. Many factors affect the traffic volume and travel speed of vehicles which reduces the congestion index value for highways.

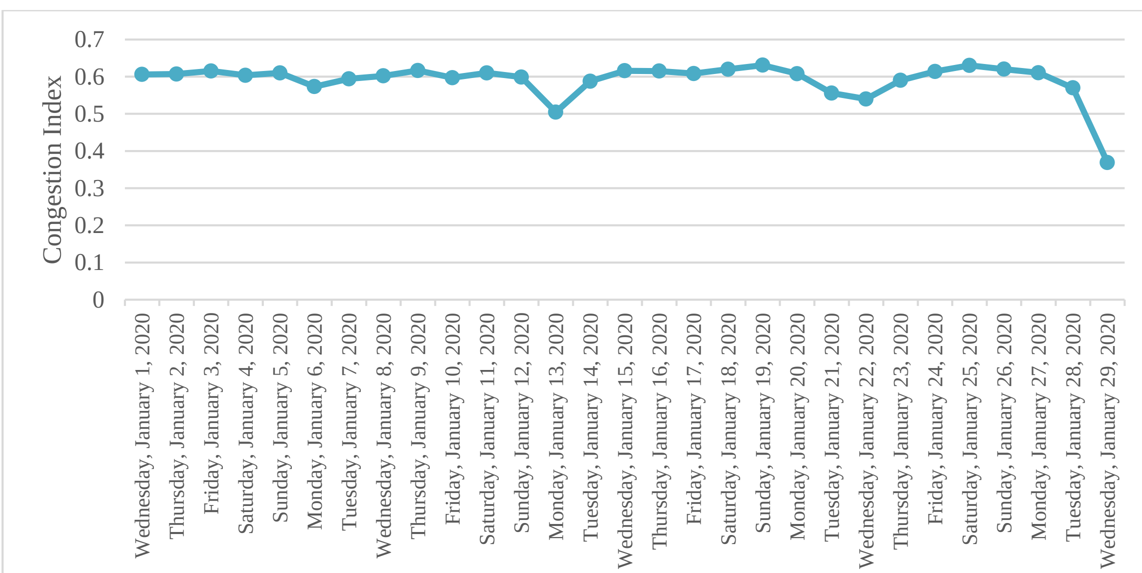


Figure 3-30 Roadway Congestion index N5 NB Lane 1 (January 2020)

Figure 3-31 shows that the congestion index value is between 0.2 and 0.6 at this value of the congestion index traffic flow is smooth without any delay. In the first half of the month traffic flow is almost the same each day but in the last half of the month fluctuation between roadway congestion indexes is observed where a sudden drop in congestion index is seen.

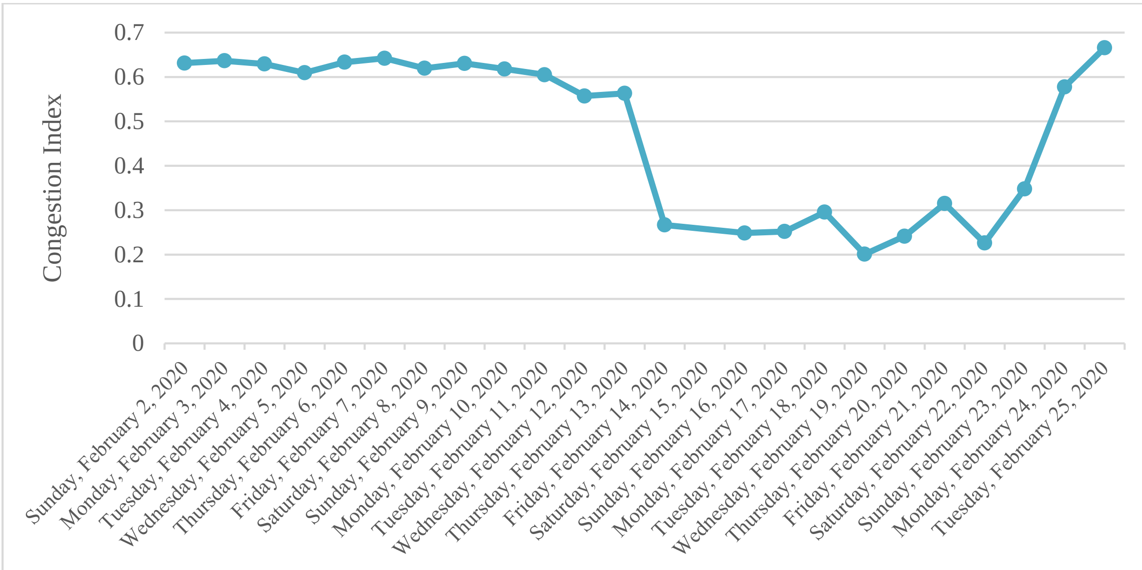


Figure 3-31 Roadway Congestion index N5 NB Lane 1 (February 2020)

Figure 3-32 shows the congestion index value for N5 northbound lane 2 for November. The roadway congestion index value is 0.8 same for the last week of November.

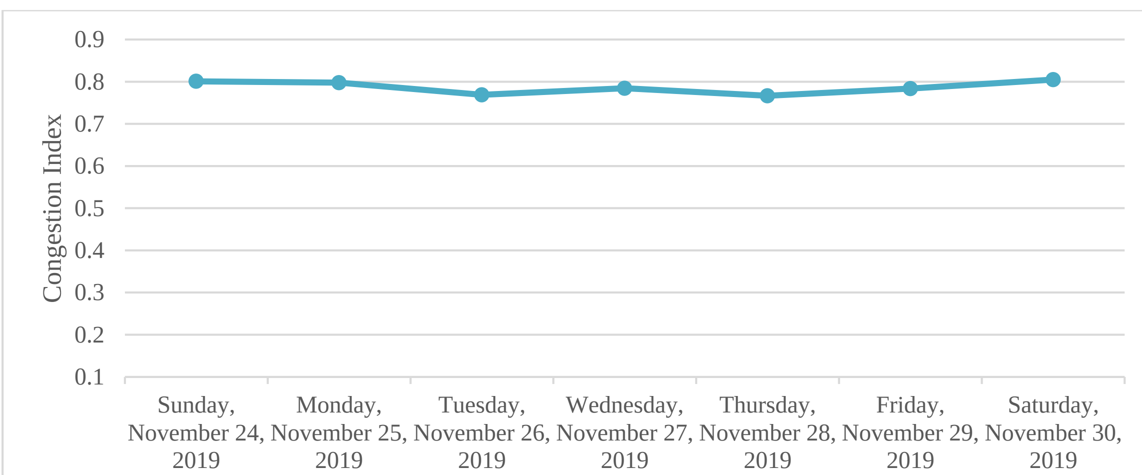


Figure 3-32 Roadway Congestion index N5 NB Lane 2 (November 2019)

Figure 3-33 shows that the congestion index value for N5 northbound lane 2 for December is between 0.6 and 0.8 at this value of the congestion index traffic flow is smooth.

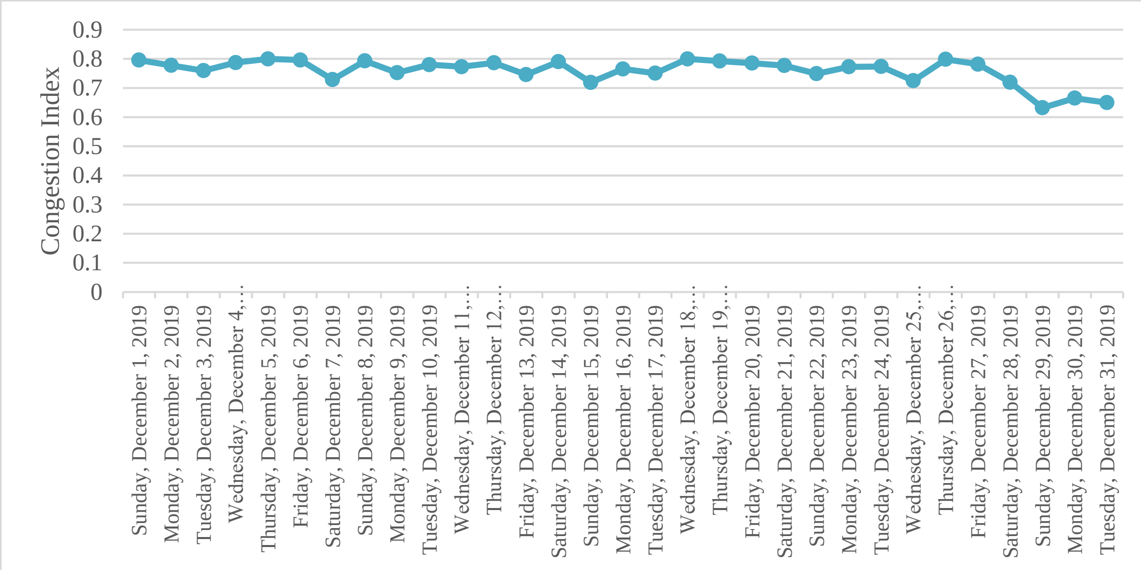


Figure 3-33 Roadway Congestion index N5 NB Lane 2 (December 2019)

The congestion index value of N5 northbound lane 2 is shown in Figure 3-34. The congestion index value ranges from 0.7 to 0.8 for January.

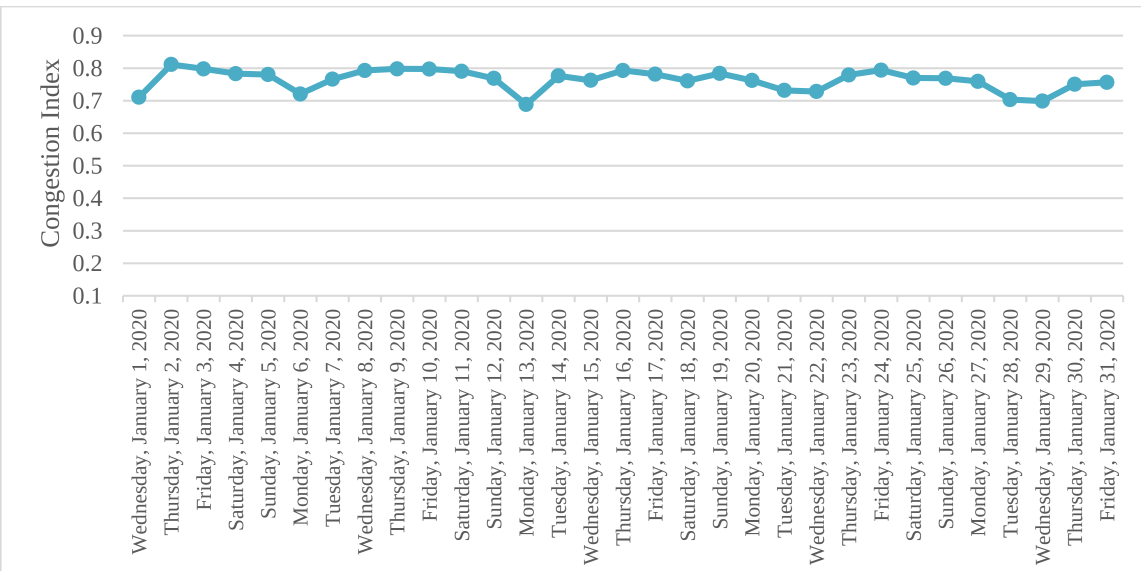


Figure 3-34 Roadway Congestion index N5 NB Lane 2 (January 2020)

Figure 3-35 shows the congestion index of N5 northbound lane 2 for February. Travel demand is the same throughout this month except for one day.

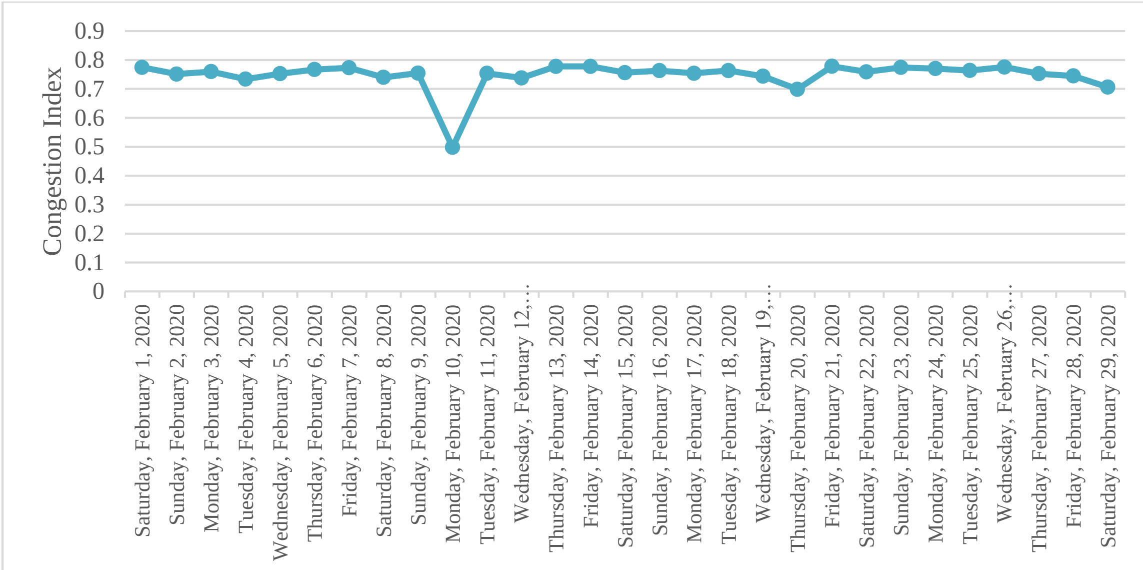


Figure 3-35 Roadway Congestion index N5 NB Lane 2 (February 2020)

Figures 3-36, 3-37, 3-38, and 3-39 show the congestion index value for N5 southbound lane 1 for November, December, January, and February. Traffic flow is smooth in November when the congestion index value is 0.5. The congestion index value ranges between 0.4 and 0.6 for December. Fluctuation in the roadway congestion index is observed for January. The congestion index value is less than 0.5 for February which shows that traffic flow is very smooth.

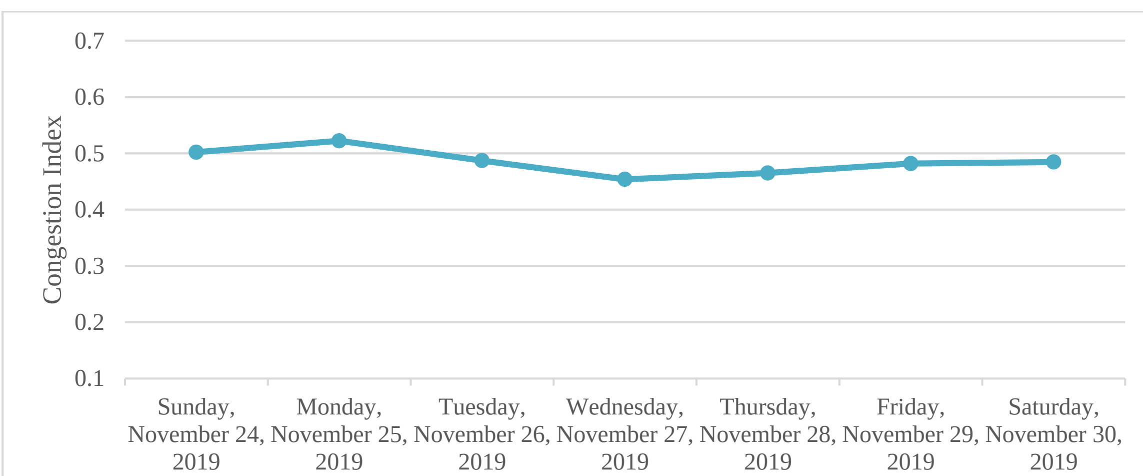


Figure 3-36 Roadway Congestion index N5 SB Lane 1 (November 2019)

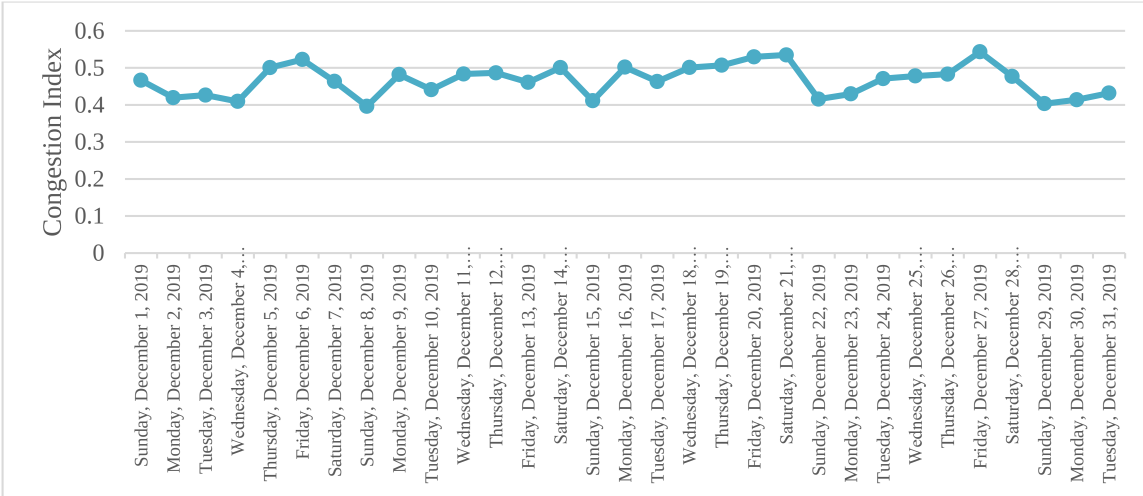


Figure 3-37 Roadway Congestion index N5 SB Lane 1 (November 2019)

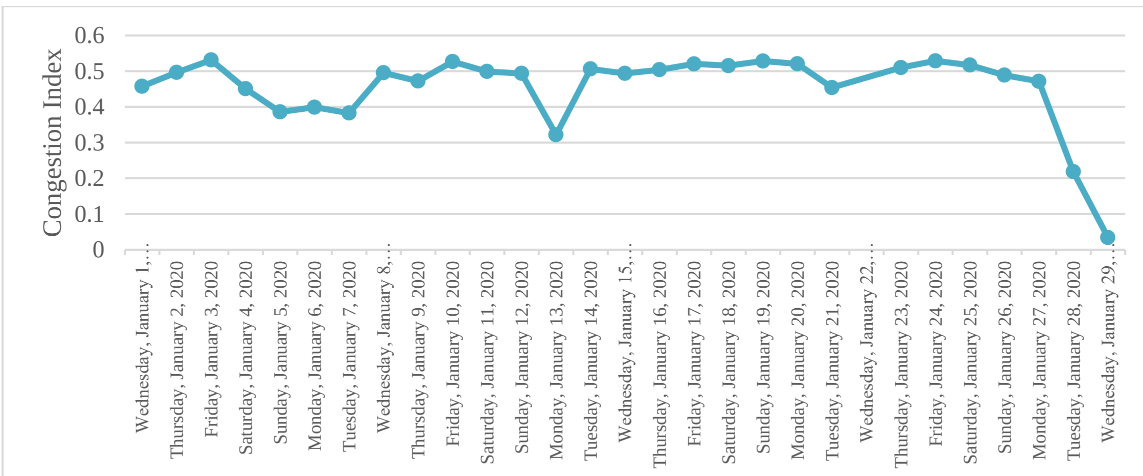


Figure 3-38 Roadway Congestion index N5 SB Lane 1 (January 2020)

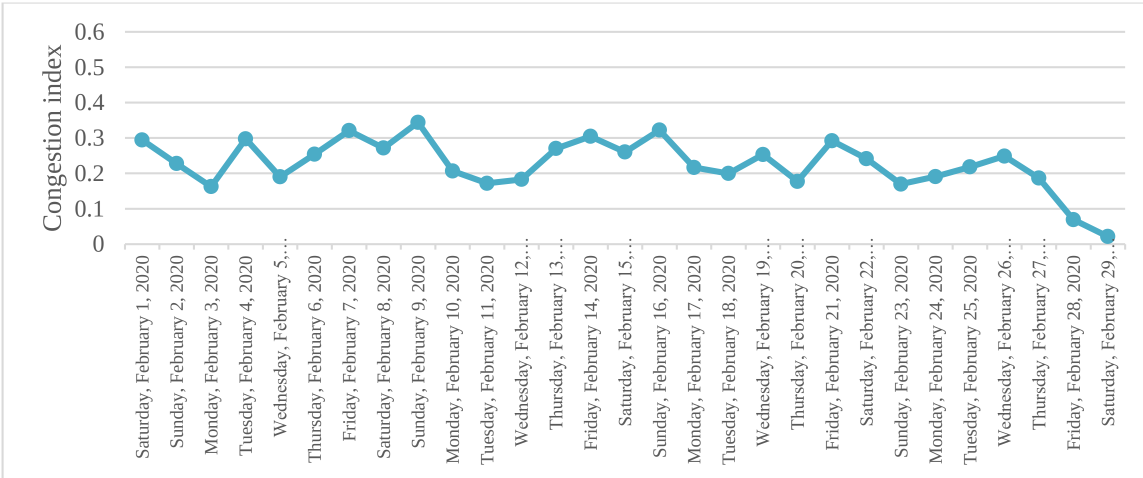


Figure 3-39 Roadway Congestion index N5 SB Lane 1 (February 2020)

Figures 3-40, 3-41, 3-42, and 3-43 show the congestion index value for N5 southbound lane 2 for November, December, January, and February respectively. Traffic flow is smooth in November when the congestion index value is 0.7. The congestion index value ranges between 0.5 and 0.7 for December. Consistency in the roadway congestion index is observed for January the value for this month ranges between 0.6 and 0.8. The congestion index value for February ranges between 0.5 and 0.8.

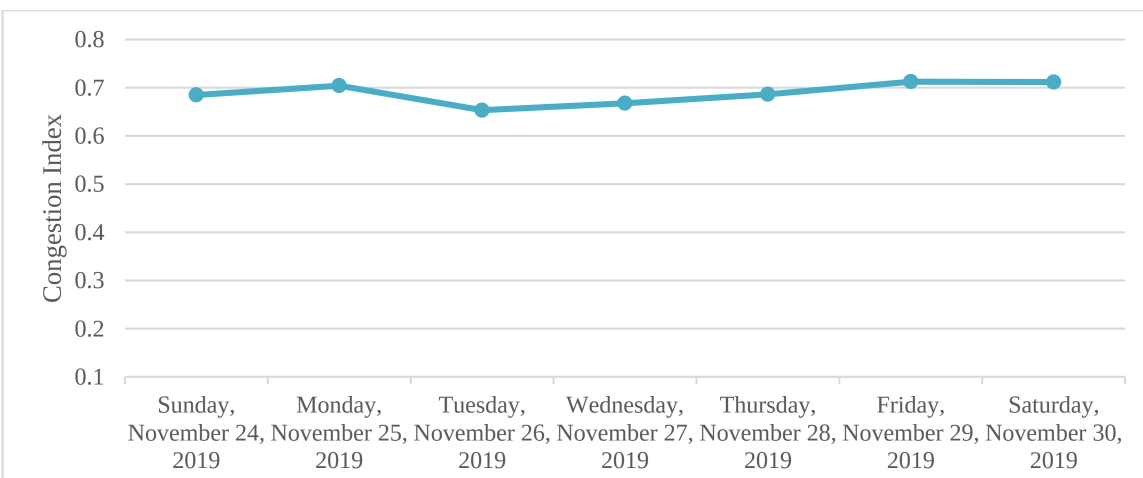


Figure 3-40 Roadway Congestion index N5 SB Lane 2 (November 2019)

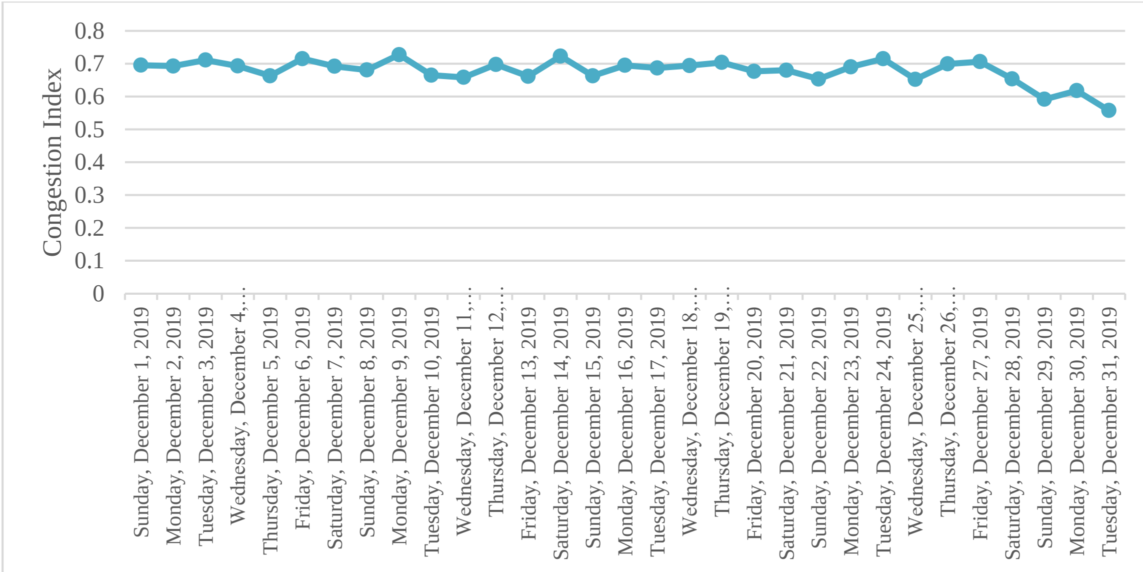


Figure 3-41 Roadway Congestion index N5 SB Lane 2 (December 2019)

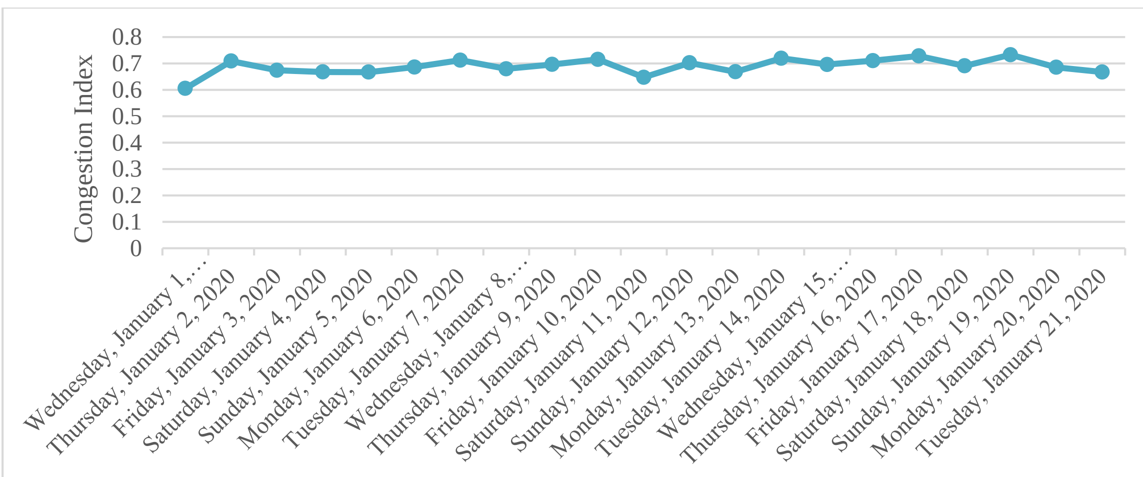


Figure 3-42 Roadway Congestion index N5 SB Lane 2 (January 2020)

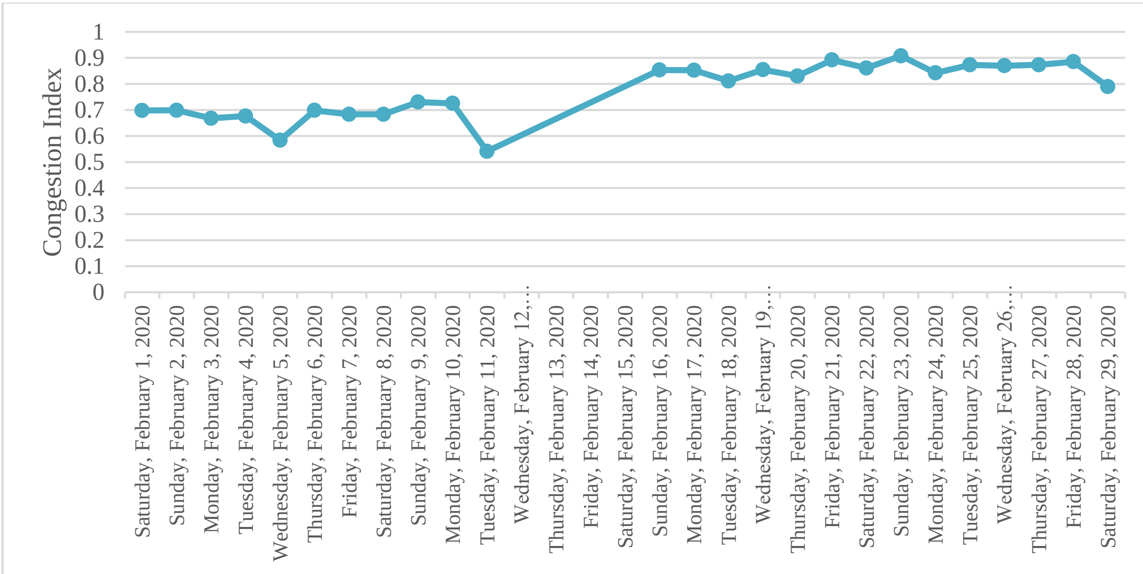


Figure 3-43 Roadway Congestion index N5 SB Lane 2 (February 2020)

CHAPTER 4

4. ANALYSIS AND RESULTS

4.1. Average Travel speed Relationship with Volume:

Considering the relationship between Traffic volume and Travel Speed on Motorway M1 Northbound Lane 1, an increase in volume by 15% can cause a decrease in travel speed by 2%.

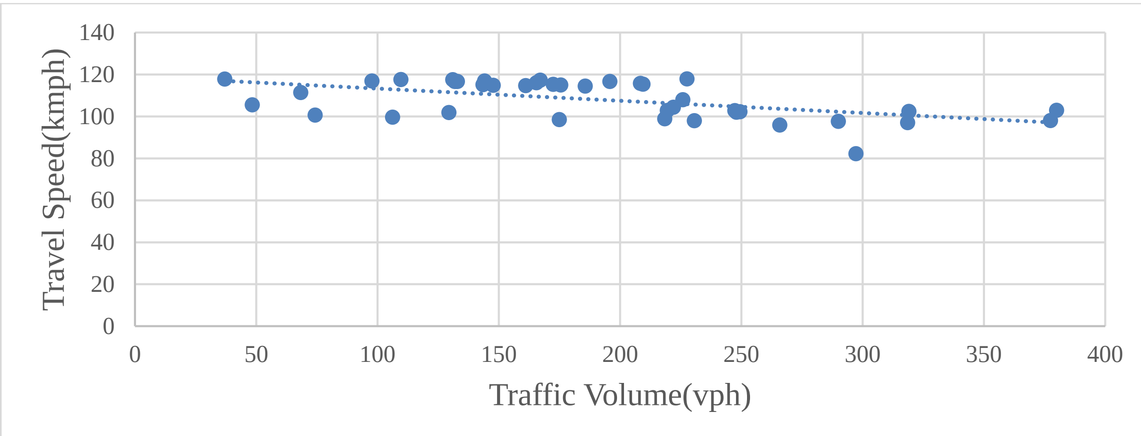


Figure 4-1 Relationship between Traffic Volume and Travel speed (M1 NB L1)

As per motorway rules in Pakistan, Heavy vehicles are not allowed to enter the first lane so considering this fact Lane 2 has more heterogeneous traffic than lane 1 with a high volume comparatively. So here in Lane 2 of Motorway M1, An increase in volume by 10% will reduce the speed to 6%.

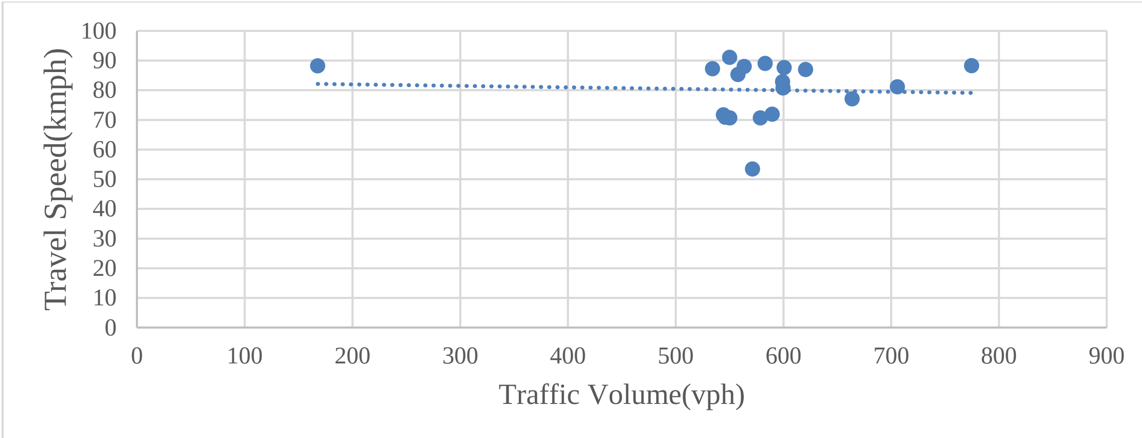


Figure 4-2 Relationship between Traffic Volume and Travel speed (M1 NB L2)

In the Southbound of M1 in which traffic is moving towards Islamabad, An increase in volume by 11% causes the reduction in speed by 2%.

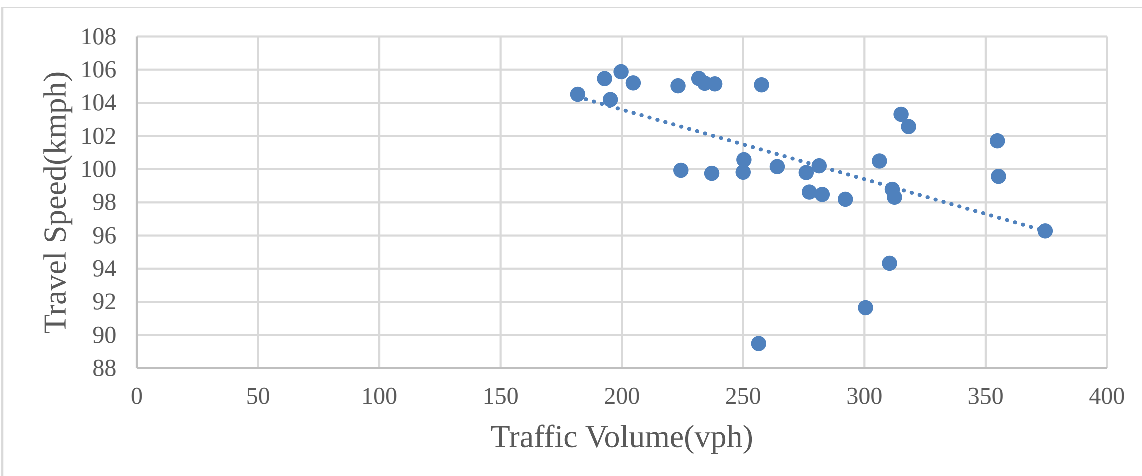


Figure 4-3 Relationship between Traffic Volume and Travel speed (M1 SB L1)

In Motorway M1 Southbound Lane 2, if there is an increase of volume by 1% it reduces the speed by 1.75%.

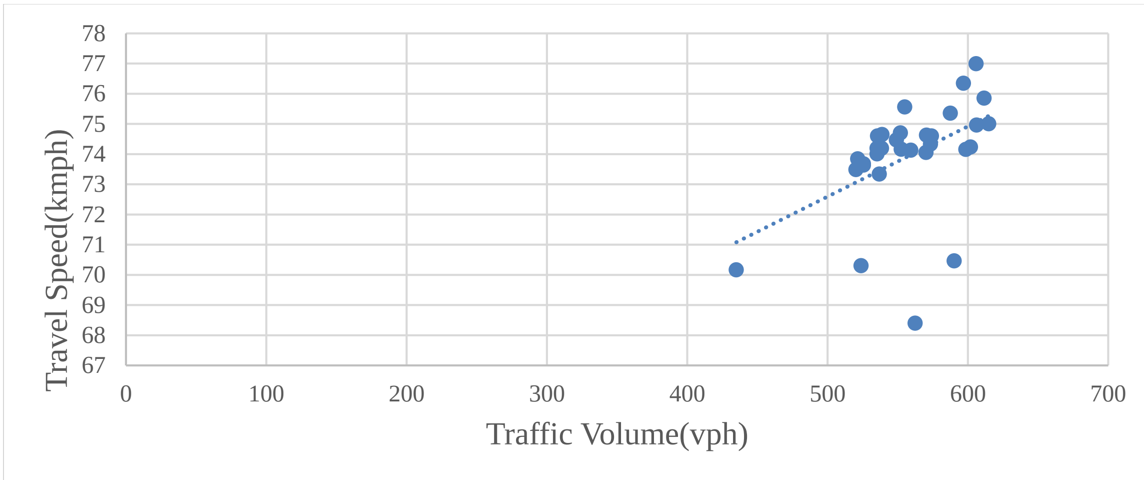


Figure 4-4 Relationship between Traffic Volume and Travel speed (M1 SB L2)

Considering the Traffic volume and speed relationship on N5, it depicts that if volume increases to 1% it causes a reduction in speed by 3.7% in lane 1. While in the case of lane 2, an increase in volume to 10% reduces the speed to 3.1%. These relationships can be seen in the figures given below.

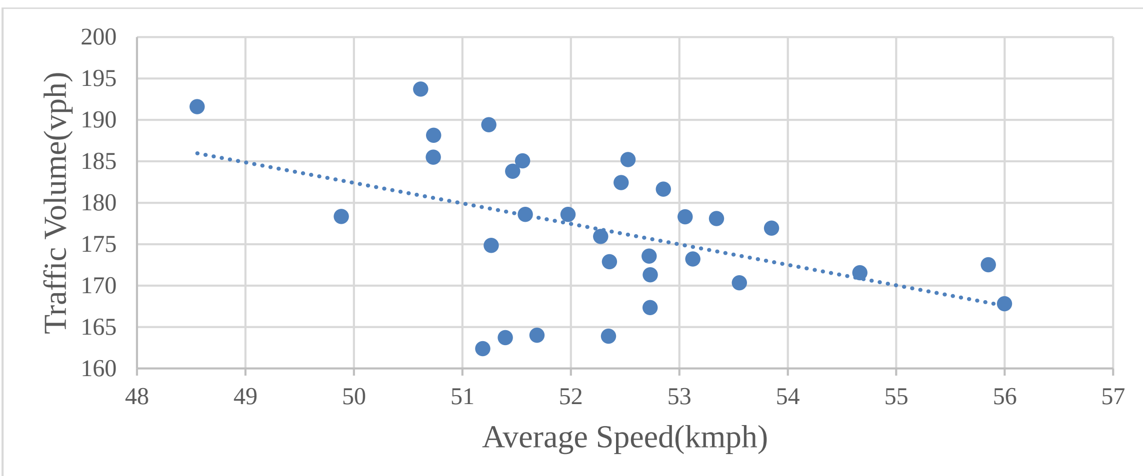


Figure 4-5 Relationship between Traffic Volume and Travel speed (N5 NB L1)

Figures 4-6 show the traffic volume and travel speed relationship on N5 northbound lane 2 in the case of lane 2, an increase in volume to 10% reduces the speed to 3.1%.

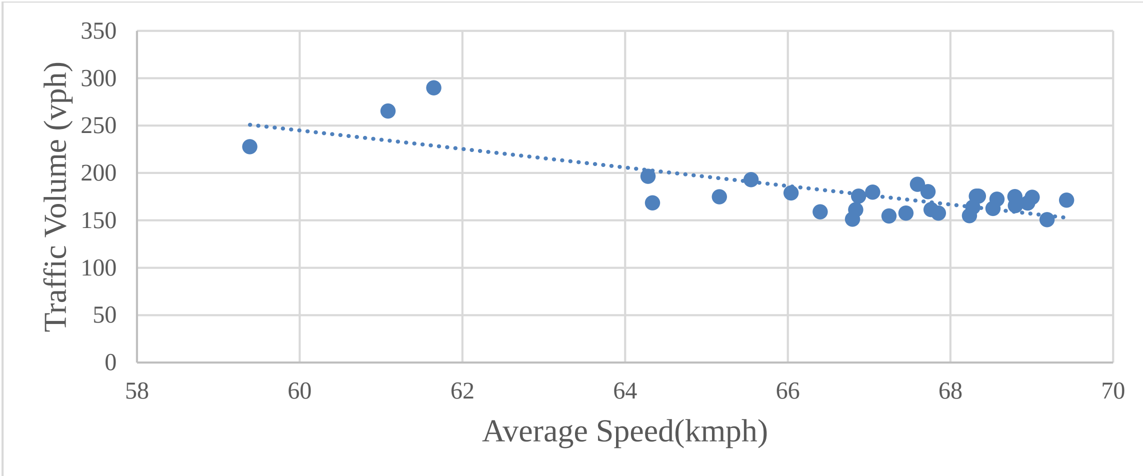


Figure 4-6 Relationship between Traffic Volume and Travel speed (N5 NB L2)

In Southbound of N5 where traffic is going towards Islamabad this relationship results that the increase of traffic volume by 16% causes the reduction in speed by 4% in Lane 1. Same as performing this analysis in Lane 2 of the southbound highway depicts that if the volume is increased by 4% it reduces the speed to 3%. Graphs for both of the following relationships are given below.

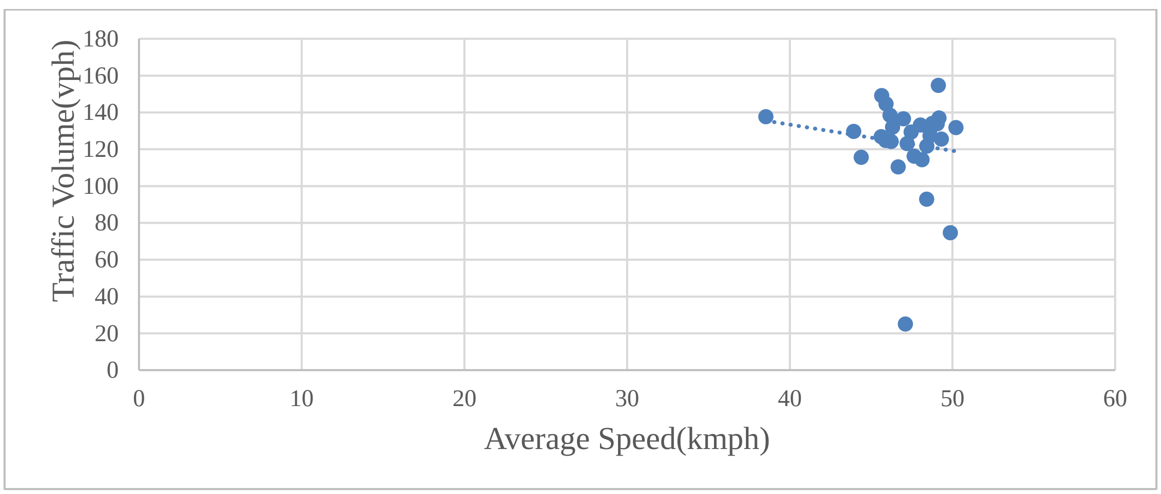


Figure 4-7 Relationship between Traffic Volume and Travel speed (N5 SB L1)

Figure 4-8 represents the traffic volume and travel speed relationship for N5 southbound lane 2 which shows that if the volume is increased by 4% it reduces the speed to 3%.

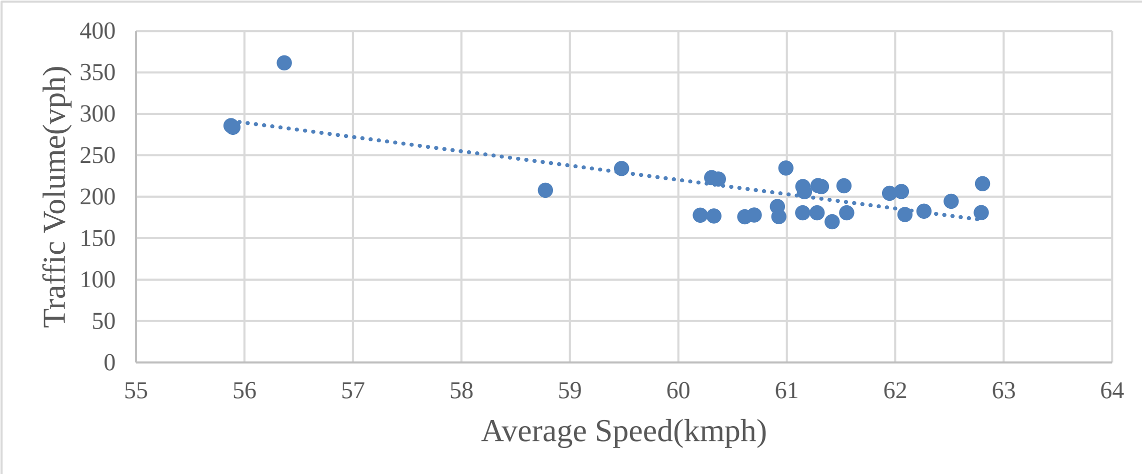


Figure 4-8 Relationship between Traffic Volume and Travel speed (N5 SB L2)

4.2. Average Travel speed Relationship with Volume to Capacity Ratio (v/c):

In the relationship between volume to capacity ratio, capacity being the constant parameter does not vary with changing traffic flow while volume is variable. So the impact of volume change can be seen in v/c which is an important parameter to assess the congestion state of roads. So similarly to the previous study the correlation found in volume and speed, can apply to the following graphs. All the graphs show that if the volume to capacity ratio increases the traveling speed of the vehicle will be decreased.

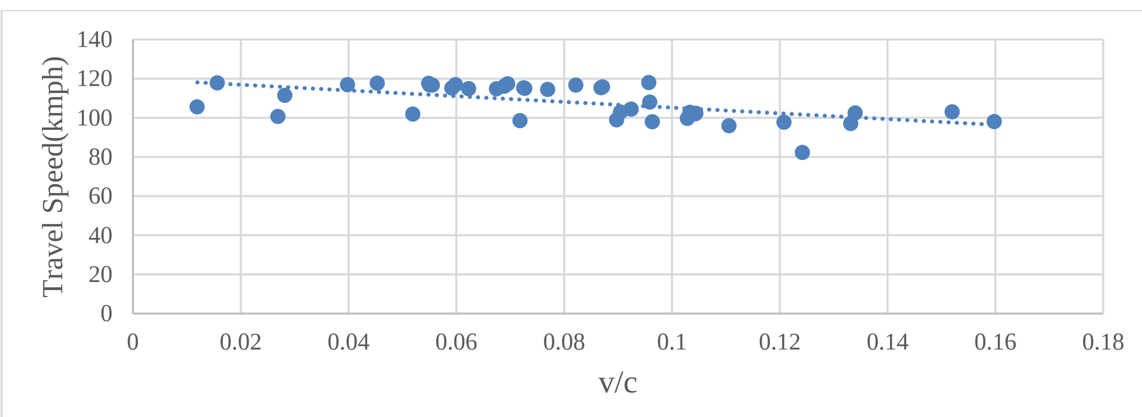


Figure 4-9 Relationship between Travel Speed and v/c (M1 NB L1)

Figures 4-10 and 4-11 show the relationship between travel speed and volume to capacity ratio of M1 northbound lane 2 and southbound lane 1 respectively. As volume to capacity ratio increases the decrease in travel speed is observed.

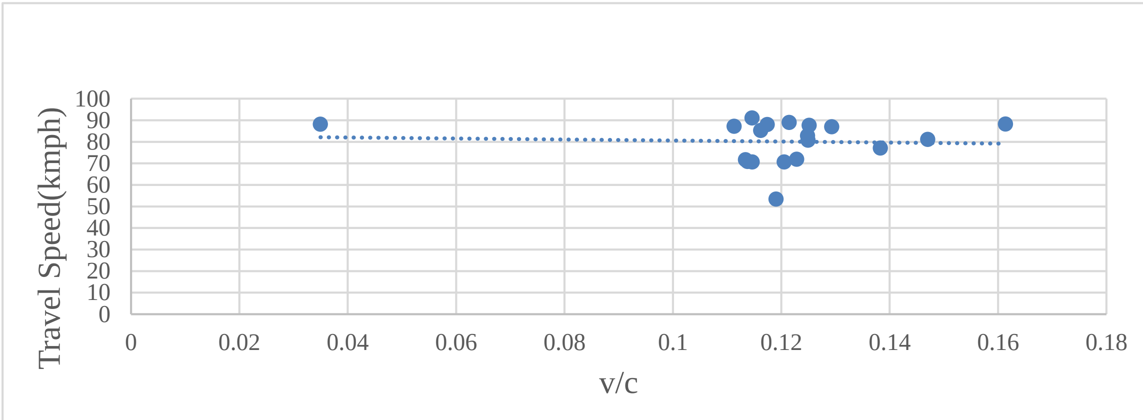


Figure 4-9 Relationship between Travel Speed and v/c (M1 NB L2)

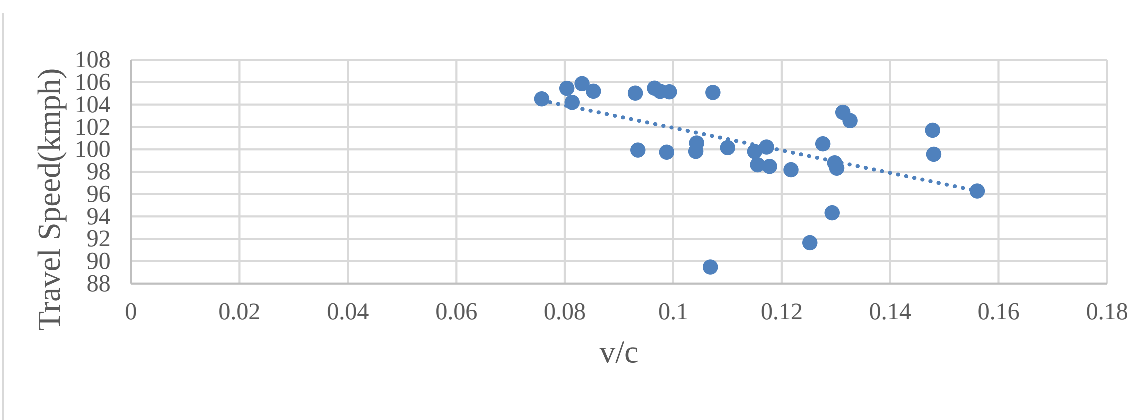


Figure 4-11 Relationship between Travel Speed and v/c (M1 SB L1)

Figure 4-12 shows that an increase in volume to capacity ratio will increase the travel speed of M1 southbound lane 2.

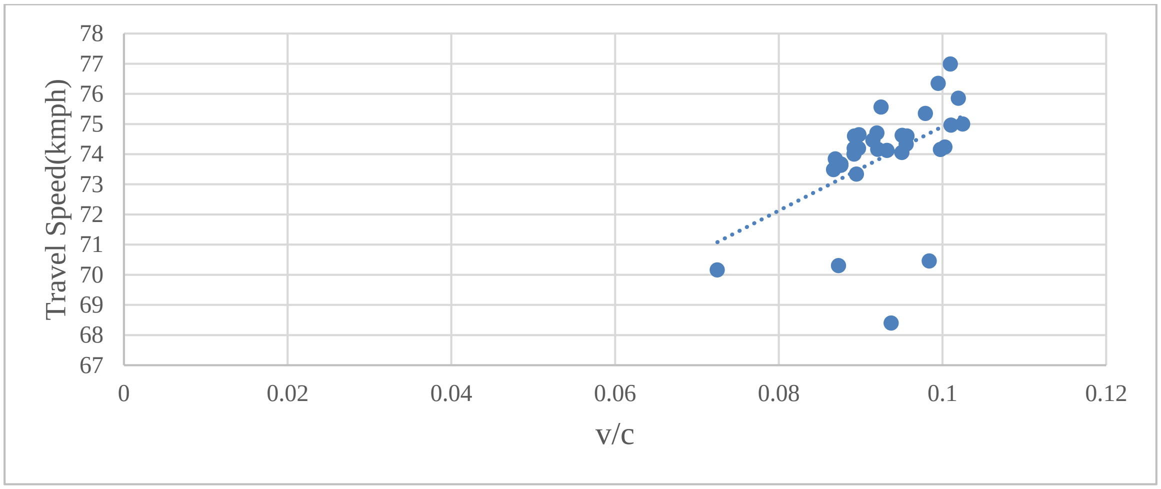


Figure 4-10 Relationship between Travel Speed and v/c (M1 SB L2)

Figure 4-13 shows the relationship between v/c and travel speed in the case of N5 northbound lane 1. An increase in volume to the capacity ratio by 2% decreases the travel speed by 0.5%.

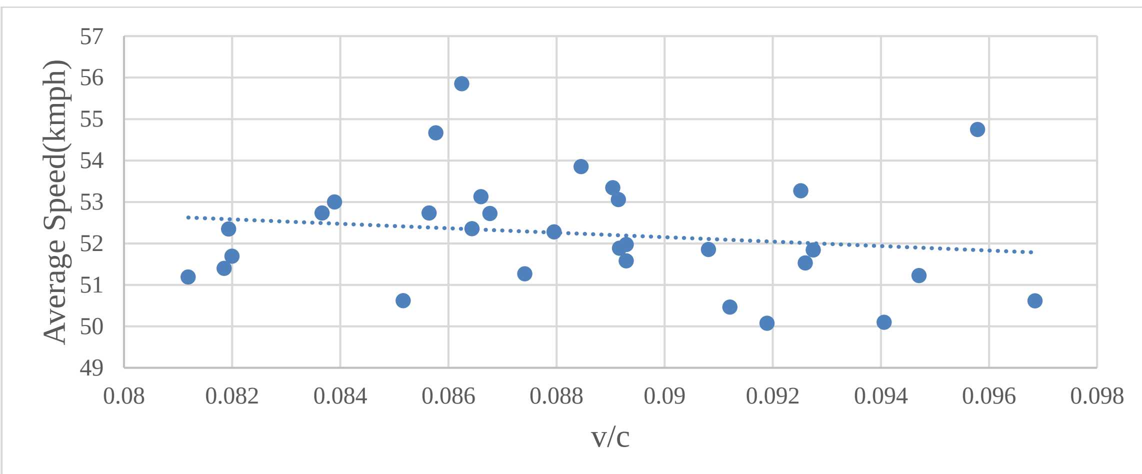


Figure 4-13 Relationship between Travel Speed and v/c (N5 NB L1)

The trend line shows a significant relationship between travel speed and v/c. Figure 4-14 shows that a 10% increase in v/c will decrease a 2% decrease in travel speed in the case of N-5 northbound lane 2.

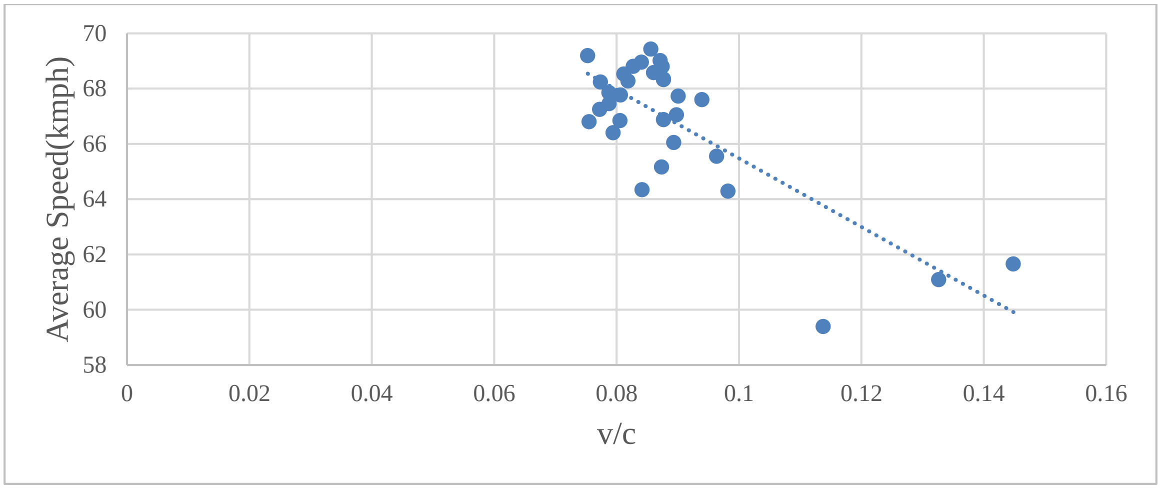


Figure 4-14 Relationship between Travel Speed and v/c (N5 NB L2)

Figure 4-15 shows the relationship between travel speed and volume to capacity ratio on N5 southbound lane 1. No significant change in travel speed is observed with a change in the v/c ratio.

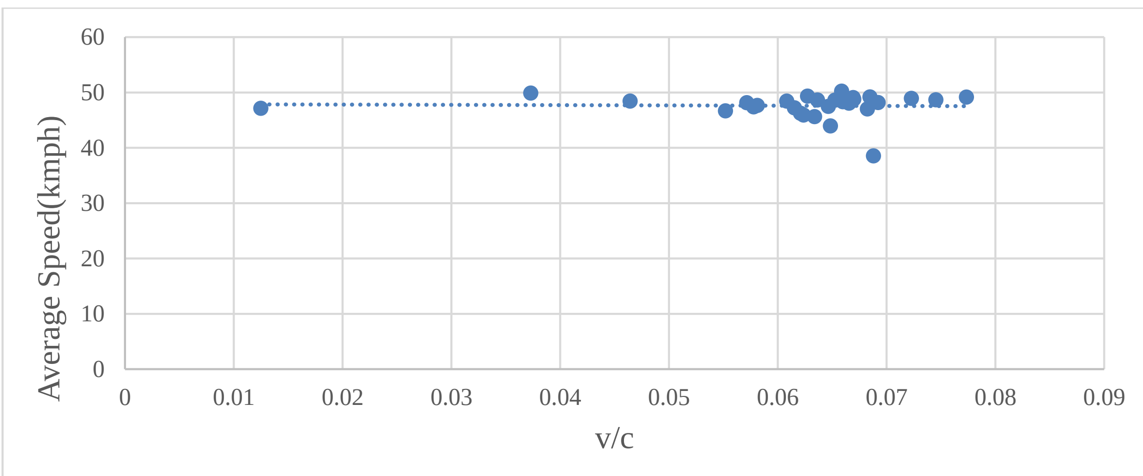


Figure 4-11 Relationship between Travel Speed and v/c (N5 SB L1)

Volume to the capacity relationship is the key parameter to determining the saturation degree of the highway. It is also used to describe the traffic state of the roadway. If the volume to capacity ratio increases it will result in a decrease in travel speed. Figure 4-16 shows the travel speed relationship with the volume to the capacity ratio for N5 southbound lane 2.

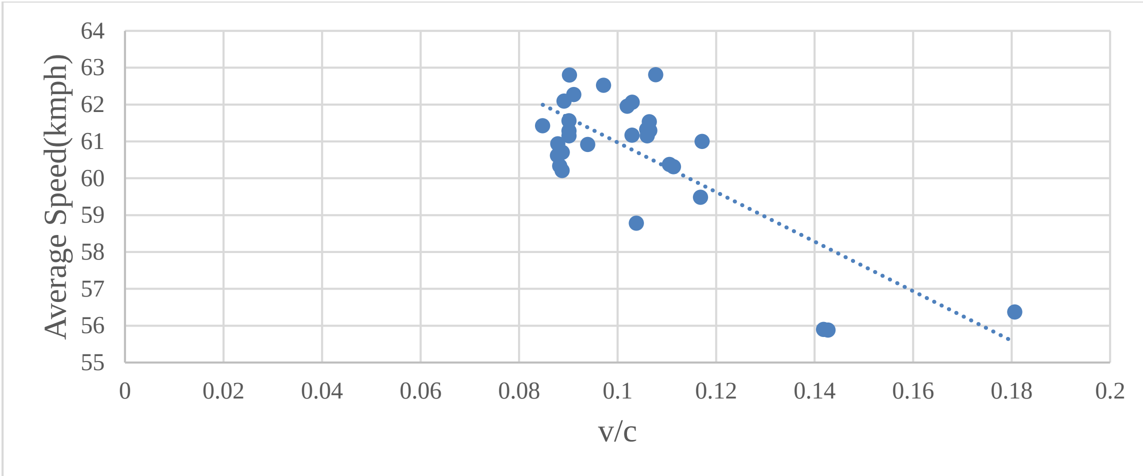


Figure 4-12 Relationship between Travel Speed and v/c (N5 SB L2)

4.3. Average Travel speed Relationship with Congestion Index (RCI):

A reverse relationship exists between speed and congestion index. If the Congestion index increase, speed decreases accordingly. Considering the relationship between motorway M1 and Northbound lane 1, if the congestion index is increased by 16% the reduction in travel speed is 4.5%. Figure 4-17 shows the relationship between congestion index and travel speed for M1 northbound lane 1.

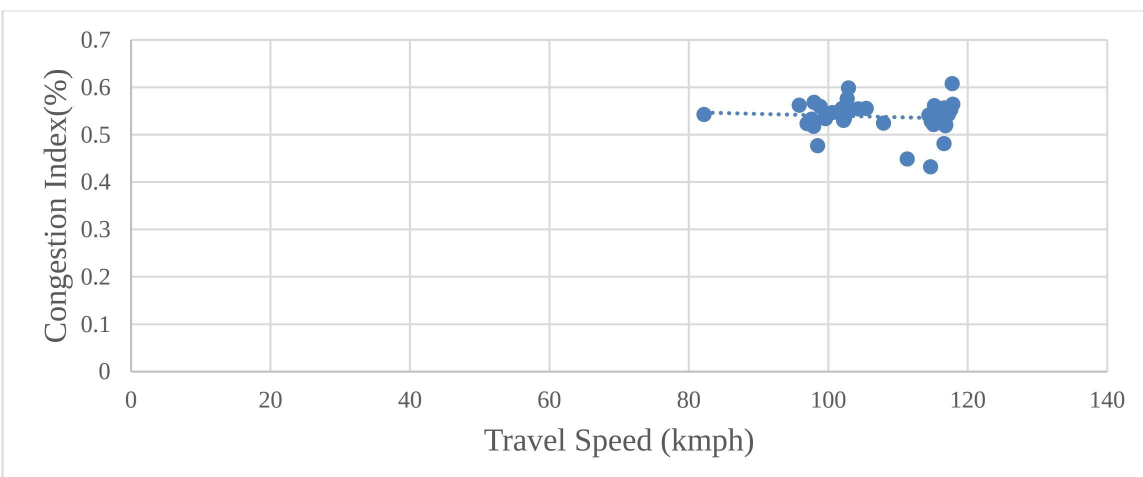


Figure 4-13 Relationship between Travel speed and Congestion Index (M1 NB L1)

Figure 4-18 shows the relationship between congestion index and travel speed for M1 northbound lane 2 which describe that if the congestion index is increased by 13% the travel speed will reduce to 2.5%.

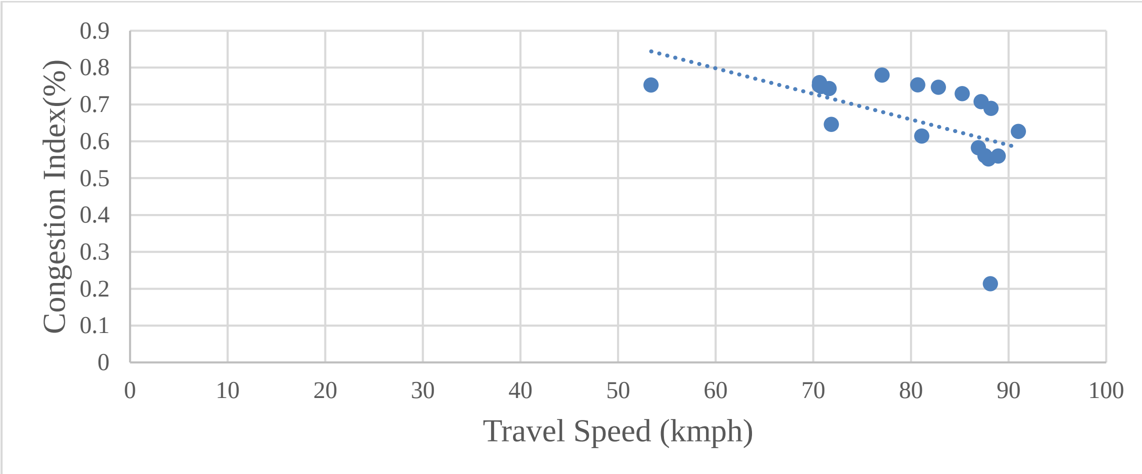


Figure 4-14 Relationship between Travel speed and Congestion Index (M1 NB L2)

In the Case of Southbound M1 in which traffic is moving towards Islamabad the relationship between Congestion Index and travel speed is as follows. In Lane 1 southbound if the congestion index increases to 7.69% the resulting speed will be reduced to 2%. Where in the case of southbound lane 2 almost a 1% increase in congestion index will cause the same decrease in speed. Figures 4-19 and 4-20 show the relationship between travel speed and congestion index for southbound lane 1 and lane 2 are given below respectively.

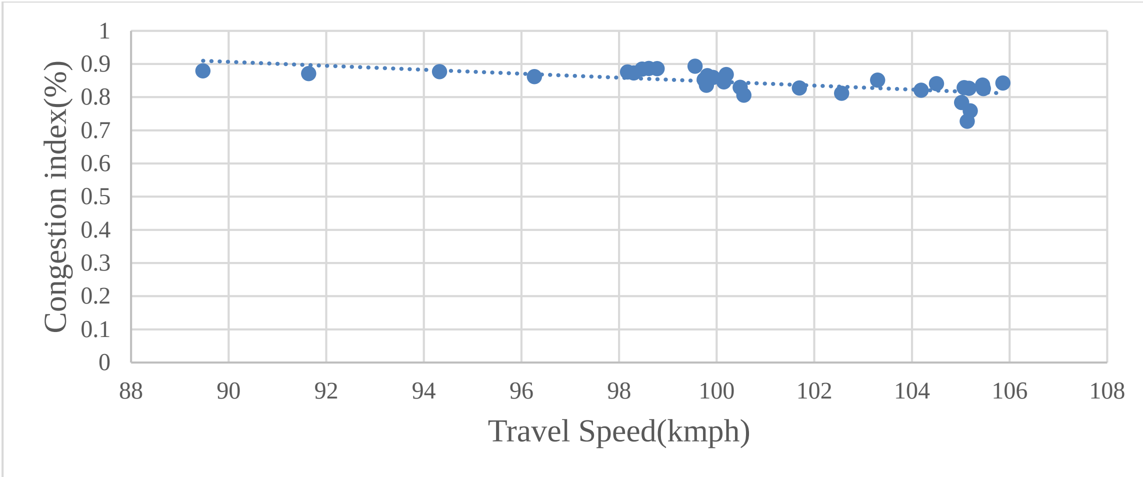


Figure 4-15 Relationship between Traffic Volume and Congestion Index (M1 SB L1)

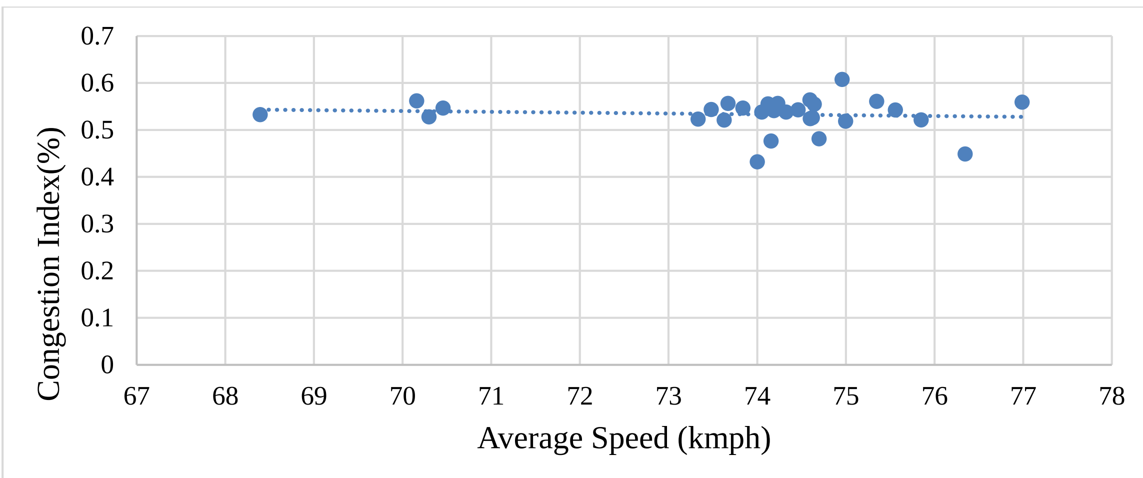


Figure 4-16 Relationship between Average speed and Congestion Index (M1 SB L2)

Considering the N5 northbound lane 1 and 2 traffic which is going towards Peshawar, in Lane 1 if the congestion index increases to 3% the resulting speed will be decreased up to 2%. Similarly, in the case of Lane 2, an increase in congestion index to 2.53% causes a decrease in speed to 1.5%. Figures 4-21 and 4-22 show the relationship between Travel speed and congestion index on N5 northbound lane 1 and N5 northbound lane 2 respectively.

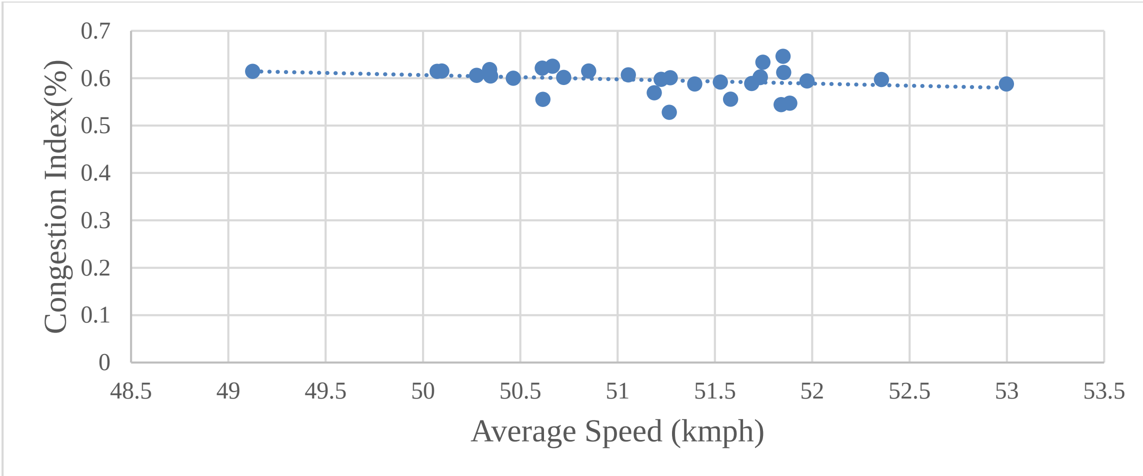


Figure 4-17 Relationship between Travel speed and Congestion Index (N5 NB L1)

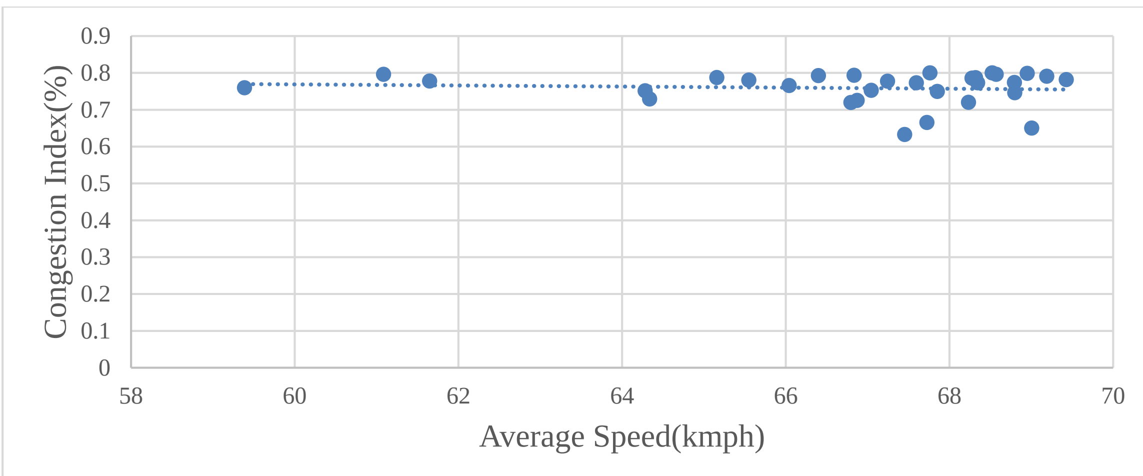


Figure 4-18 Relationship between Travel speed and Congestion Index (N5 NB L2)

In the case of N5 southbound traffic which is going towards Islamabad, in lane 1 if the congestion index is increased at the rate of 6% the resulting speed will be decreased to 1.63%. Similarly in the case of lane 2 of southbound traffic if the congestion index is increased by 4% the result will come out as a reduction in speed with the rate of 2%. Figures 4-23 and 4-24 show the relationship between Travel speed and congestion index on N5 southbound lane 1 and N5 southbound lane 2 respectively.

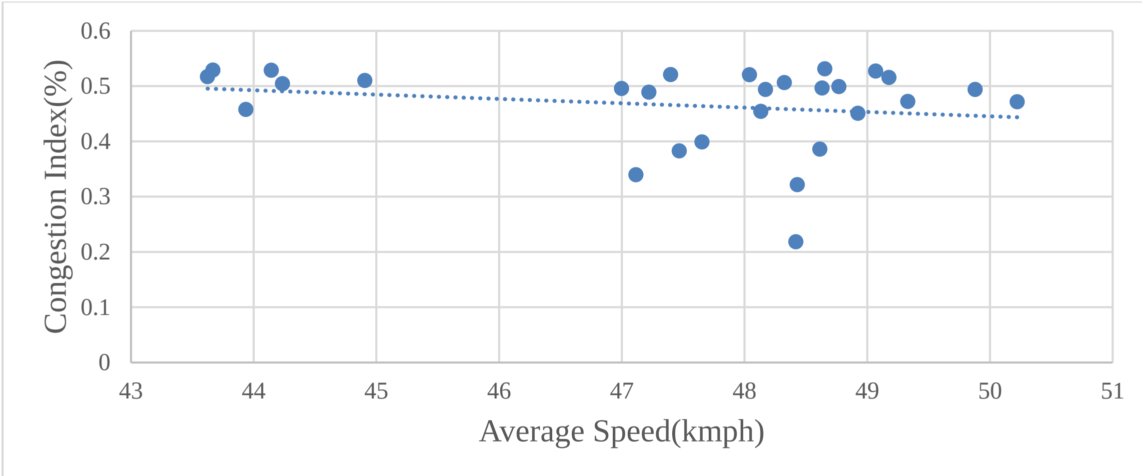


Figure 4-19 Relationship between Travel speed and Congestion Index (N5 SB L1)

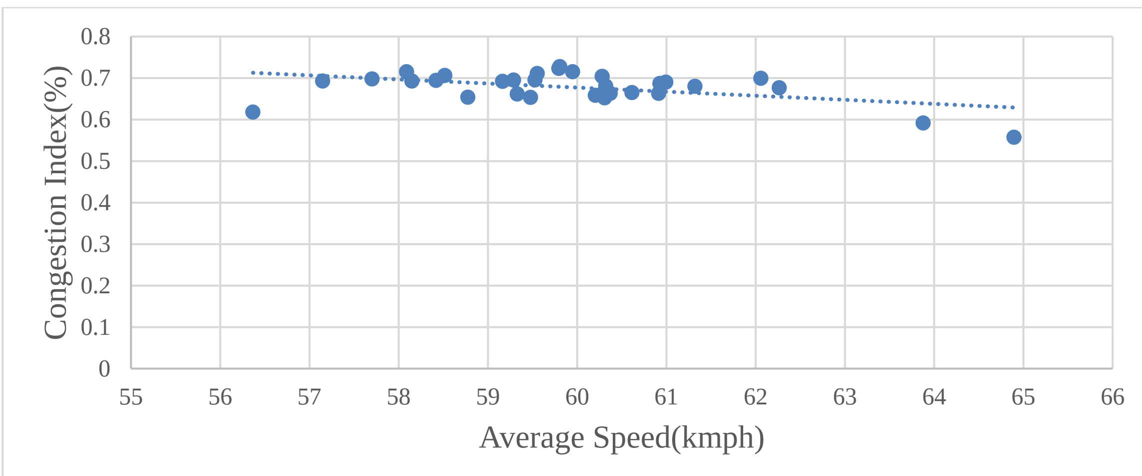


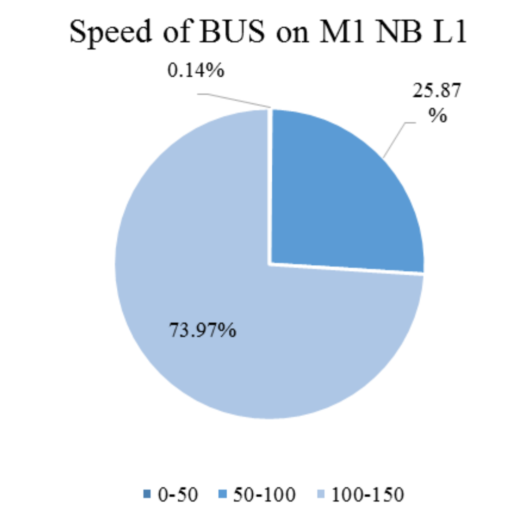
Figure 4-20 Relationship between Travel speed and Congestion Index (N5 SB L2)

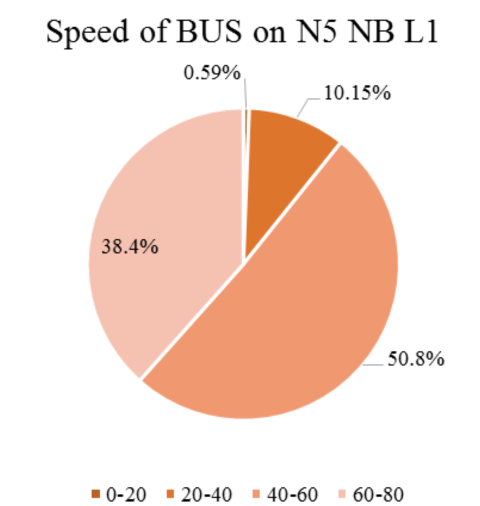
4.4. Average Operating Speed on National Highway vs. Speed on Motorways for each vehicle class

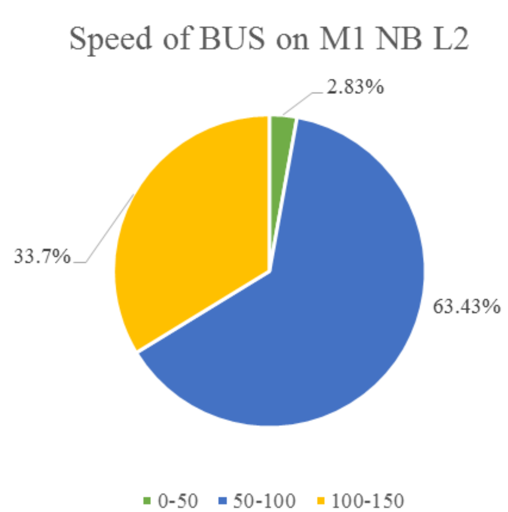
In the case of buses, the average speed of buses on Lane 1 is near to speed limit (which is 110kmph) as lane 1 is a fast lane generally slow-moving vehicles are prohibited. But in lane 2 of northbound traffic of M1 63% of vehicles travel at speeds between 50kmph to 100kmph. In the case of N5 northbound lane 1 average speed of buses lies in the range of

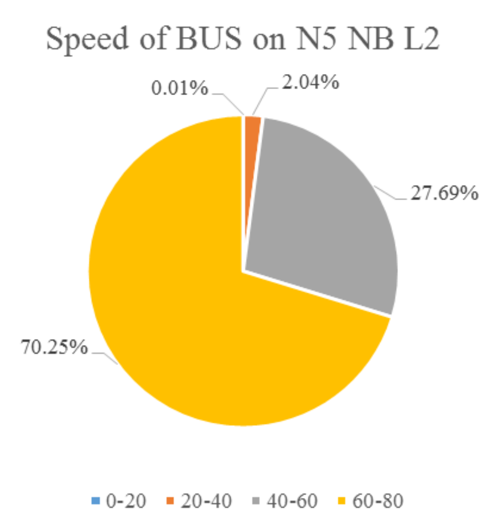
40kmph to 60kmph. While in lane 2 northbound of N5 70% of vehicles travel between the speeds of 60kmph to 80kmph.

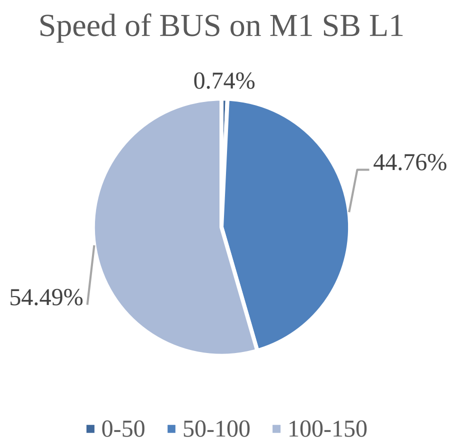
Considering the southbound of M1 and N5, In the case of M1 southbound lane, 1 majority of buses are running between the speeds of 100kmph to 150kmph.while in lane 2, 61% of buses speed lies between the ranges of 50kmph to 100kmph. In the case of the N5 southbound lane, 1 half of the buses are running at speeds ranging between40kmph to 60kmph. Whereas in lane 2 of southbound 90% of the bus's speed is ranging between 40kmph to 80kmph.

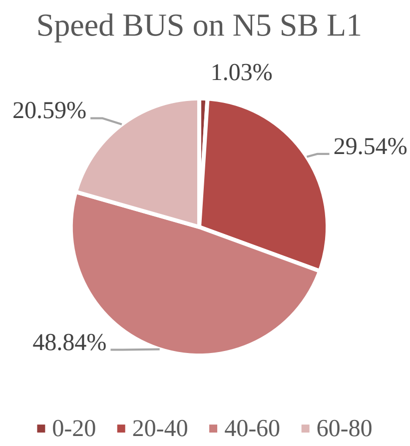


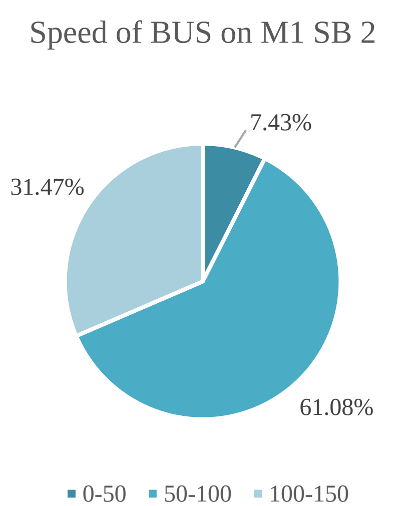


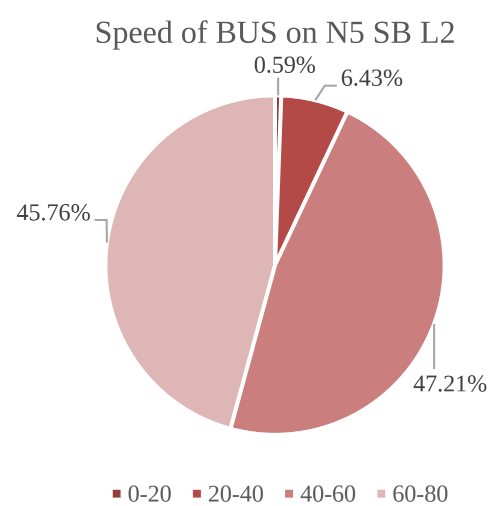




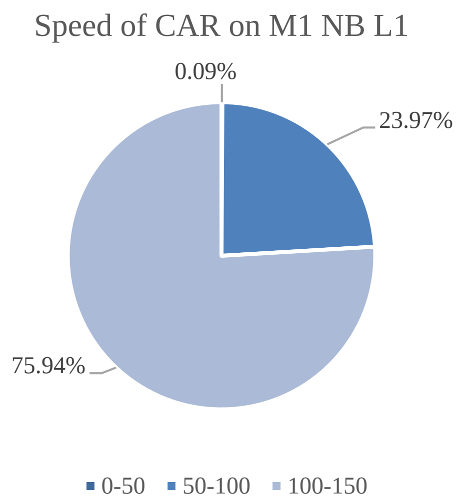


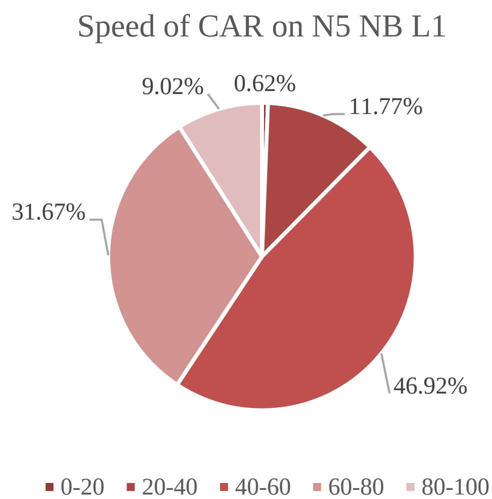


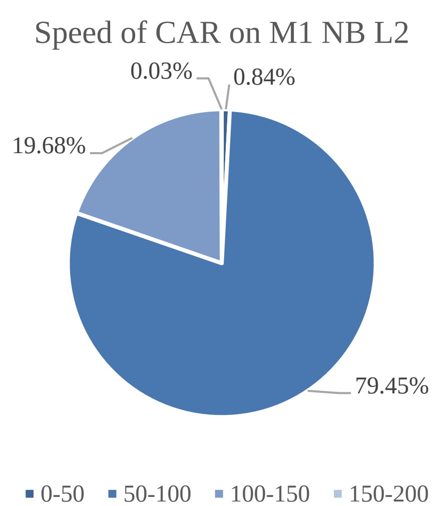


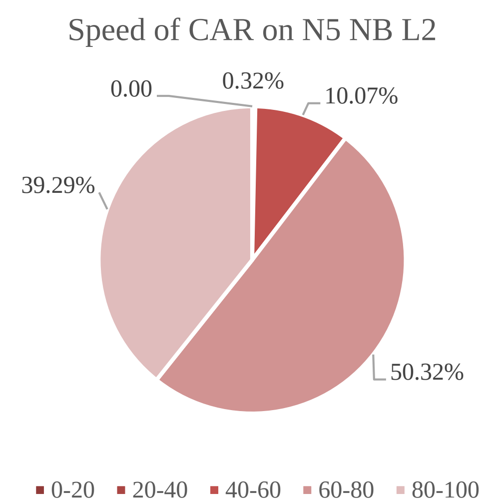


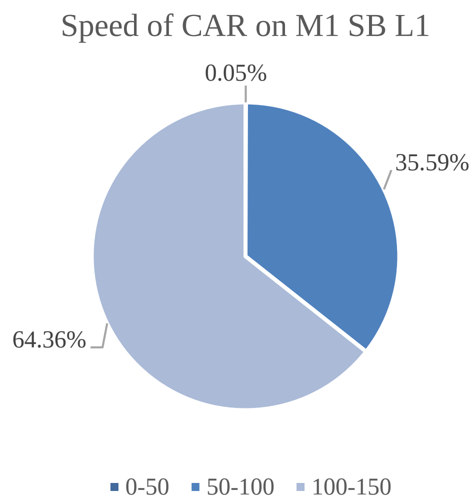
Cars are considered LTV or light traffic vehicles. The speed limit of the car on M1 is 120kmph while on N5 speed limit is 100kmph in this region. In the case of Cars, the average speed of cars in Lane 1 is near to speed limit (which is 120kmph) lane 1 is the fast lane, and almost 75% of vehicle speeds are more than 100kmph. But in lane 2 of northbound traffic of M1 80% of cars travel at speeds between 50kmph to 100kmph. In the case of the N5 northbound lane, 1 47% speed of cars lies between the ranges of 40kmph to 60kmph. While in lane 2 northbound N5 50% of vehicles travel between the speeds of 60kmph to 80kmph.The almost same trend is seen in southbound traffic. Pie charts are given below.

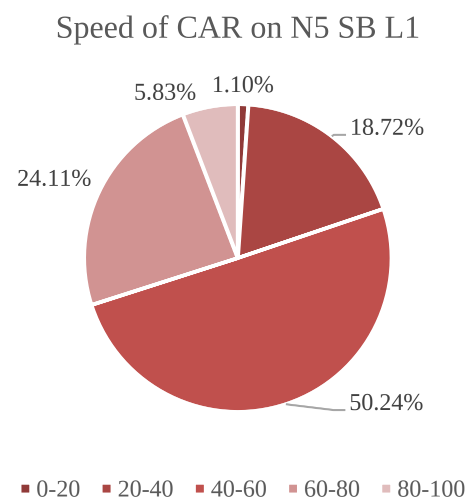

Speed of CAR on M1 NB L1
0.09%
23.97%
75.94%
0-50
50-100
100-150

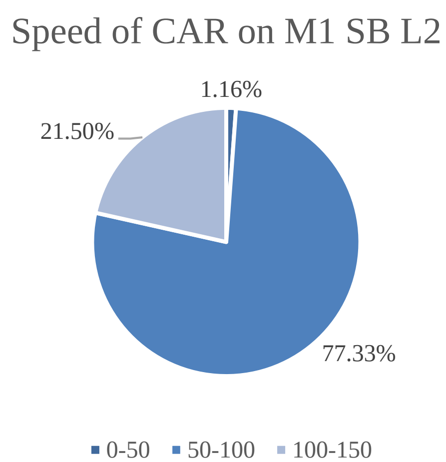

Speed of CAR on N5 NB L1
9.02%
0.62%
11.77%
31.67%
46.92%
0-20
20-40
40-60
60-80
80-100

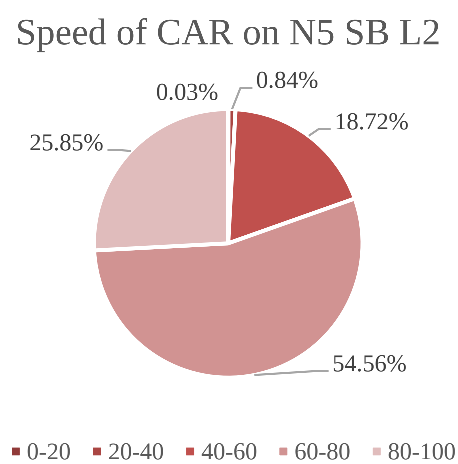

Speed of CAR on M1 NB L2
0.03%
0.84%
19.68%
79.45%
0-50
50-100
100-150
150-200


Speed of CAR on N5 NB L2
0.00
0.32%
10.07%
39.29%
50.32%
0-20
20-40
40-60
60-80
80-100

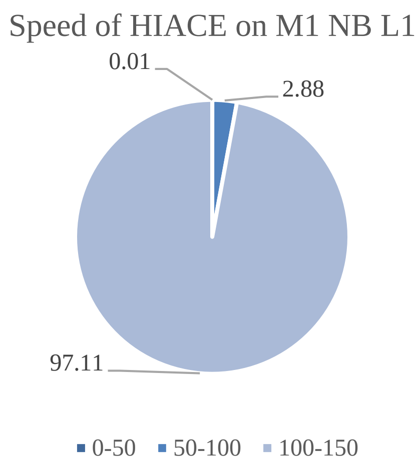


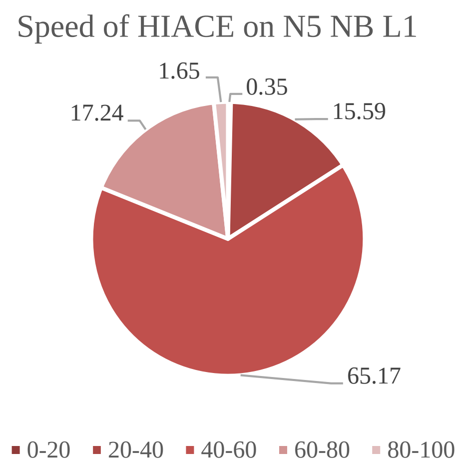


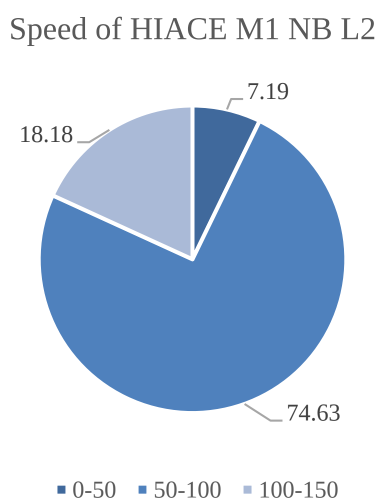


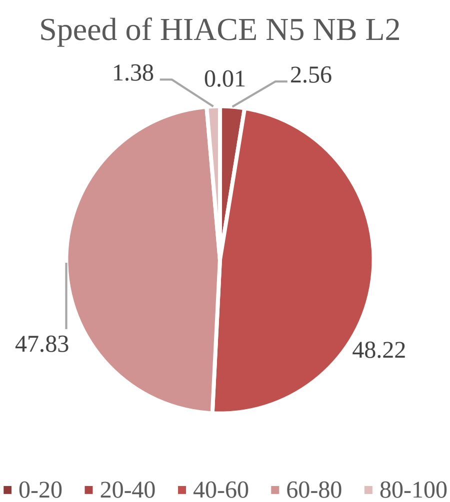


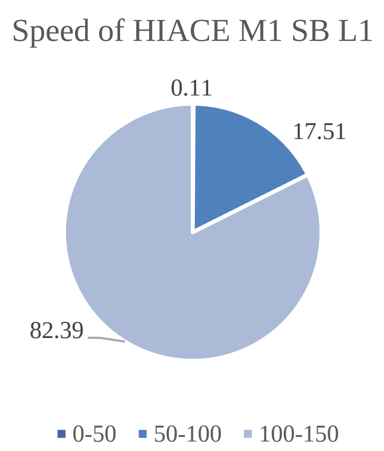
Hiace lies in the category of public transport on M1 northbound lane 1 97% hiace moves in speed ranging between 100kmph to 150kmph. While lane 2 of this direction 75% hiace speed lies between 50kmph to 100kmph. In the case of N5 northbound, most of hiace is moving between the speeds of 40kmph to 80kmph.

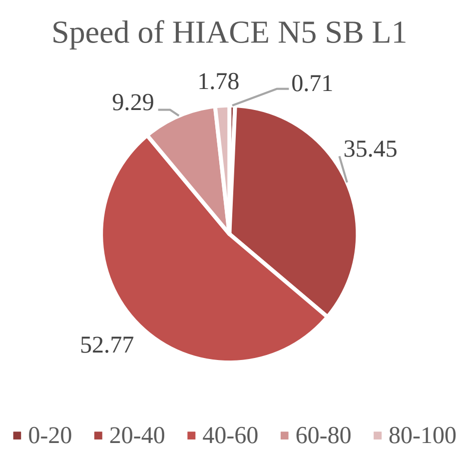

Speed of HIACE on M1 NB L1
0.01
2.88
97.11
0-50
50-100
100-150

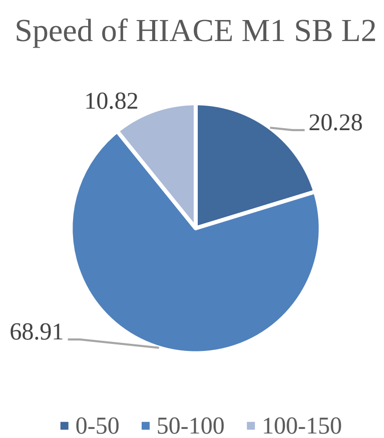

Speed of HIACE on N5 NB L1
1.65
0.35
17.24
15.59
65.17
0-20
20-40
40-60
60-80
80-100

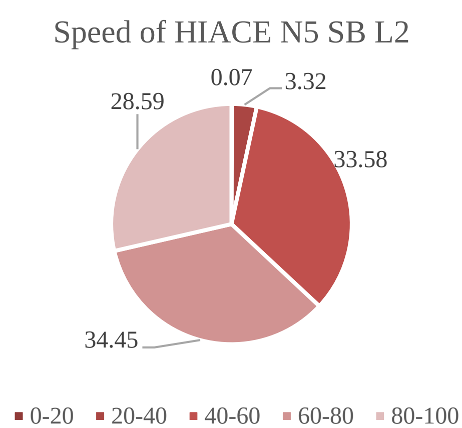

Speed of HIACE M1 NB L2
7.19
18.18
74.63
0-50
50-100
100-150


Speed of HIACE N5 NB L2
1.38
0.01
2.56
47.83
48.22
0-20
20-40
40-60
60-80
80-100

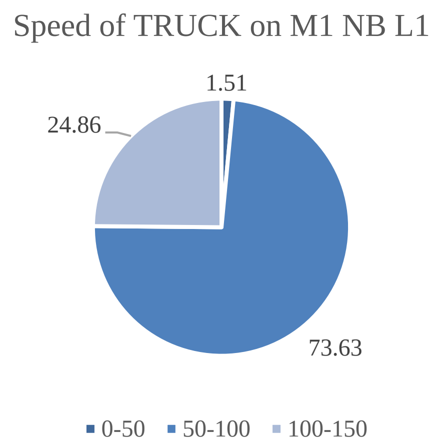


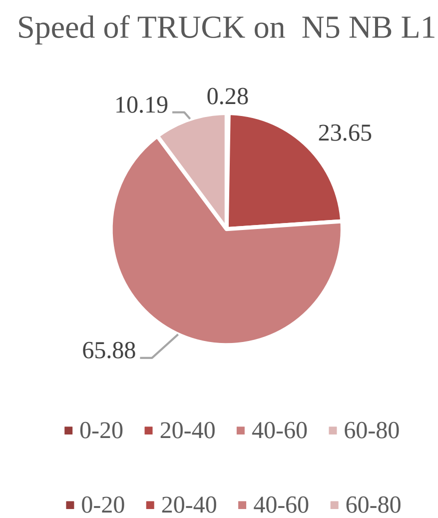


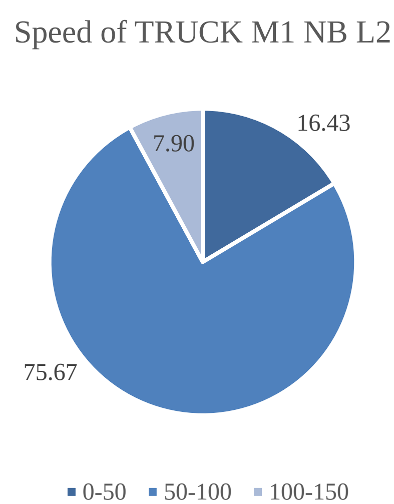


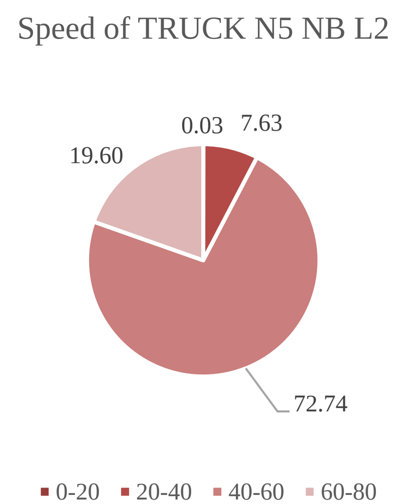


2 axles, 3 axles, 4 axles, 5 axles, and 6 axle trucks are considered in the category of Trucks. The average running speed of trucks on M1 northbound is between 50kmph to 100kmph. While southbound is slightly higher. While in the case of N5 average running speeds of trucks lie between 40kmph to 60kmph.









4.5. Comparison between Average Speed on National Highways and Motorways at Similar Traffic Demand

Taking congestion index values to assess the demand on N5 and M1. At the same congestion index on M1 and N5, Speeds on M1 are higher than that of N5. In the case of lane 1 of M1 and N5, the speeds of the vehicle on M1 are almost double that of N5. While considering northbound lane 2 of M1 and N5, the speed of traffic on M1 is relatively higher with a ratio of 2/4 than that of N5. Southbound lanes 1 of M1 and N5 don’t have the same congestion index value. In the case of southbound lane 2 of M1 and N5, the speed of traffic on M1 is relatively higher with a ratio of 1/3 than that of N5. The resulting graphs are given below.

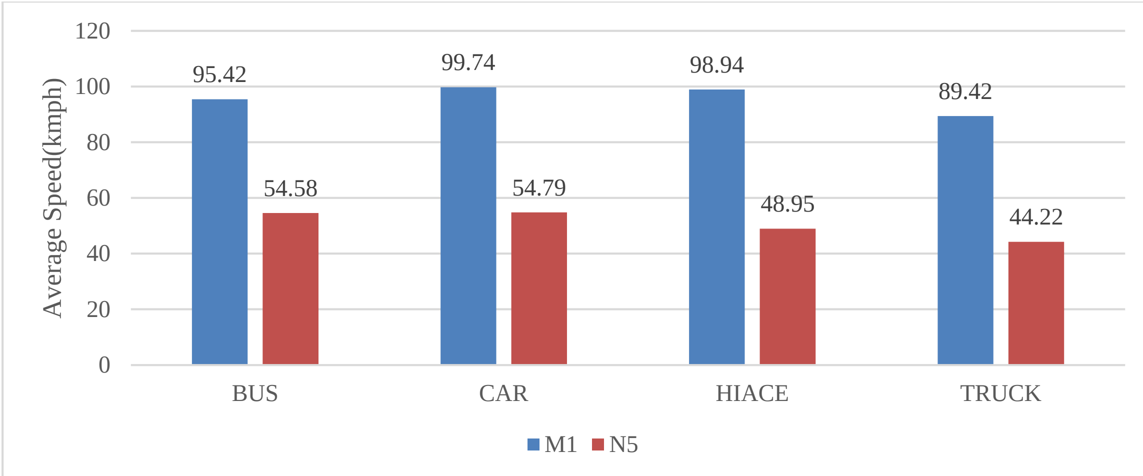


Figure 4-21 Northbound lane 1 of M1 and N5 (RCI=0.55)

For the Roadway congestion index of 0.56 in Figures 4-26, on M1 and N5 northbound lane 1 travel speeds on M1 are higher than on N5. M1 and N5 belong to two different highway entities.

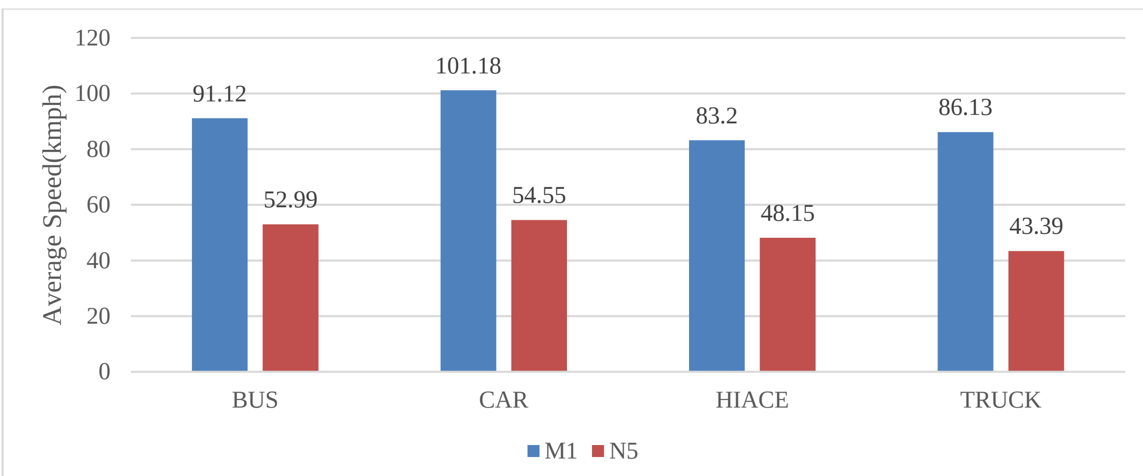


Figure 4-22 Northbound lane 1 of M1 and N5 (RCI=0.56)

For Roadway congestion index 0.546 in figure 4-27, on M1 and N5 northbound lane 1 travel speeds on M1 are higher than on N5. Travel speeds on M1 are almost double than on N5 concerning each vehicle categorization.

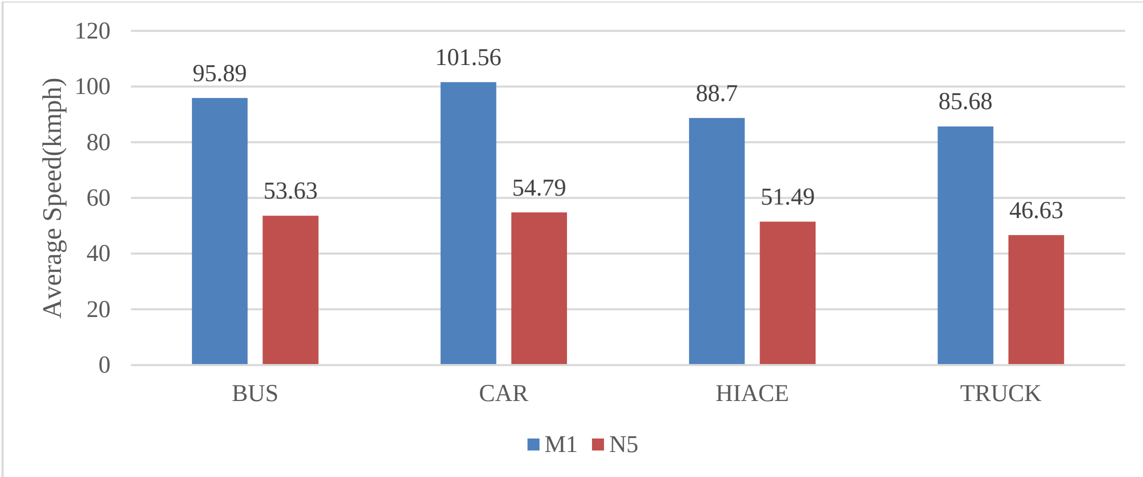


Figure 4-23 Northbound lane 1 of M1 and N5 (RCI=0.546)

Figure 4-28 shows the travel speed comparison for northbound lane 2 between M1 and N5 with a roadway congestion index of 0.74. Travel speeds on M1 are slightly higher than on N5.

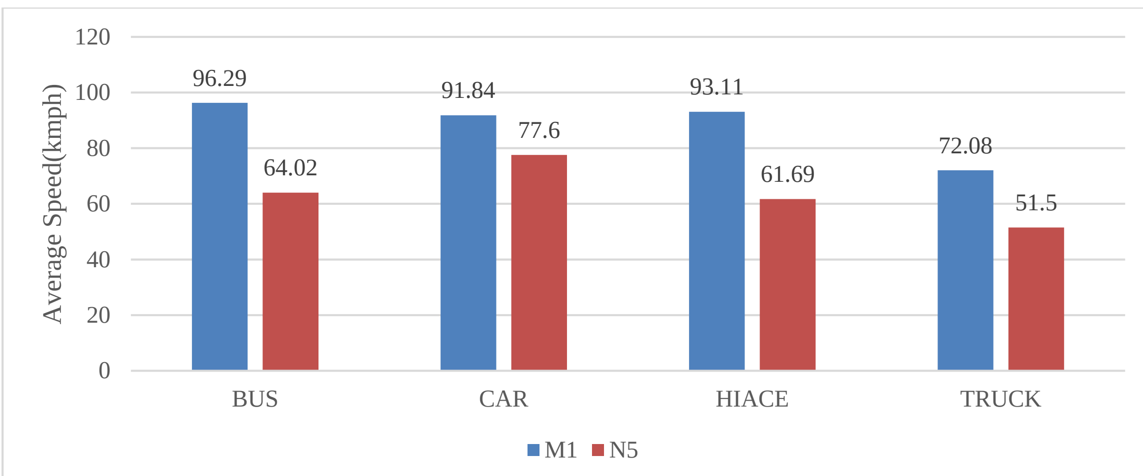


Figure 4-24 Northbound lane 2 of M1 and N5 (RCI=0.74)

Figure 4-29 shows the travel speed comparison for northbound lane 2 between M1 and N5 on a roadway congestion index of 0.78. Travel speeds on M1 are slightly higher than on N5.

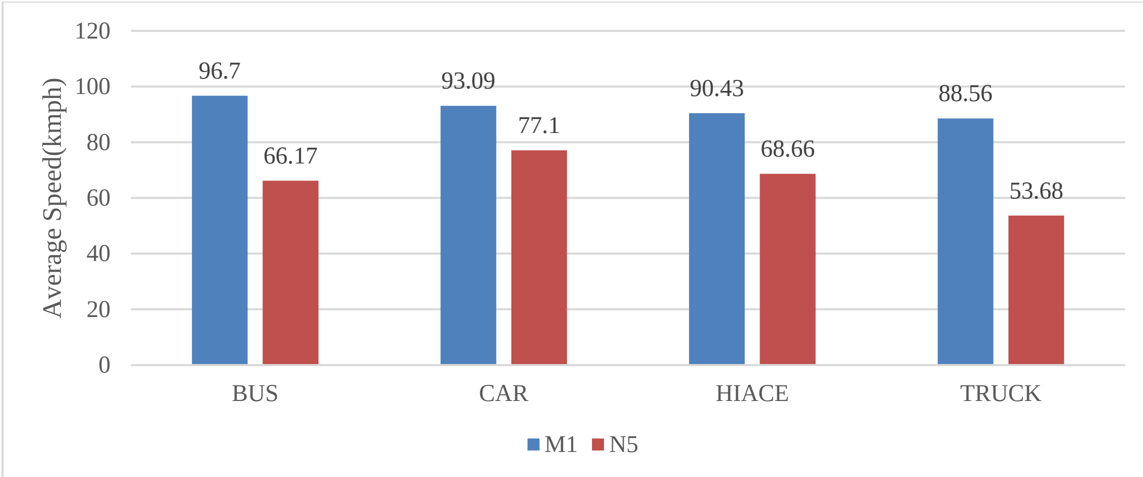


Figure 4-25 Northbound lane 2 of M1 and N5 (RCI=0.78)

For the Roadway congestion index of 0.77 in figure 4-30, on M1 and N5 northbound lane 2 travel speeds on M1 are higher than on N5. Travel speeds on M1 are almost double that on N5 for each vehicle categorization. Southbound lanes 1 of M1 and N5 don’t have the same congestion index value. So, there is no comparison exists between M1 and N5 on southbound lane 1.

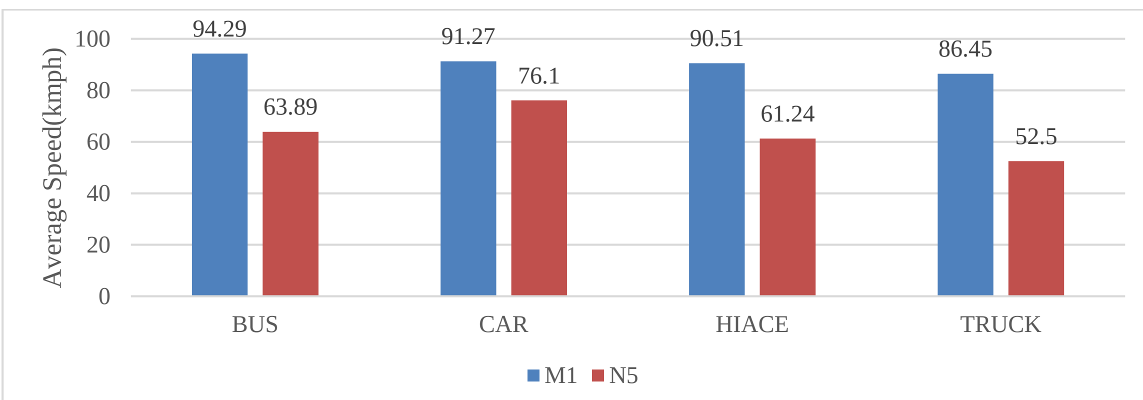


Figure 4-26 Northbound lane 2 of M1 and N5 (RCI=0.77)

In the case of southbound lane 2 of M1 and N5, the speed of traffic on M1 is relatively higher with a ratio of 1/3 than that of N5. Figures 4-31, 4-32, and 4-33 show the travel speed comparison between M1 and N5 southbound lane 2 for congestion index values of 0.55, 0.66, and 0.54 respectively.

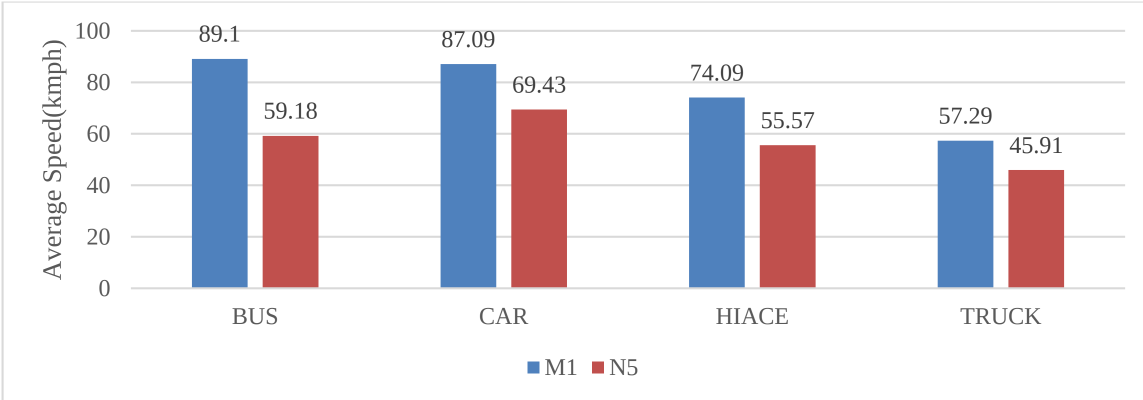


Figure 4-27 Southbound lane 2 of M1 and N5 (RCI=0.55)

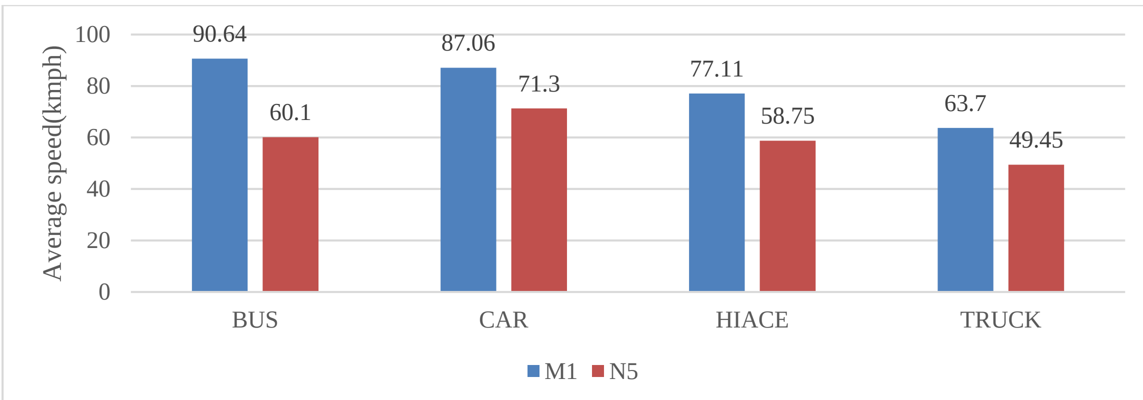


Figure 4-28 Southbound lane 2 of M1 and N5 (RCI=0.66)

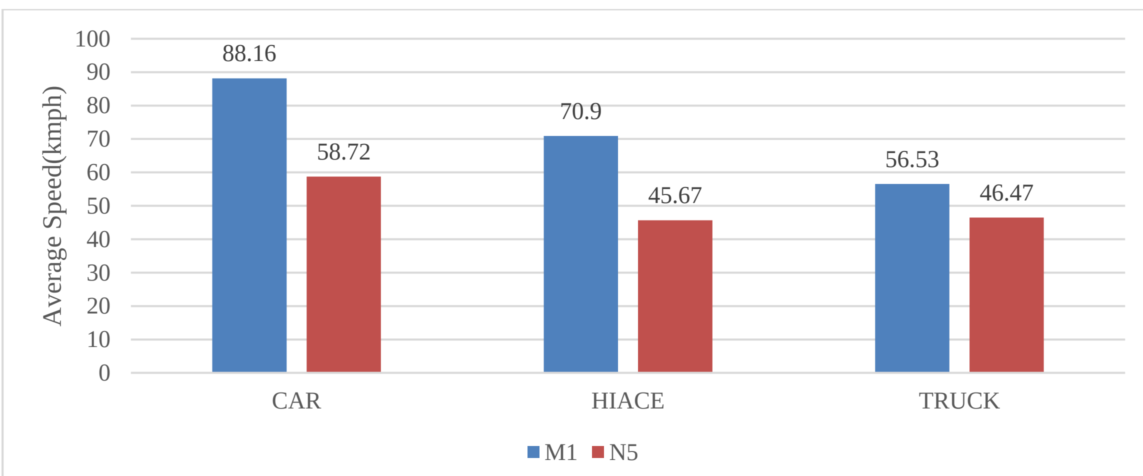


Figure 4-29 Southbound lane 2 of M1 and N5 (RCI=0.54)

4.6. Speed Analysis for Day and Night

The figures given below show the effect of daylight on traffic speed. Daytime is considered from 10:00 am to 3:00 pm noon. Traffic passing the loops from 10:00 pm to 3:00 am is taken for night-time analysis. Almost in every case speed of vehicles are greater in daylight than that of vehicle speeds at night except LTV speed on northbound and southbound lane 1 of N5. Figure 4-34 shows the comparison of travel speed day and night time on northbound lane 1 for M1.

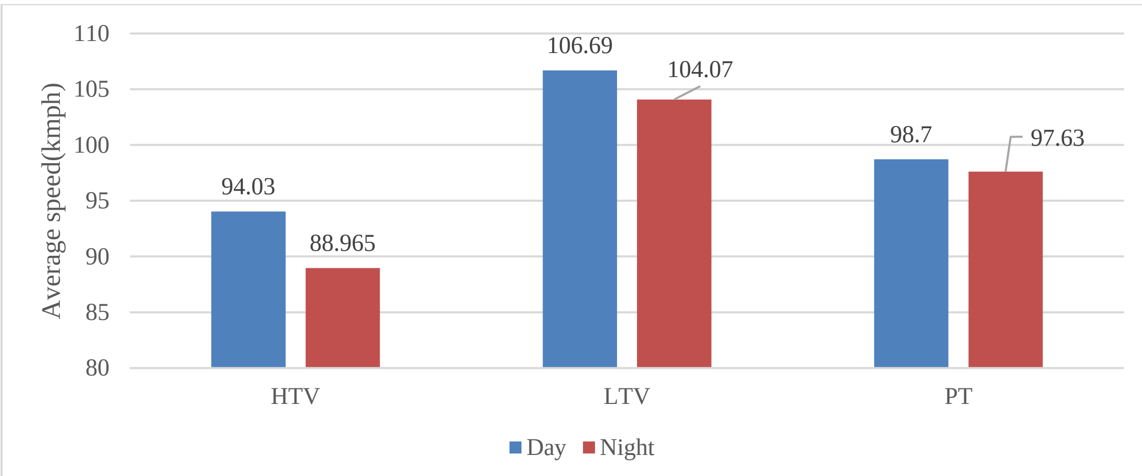


Figure 4-30 Day and Night speed comparison of M1 northbound lane 1

Figure 4-35 shows the comparison of travel speed day and night time on northbound lane 2 for M1. Travel speeds are higher during the day than at night time.

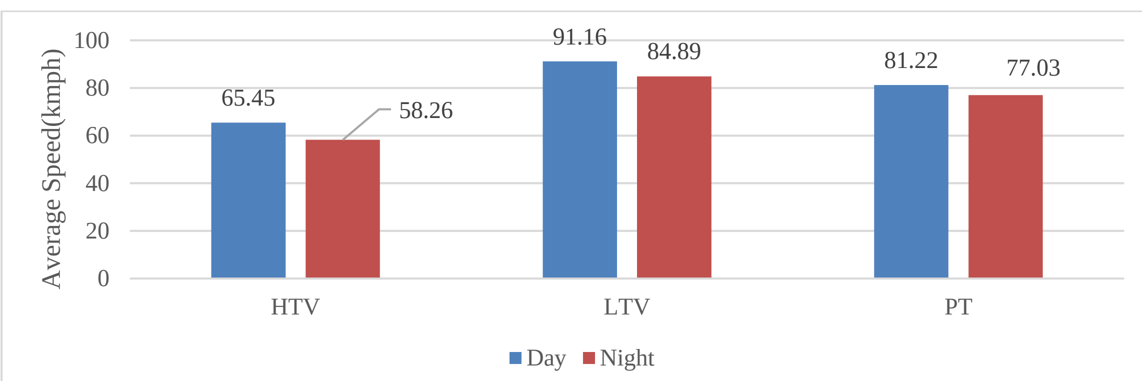


Figure 4-31 Day and Night speed comparison of M1 northbound lane 2

Figure 4-36 shows the comparison of travel speed day and night time on southbound lane 1 for M1. Travel speeds are higher during the day than at night time.

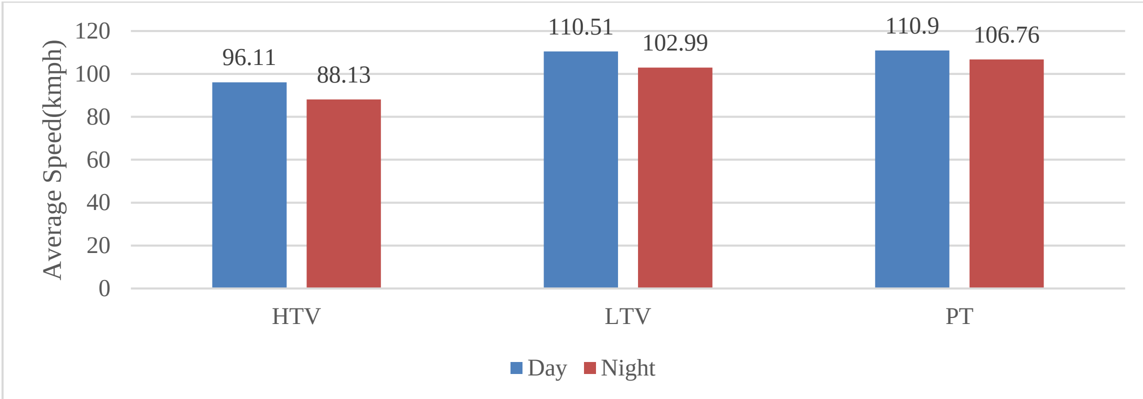


Figure 4-32 Day and Night speed comparison of M1 southbound lane 1

Figure 4-37 shows the comparison of travel speed day and night time on southbound lane 2 for M1. Travel speeds are slightly higher during the day than at night time.

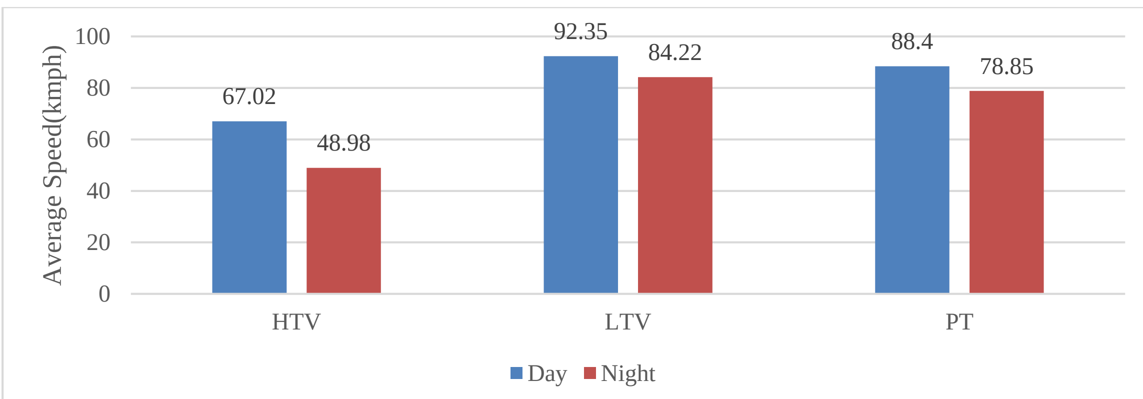


Figure 4-33 Day and Night speed comparison of M1 southbound lane 2

Figure 4-38 shows a comparison of travel speed on day and night time on northbound lane 1 for N5. Travel speeds are slightly higher during the day than at night time except in the case of LTV where vehicle speeds are slightly higher at night.

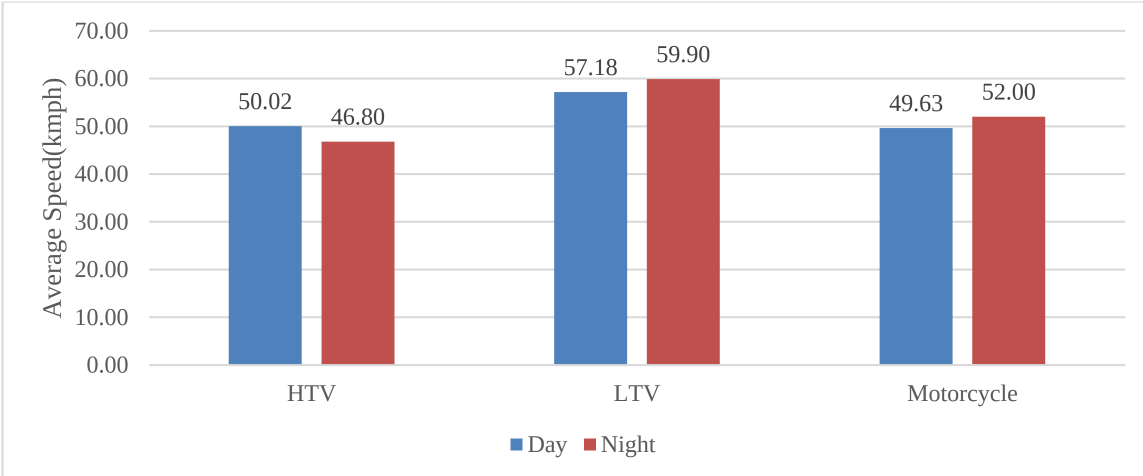


Figure 4-34 Day and Night speed comparison of N5 northbound lane 1

Visibility impacts travel speed and driver behavior on highways. Figure 4-39 shows the comparison of day and night time travel speed on N5 northbound lane 2 for each vehicle category. Vehicle categorization is made based on Light transport vehicles, heavy transport vehicles, and motorcycles. Travel speeds are slightly greater in the case of daylight than at night.

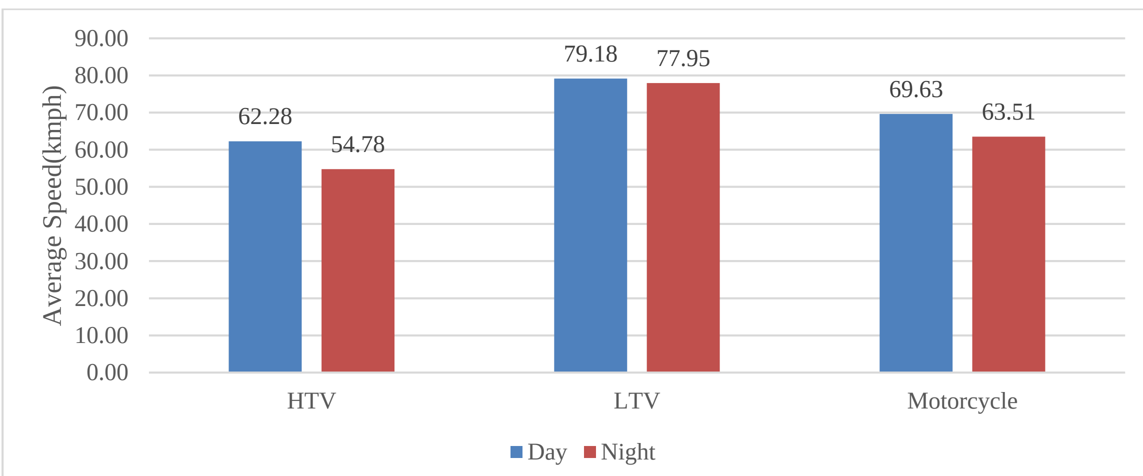


Figure 4-35 Day and Night speed comparison of N5 northbound lane 2

Figures 4-40 and 4-41 show a comparison of day and night time travel speed on N5 southbound lane 1 and N5 southbound lane 2 for each vehicle category respectively. Travel speeds are slightly greater in the case of daylight than at night except for LTV in the case of N5 southbound lane 1 where travel speeds at night are greater than in daylight.

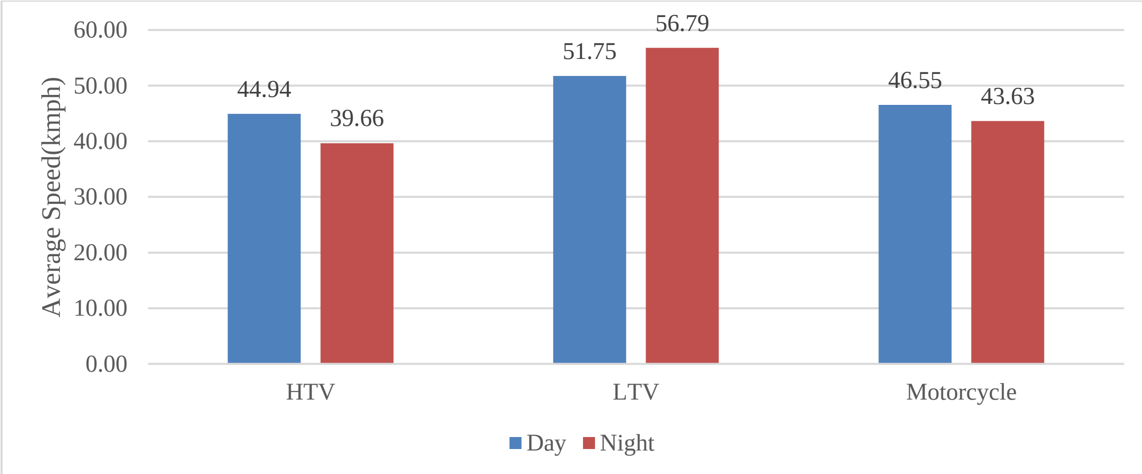


Figure 4-36 Day and Night speed comparison of N5 southbound lane 1

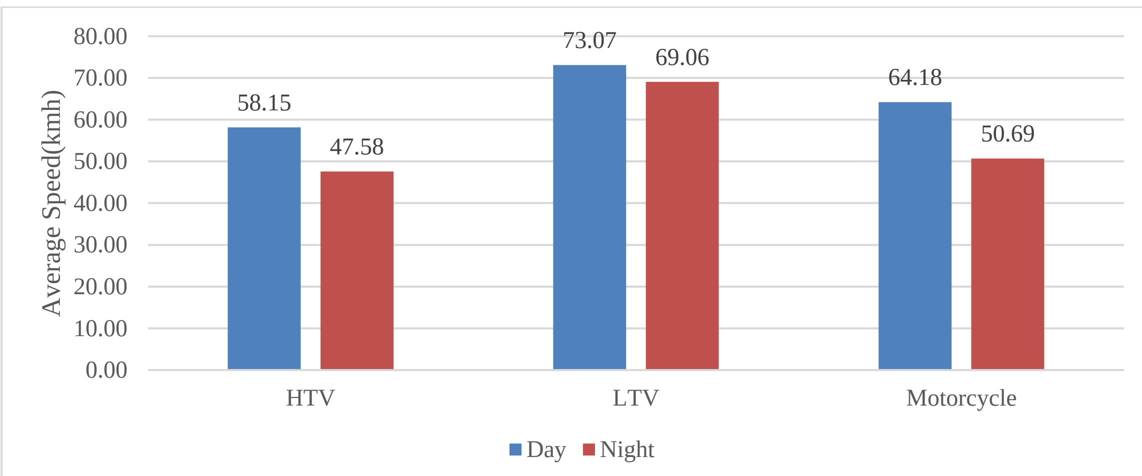


Figure 4-37 Day and Night speed comparison of N5 southbound lane 2

4.7. Weather Conditions impact Travel Speed

On M1 and N5 weather conditions' impact on Traffic, speed is assessed. Precipitation data was received from PMD near research sites. In the case of public transport on M1 northbound, almost a reduction in speed up to 20kmph has been seen while in the southbound direction of M1 only a 3kmph reduction in travel speed has been noted. While almost 10kmph reduction in speed of LTV is noted but no significant impact is seen on southbound traffic. In the case of HTV speed significant reduction can be seen in the northbound direction but relatively less impact on southbound traffic. Figure 4-42 shows a speed comparison for dry and wet pavement conditions in the case of M1 northbound lane 1.

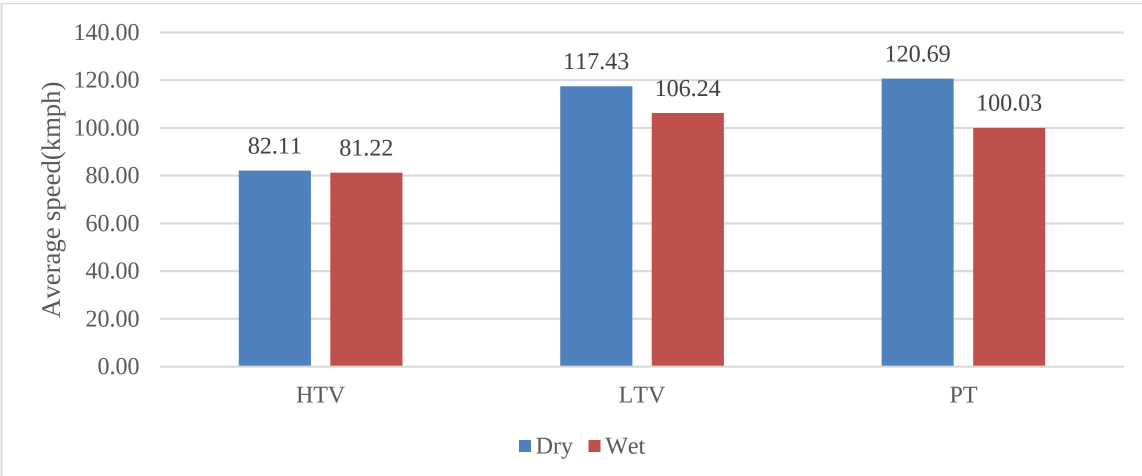


Figure 4-38 Speed Comparison of weather condition M1 Northbound Lane 1

Figure 4-43 shows speed comparison in the case of M1 northbound lane 2 for dry and wet pavement conditions. Travel speed in case of dry pavement conditions is more than travel speed in wet pavement conditions.

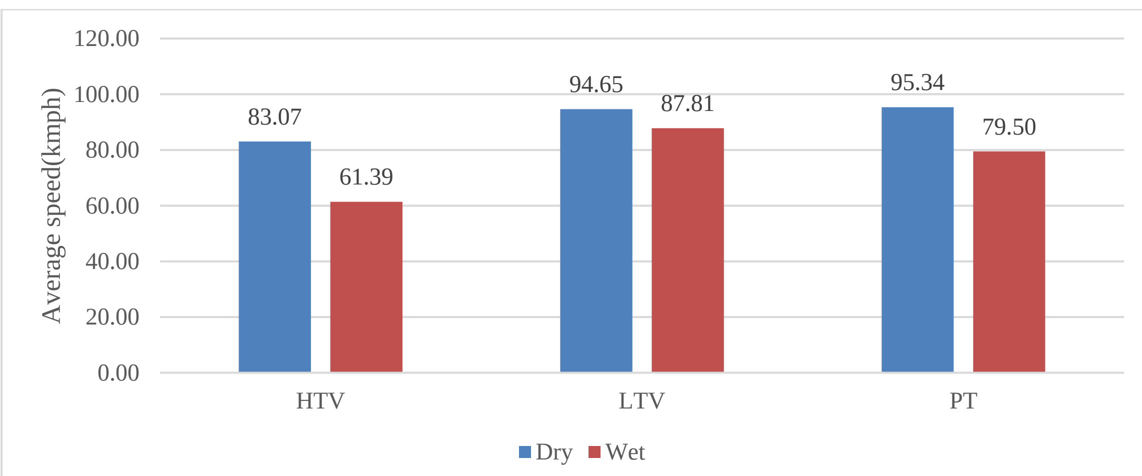


Figure 4-39 Speed Comparison of weather condition M1 Northbound Lane 2

Figure 4-44 and 4-45 shows speed comparison in the case of M1 southbound lane 1 and M1 southbound lane 2 respectively for dry and wet pavement condition. Travel speed in the case of dry pavement conditions is slightly higher than travel speed in wet pavement conditions.

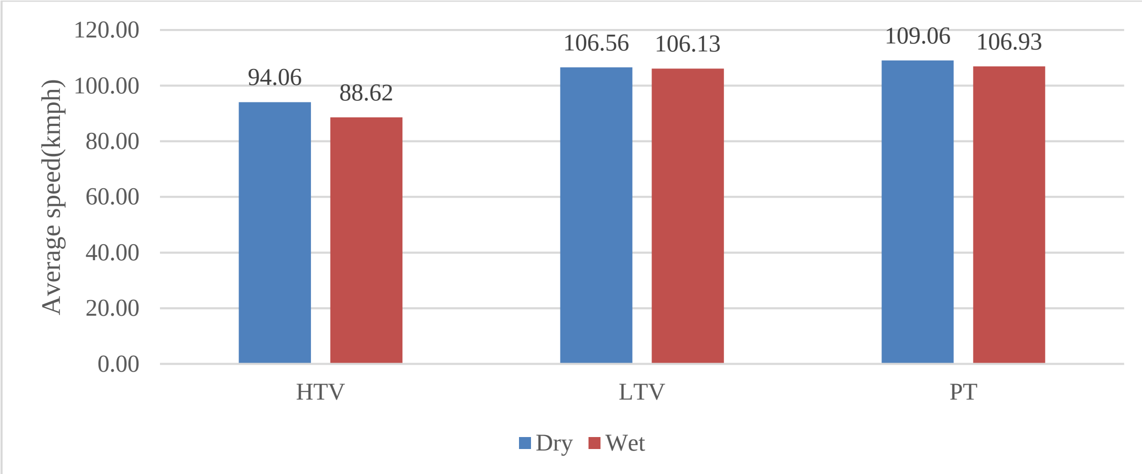


Figure 4-40 Speed Comparison of weather condition M1 Southbound Lane 1

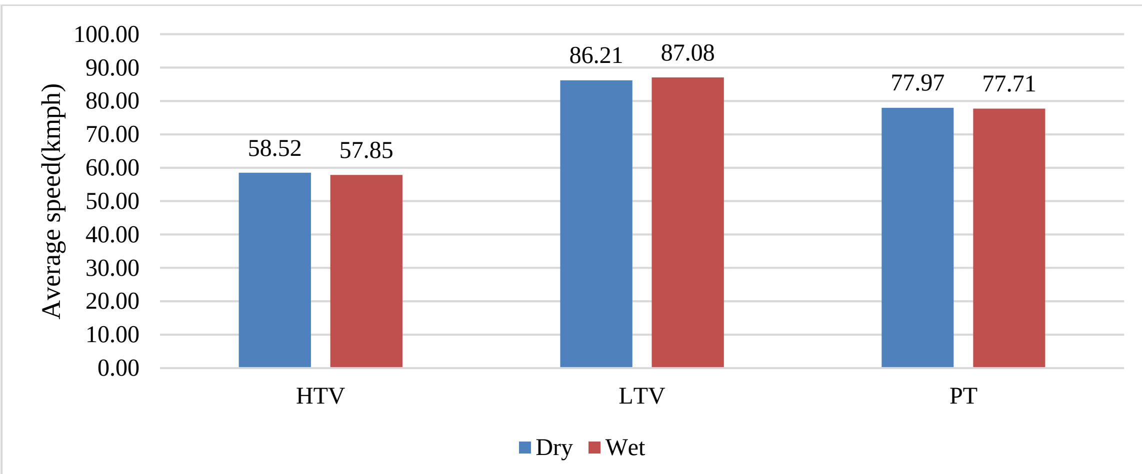


Figure 4-41 Speed Comparison on weather condition M1 Southbound Lane 2

Considering the case of N5 traffic in different weather conditions only up to a 2kmph reduction in traffic speed can be seen. Figure 4-46 shows speed comparison in the case of N5 northbound lane 1 for dry and wet pavement conditions.

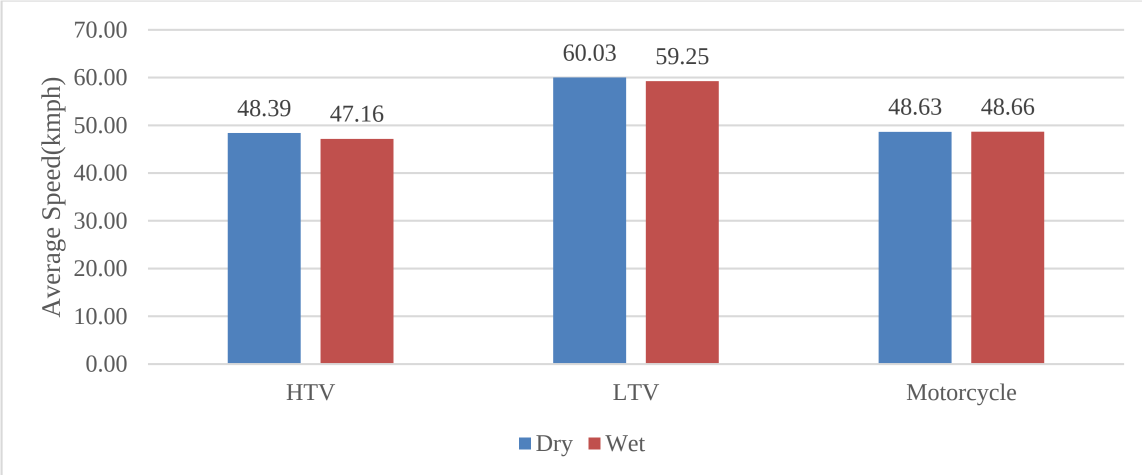


Figure 4-42 Speed Comparison of weather conditions N5 Northbound Lane 1

Figure 4-47 shows speed comparison in the case of N5 northbound lane 2 for dry and wet pavement conditions. Travel speed varies with the change in intensity of rain.

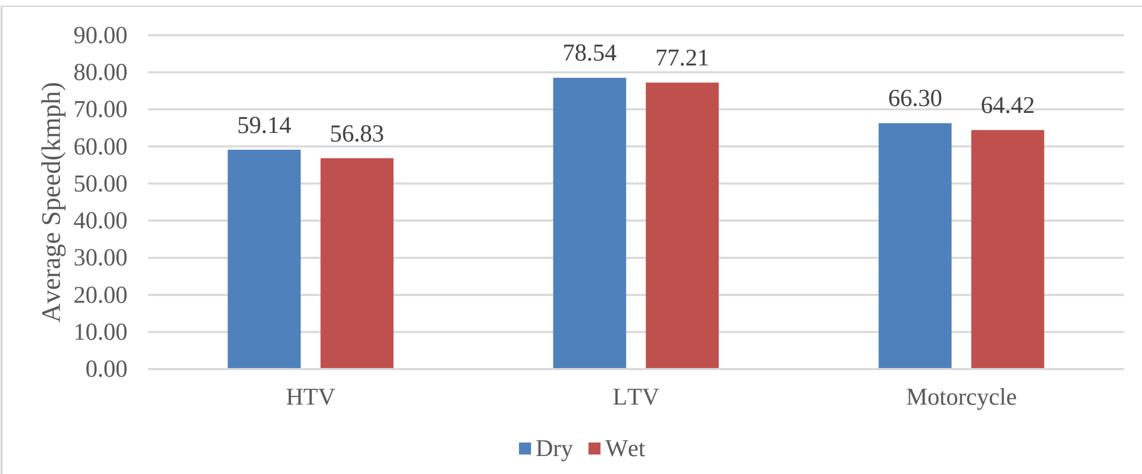


Figure 4-43 Speed Comparison on weather condition N5 Northbound Lane 2

Figure 4-48 and 4-49 shows speed comparison in the case of N5 northbound lane 2 for dry and wet pavement condition. Travel speeds reduce in wet weather conditions because it directly impacts driver behavior as well as the vehicle. A very slight reduction is observed in the case of LTV which is up to 1km/hr. while in the case of HTV reduction of 3km/hr is observed. Reduction of 5km/hr and 3km/hr in the speed of motorcycles for N5 southbound lane 1 and southbound lane 2 respectively.

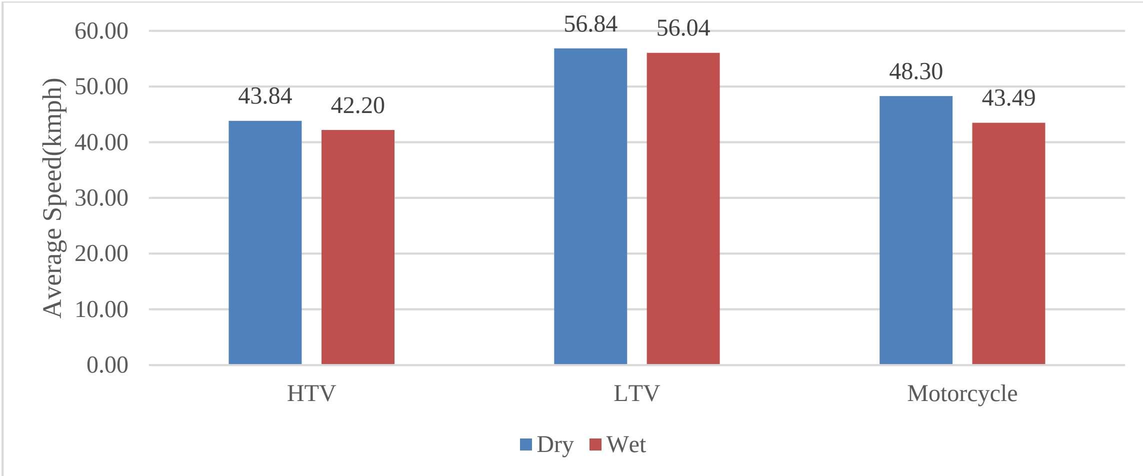


Figure 4-44 Speed comparison on weather condition N5 Southbound Lane 1

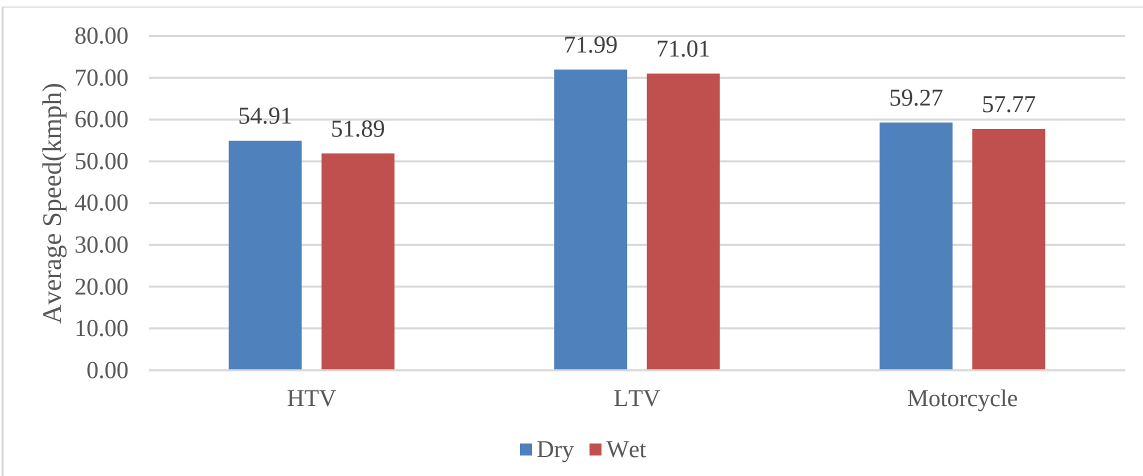


Figure 4-45 Speed Comparison of weather condition N5 Southbound Lane 2

CHAPTER 5

5. Conclusion and Discussion

The following conclusion was reached by the results of the study.

- This study selected the speed performance index as the road network state evaluation indicator and divided the traffic state into four categories: heavy congestion, mild congestion, smooth, and very smooth. Based on the traffic state classification standards, the study proposed the road network congestion index and the road network congestion index to measure the congestion degree of the road segment. Taking Islamabad Peshawar Motorway (M-1) and National Highway (N-5) congestion analysis as a case study, this study carried out national highway and motorway traffic characteristics analysis, road segment congestion assessment, and road network congestion assessment. This analysis can help us to assess accurately and grasping of traffic operation status, which provides important information for future traffic management. On M1, 98% of traffic is very smooth in lane 1. While in lanes 2 and 3 almost 78% of traffic flow is smooth and running at maximum permissible speed. The congestion index peaks at weekends. In the case of N5, the average speed performance index is 70% which is considered for smooth traffic flow. According to road segment congestion, on M1 average congestion index assessment is less than 1 which means smooth traffic flow similarly in southbound traffic same trend is seen. The congestion index on National Highway N5 is also less than 1 which means traffic flow is very smooth.
- Inclement weather appeared to have an impact on speeds on both roadways studied. Rain reduced the average vehicular speed. Wet surface conditions resulted in a reduction of average speeds by 7% in Motorway M1. In the case of N5, a 3% reduction in average travel speed is noticed.
- Change in visibility affects the driver's behavior so the resulting speed is reduced in case of night. The same trends of speed reduction are seen on both highways

and motorways. Research shows an 8% reduction in traffic speed due to darkness in the case of M1 and a 5% reduction in speed on N5.

- The average speed of vehicular traffic on Motorway M1 was recorded at 90kmph. Which is less than the maximum permissible speed. But this resulting average speed has an impact on changes in weather conditions, driver behavior, etc. This discrepancy was attributed to its homogenous traffic composition with higher percentage composition of heavy vehicles and very fast-moving vehicles. The spot speed of vehicular traffic on national highway N5 falls within the range of 50 – 70 kmph. A general speed limit of 80-100km/h is reasonable and guarantees the safety of motorists on highways.

Table 5-1 Conclusion of Spot speed study of M1 and N5

Sr. No.	Traffic Directions	v/c	Average Speed(kmph)	SPI(%)	RCI	LOS
1	M1 Northbound Lane 1	0.05	106.36	90.76	0.923	A
2	M1 Northbound Lane 2	0.12	78	67.57	0.64	A
3	M1 Southbound Lane 1	0.09	98.14	83.57	0.83	A
4	M1 Southbound Lane 2	0.11	73.99	63.11	0.54	A
5	N5 Northbound Lane 1	0.07	51.69	59.78	0.56	A
6	N5 Northbound Lane 2	0.08	66.52	69.37	0.758	A
7	N5 Southbound Lane 1	0.06	46.51	53.55	0.388	A
8	M1 Southbound Lane 2	0.08	62.95	72.59	0.71	A

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