

**IMPACT ANALYSIS OF METRO RAIL
CONSTRUCTION WORK ZONE ON URBAN ROAD TRAFFIC
AND NOISE LEVEL:
A CASE STUDY OF
AHMEDABAD METRO RAIL PROJECT LINKS**

A Thesis submitted to Gujarat Technological University

for the Award of

Doctor of Philosophy

in

Civil Engineering

By

Toral H. Vyas

[179999912018]

under supervision of

Dr. Harishkumar R. Varia



GUJARAT TECHNOLOGICAL UNIVERSITY

AHMEDABAD

[December - 2023]

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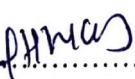

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ABSTRACT

Cities play a vital role in generating economic growth and prosperity. The sustainable development of cities largely depends on their physical, social and institutional infrastructure. In this context, the importance of transport infrastructure is paramount. To cater the increased demand for passenger trips in the large city areas, nowadays metro rail construction is now envisaged in several metropolitan cities. The construction of metro rail systems has become increasingly common in urban areas to address the growing transportation needs of a rapidly developing society. However, the construction work zones associated with metro rail projects can have significant impacts on traffic flow and noise levels in the surrounding areas. This thesis aims to assess the effects of metro rail construction work zones on traffic flow, delay and noise level.

To achieve this goal, a comprehensive impact analysis was conducted by collecting and analysing data from a case study of a metro rail construction project. The traffic data have been collected using the videography method during morning, noon and evening hours. The study focused on evaluating traffic patterns, including traffic volume, speed, travel time, and delay during and after the construction work zone. Additionally, noise level measurements were recorded at various locations in the study area. Traffic and noise level data have been collected during the construction stage and after the construction stage of metro rail construction using the noise level meter. The collected data have been processed using MS Excel 2010. In addition to this, the prediction models are also developed to study the major factors affecting the traffic flow, delay and noise level in the study area.

The findings of the study revealed that the presence of a metro rail construction work zone resulted in noticeable disruptions to traffic flow during the construction stage. The observed reduction in flow varies between 1% and 11% on the majority links of the study area. The observed increase in delay varies between 11% and 37% on various links in the study area. The study demonstrated that metro rail construction work zones had a substantial impact on noise levels in the study area. The observed increase in noise level varies between 1% and 6% in the study area.

Furthermore, the factors affecting traffic flow, delay and noise level are identified for

during the construction stage and after the construction stage in the study area of the metro rail project. The prediction models for flow, delay and noise are developed using the regression technique. For the developed models, two validation techniques, i.e., cross validation and statistical validation are applied. The common factors affecting flow during and after construction stages are the available carriage way width, proportion of car and proportion of two-wheeler. The common factors affecting delay during and after the construction stages are flow and length. The common factors affecting noise level during and after construction stage are honking event, no. of two wheeler and car. This research enables to estimate and quantify the impacts of construction work zone on existing traffic and noise level. From the study, it can be concluded that per link per direction of traffic, (1) reduction in traffic flow can be estimated as about 76 PCU/hr per 1000 sq. m increase in restricted area, (2) increase in delay can be estimated as about 1.3 sec/veh per 1000 sq. m increase in restricted area and (3) increase in noise level can be estimated as 2.00 dB(A) per three min per 1000 sq. m increase in restricted area.

Based on these findings, recommendations are proposed to mitigate the negative impacts of metro rail construction work zones. By understanding the impact of metro rail construction work zones on traffic and noise levels, policymakers, urban planners, and project managers can make decisions to minimise the disruptions caused during the construction phase.

Key Words: Work zone, traffic flow, delay, noise level, regression analysis

Acknowledgement

I would like to express my sincere gratitude to my supervisor, Prof. (Dr.) Harish Kumar R. Varia, for their unwavering support, invaluable guidance, and insightful feedback throughout the entire research process. Their expertise and encouragement have been instrumental in shaping the direction of this study.

I am thankful to Late Prof. (Dr.) Pradip Kumar J. Gundaliya for his support and motivation in this journey. I am deeply grateful to the members of Doctoral Progress Committee, Prof. (Dr.) A. M. Jain and Prof. (Dr.) Jiten Shah for reviewing my research work and suggesting valuable inputs and scope for improvements to it on a regular basis. I am thankful to Prof. (Dr.) R. B. Khasiya and Prof. (Dr.) R. K. Jain, Head of Civil Engineering Department for creating a stimulating environment that fosters intellectual growth. I am thankful to the faculty members Prof. V. J. Chitaria and Prof. R. N. Shukla, Associate Professor, Civil Engineering Department. Their dedication to teaching and research has been an inspiration to me.

I am deeply grateful to Prof. Jalpa P. Modi, Prof. Jitisha Kamble for their continuous encouragement. I am thankful to Prof. (Dr.) P. S. Ramanuj and Prof (Dr.) P. R. Patel for their support. I am thankful to the P.G. students, Rajnish, Piyush, Stuti and Divyaraj for helping me in the data collection. I would like to acknowledge the Gujarat Technological University for granting access to their resources and facilities for research work.

I am indebted to family members for their unwavering support, understanding and encouragement throughout this journey. Their belief in my abilities and their patience during the challenging times have been a constant source of motivation.

Finally yet importantly, I am thankful to almighty God for giving me enough courage and strength throughout my research work.

Dedicated to

My Father in Law

Late Shri M. K. Vyas

&

My Father

Shri R. U. Pandya

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List of Abbreviation

ANPR	Automated Number Plate Recognition
ATIS	Advanced Traveller Information Systems
AVI	Automated Vehicle Identification
AVL	Automatic Vehicle Location
BPNN	Back Propagation Neural Network
CNOSSOS-EU	Common Noise Assessment Methods in Europe
CORSIM	Corridor Simulation
CORTN	Calculation of Road Traffic Noise
DLLMS	Dynamic Late Lane Merge System
EKF	Extended Kalman Filter
GRIP	Graphical Route Information Panels
HCA	Heterogeneous Cellular Automata
HCM	Highway Capacity Manual
HCS	Highway Capacity Software
LRT	Light Rail Transit
LUR	Land Use Regression
MARD	Mean Absolute Relative Difference
MLR	Multilinear Regression
MOT	Maintenance of Traffic
MP	Max Pressure
ODOT	Ohio Department of Transportation
OFD	Optimal Flow Distribution
PCE	Passenger Car Equivalent
PCU	Passenger Car Units
QOS	Quality of Service
RMSE	Root Mean Square Error
RSR	Root Mean Square Error -Observations Standard Deviation Ratio

SOC	Self-Organized Criticality
STSGRU	Spatio-Temporal Shared Gated Recurrent Unit
SVR	Support Vector Regression
TTC	Temporary Traffic Control
VISSIM	Verkehr In Stadten Simulations Model
VMS	Variable Message Signs
WZCAT	Work Zone Capacity Analysis Tool

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Appendix-C:	Noise Level data collection form

Chapter- 1

Introduction

1.1 General

India is one of the world's fastest-growing economies, aiming to be a \$5 trillion economy by 2026 and a \$40 trillion economy by 2047, when India will celebrate its 100th anniversary of independence. However, in order to become a global economic powerhouse, several steps should be taken. Cities are the loci of economic growth and innovation, where productive firms, better-paying jobs, and key institutions are located. Cities in India will need to play a critical role if the country is to become a global economic powerhouse. Between 1970 and 2018, the population of Indian cities has increased from 109 million to 460 million. Already the world's second-largest urban community, the country is expected to add another 416 million people to its cities by 2050, giving it a 50 percent urban population share [1]. Figure 1.1 shows the urban population growth in India.

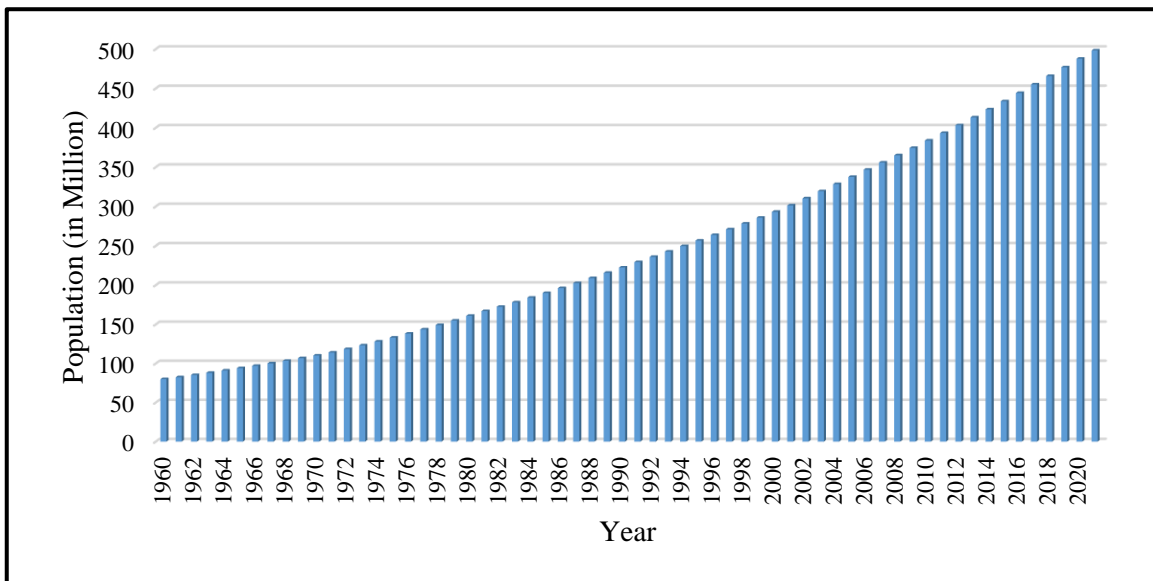


Figure 1.1 Urban population growth in india

(Source: data.worldbank.org) [2]

Because of urbanization, rising incomes and lack of adequate public transportation, there has been an increase in personalized vehicular growth. Figure 1.2 shows No. of registered vehicles in India.

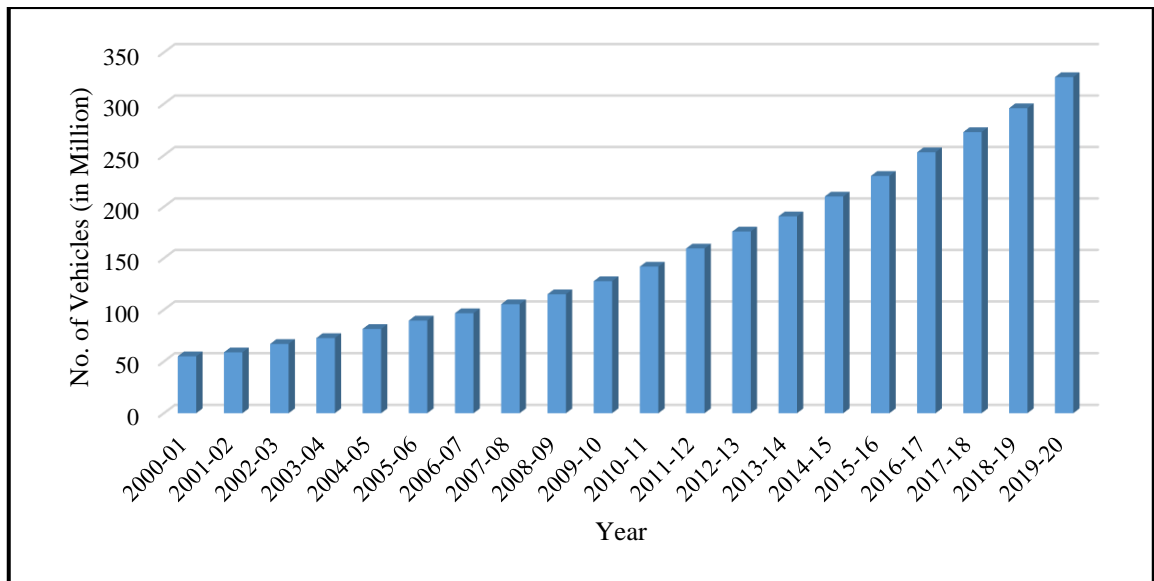


Figure 1.2 No of registered vehicles in India

(Source : MoRTH 2018-19) [3]

As per the Road Transport Year Book 2019-20 [4], India ranks first in terms of motorcycle and moped strength of 18,70,91,00 and third in terms of bus and motor coach strength of 18,64,000. Every year, the number of vehicle kilometers travelled on highways increases significantly. Better transportation infrastructure is always needed to keep up with the growing demand for transportation.

Many initiatives have been taken by the Government of India to improve the urban transportation system. In the 12th five-year plan, goals have been identified on the recommendation of the working group on urban transport, such as augmenting public transport with part funding from the Government of India, to add rail transit @ 10 km/ Million Population, to start planning rail transit projects in cities with a population in excess of 2 Million, and to start construction in cities with population in excess of 3 Million [5].

This has resulted in the construction of numerous flyovers, new bridges, and highways, as well as the introduction of improved public transportation facilities such as BRTS and Metro rail. Metro rail systems in India have the potential to significantly reduce traffic delays by providing an efficient, reliable, and safe mode of transportation for commuters. As metro rail systems operate on dedicated tracks and are not affected by road traffic congestion, they can provide a fast and predictable travel time for passengers. By providing an alternative mode of transportation, metro rail systems can also help to reduce the number of vehicles on the road, which in turn

can help alleviate traffic congestion and reduce travel times for all road users. In recent years, metro systems in India have grown significantly, with several cities establishing or expanding their metro networks. Figure 1.3 shows the growth of metro rail in India.

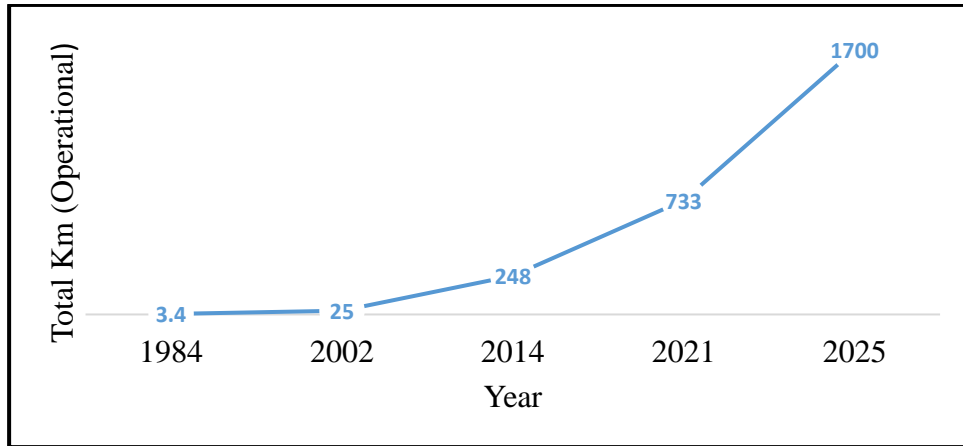


Figure 1.3 Growth of metro rail in India
(Source: MHUA GoI 2020) [6]

The Kolkata Metro, India's first metro system, began operating in 1984. Since then, several more cities have launched metro systems, including Delhi, Mumbai, Chennai, Bengaluru, Hyderabad, and Kochi. Figure 1.4 shows metro rail spread across the country.

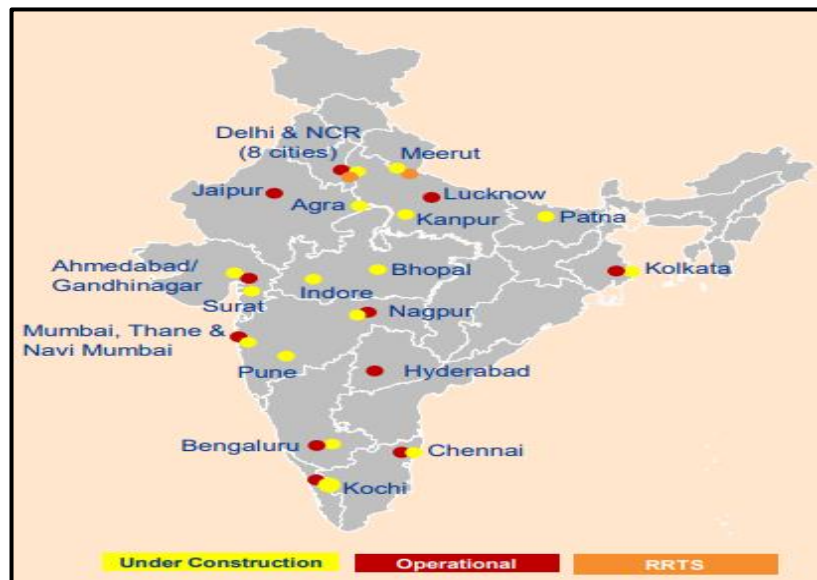


Figure 1.4 Metro rail spread across the country
(Source: MHUA GoI 2020) [6]

The expansion of metro systems in India has been fueled by several factors, including increasing population and urbanization in Indian cities, the need for efficient and

sustainable modes of transportation, and the success of existing metro systems in reducing traffic congestion and improving mobility. The Indian government has also offered financial assistance for metro system development; some metro projects are receiving funds from both the national and state governments.

Metro rail has grown significantly in India in recent years, and the rate of growth is expected to double in the coming years. Cities are facing the need for metro rail to meet their daily mobility needs. The metro rail system promotes walkable development, which is also beneficial to society. Another advantage of Metro rail is that it reduces costs and travel time, which lowers the cost of producing goods and services and thus improves the city's competitiveness. The use of public transportation has also reduced pollution, lowering chronic diseases and resulting in public health benefits [7].

The urban transportation facilities are initially intended to reduce traffic congestion and to gain long-term environmental benefits. During the execution of these projects, many times lane closure or partial lane closure is required. Road construction work zones have become an unavoidable aspect of the highway system in order to keep up with rising demand and provide a high level of service to motorists. Many countries have a considerable number of work zones on urban arterials, which has had a significant detrimental influence on urban traffic. Work zones cause significant traffic delays and travel costs [8].

A road section or area that is under construction, maintenance or utility work, is designated as a work zone with the provision of signs, channelizing devices, barriers, and pavement markings. As shown in figure 1.5, a work zone is divided into the following zones: advance warning zone, activity zone, transition zone, and work zone end zone [9].

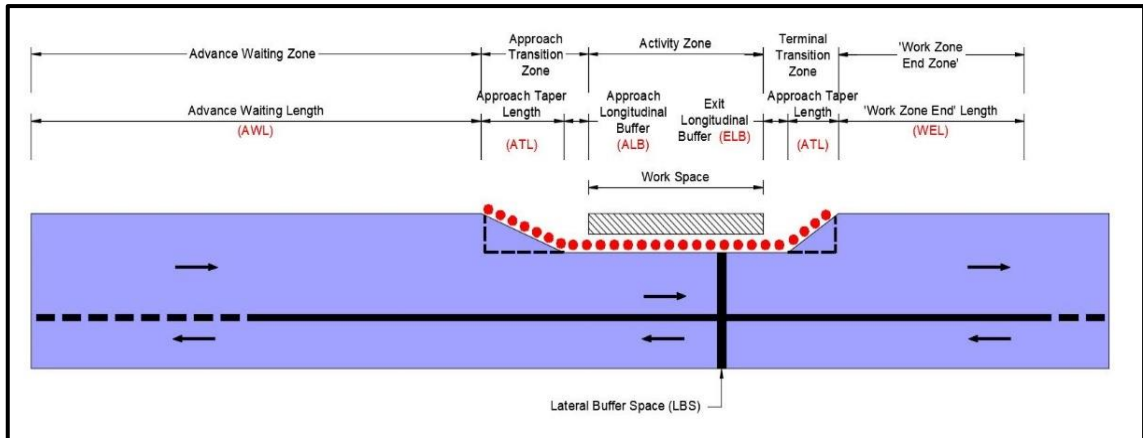


Figure 1.5 Layout of work zone
 (Source: IRC SP 055, 2014) [9]

Work zones have a significant impact on traffic flow operations on urban roadways. Due to the closure of available lane width, long-term work zones create many traffic problems such as decreased capacity, increased delay, decreased space mean speed, increased density, decreased LOS, and environmental issues such as noise pollution and deterioration of air quality. Work zones frequently reduce highway system efficiency [10]. During the construction stage of any transportation infrastructure project, the road users have to suffer due to congestion. The cost of user delay can be reduced by proper and effective management actions [11]. In recent years, urban noise pollution has risen to the top of the list of the most serious human health issues. Automobiles are the most common source of noise in urban areas. The road system is important part of infrastructure, which can affect the economic development of any country. Rapid urbanization caused by infrastructure expansion has negative environmental consequences in the form of air, noise, water, and land pollution. A variety of factors, including traffic and vehicle transportation, contributes to noise pollution.

Noise is defined as a level of sound that exceeds what is acceptable and causes annoyance. Noise is an unfavourable or unpleasant sound that has an impact on a person's psychological and physical well-being, causing irritation, headaches, ear impairment, nausea, vomiting, sleep disruption, hypertension, and cardiovascular problems. It also has a negative impact on task performance. The noise produced by automobiles is referred to as "community noise." Noise emitted from sources other than industrial workplaces is referred to as community noise. Road, rail, and air traffic, as well as construction and public works, are all significant sources of noise in the community [12].

Many countries have implemented noise regulations by enacting emission guidelines and regulating building acoustics. Few countries, on the other hand, have regulations on neighbourhood noise, but due to a lack of methods to define and measure it, as well as the difficulty of controlling it, the health effects of these exposures have risen and resulted in interference with communication.

1.2 Need of the study

As discussed above, these work zones create traffic delays, a reduction in flow, and an increase in noise level. These parameters are important to understand the performance of better quality transportation. However, the flow and delay depend on congestion, inadequacy of carriageway width, mixed traffic conditions, parked cars, heavy pedestrian flow and type of land use and so on. The types of noise generated in construction work zone are vehicle noise, equipment noise and construction activity noise. It is ambient noise which affects the nearby residents and road users. Long-term work zone implementation necessitates lane closures and narrowing. It causes a bottleneck, resulting in a queue with a delay, which causes a lot of economic and mental inconvenience to the public. It is necessary to resolve this issue.

Long-term construction projects, such as metro rail work, are intended to reduce traffic in the future, but during the construction stage, there are negative impacts such as increased travel time, increased delay, increase in noise level etc. Lane closures and partial closures are required for maintenance and construction activities. It is essential for traffic planners to consider these factors while planning and designing the construction and maintenance activities. These impacts can be quantified in monetary terms and shall be included in economic analysis as the cost elements while preparing the project report. Unfortunately, the construction zones would cause traffic congestion and potentially traffic accidents. As a result, studying the peculiarities of traffic flow in construction zones has become a prominent topic. [13].

Precise estimation of traffic flow and delay at work zones is crucial for effective scheduling and planning of work zone operations. It is also important to identify various factors affecting the traffic flow and delay. Identifying the factors that contribute to traffic flow and delays are critical for addressing various challenges associated with urban mobility. This understanding enables the implementation of

targeted interventions, policies, and infrastructure upgrades to create more efficient, safer, and sustainable transportation systems. The impact of construction work zones on traffic delays can be used to calculate excess user costs. Study of impact of noise is important for assessing environmental consequences and implementing mitigation measures. Based on various ill effects of construction work zone, it is required to quantify the impact for better work zone management planning, to minimize carbon footprint, and to provide safe environment to the road users.

Traffic work zone management devices such as road signs, channelizing devices, lighting devices and traffic management practices such as detour, diversion, partial or full lane closures and night constructions are required for minimum traffic disruption. It also provides safe access to the properties and better movement of pedestrians [9]. Construction noise can also be reduced by temporary noise barriers for construction sites, such as acoustic quilts and barriers.

1.3 Aim of the study

The aim of this study is to understand and to analyze the impacts on traffic flow, delay and noise level due to the presence of construction work zone on urban streets.

1.4 Objectives

- To study the influence of construction work zone of metro rail on traffic flow parameters and delay in the study area.
- To determine the effect of construction work zone of metro rail on noise level in the study area.

1.5 Scope of work

- The study is limited to the construction work zone of selected links of Ahmedabad metro rail project.
- This study is focusing on determining the effects of work zone on traffic flow parameters, delay and noise level.
- From the collected data, regression models are developed for during and after construction stage which may be useful to predict the impact of construction work zone on traffic flow, delay and noise level for the similar conditions.

1.6 Thesis organization

The thesis is organized into the following chapters.

Chapter-1 includes background of the Metro rail construction project in Ahmedabad. It covers importance of studying the impact on urban road traffic and noise levels. Based on the problem identification, the aim and objectives of the research are defined. The chapter also includes need of the study. At the end, the chapter describes organization of the thesis in brief.

Chapter-2 describes previous studies carried out for the impact analysis of construction work zone on urban road traffic flow and delay. It also covers the critical review of literature on the effects of construction work zone on noise levels. The literature is divided mainly in to three sections i.e., literature review for flow, delay and noise level. Furthermore, each section is again divided in to two subsections i.e., major factors affecting the impacts and various methods and approaches for estimating the impacts. Relevant theories and models related to construction impacts are included in this chapter. From the literature review study, the inference is carried out. Based on the critical review, research gaps are identified for the present research work.

Chapter-3 discusses the methodology adopted for the research work. It covers each aspect and process used in the thesis to attain the objectives of the research work. This chapter covers the basic information of Ahmedabad city. The information and justification of selected corridor for the research work are also elaborated in the chapter.

Chapter-4 throws light on data requirements i.e., primary and secondary data for the research. The data collection techniques/methods for flow, delay and noise level are described in this chapter. Sample size calculation is also mentioned in this chapter. The chapter shows data presentation and analysis using tables, pie charts and bar charts for during and after construction stage of metro rail construction project. The summary of the analysis is also included in the chapter.

Chapter-5 describes about the models developed for flow, delay and noise level during and after the construction stage using the regression analysis. The major factors affecting the flow, delay and noise level are identified. The correlation analysis of the required independent variables for flow, delay and noise level for during and after construction stage are covered in the chapter. Their statistical significant is also checked in the chapter. The

chapter also covers the model validation techniques adopted in the thesis. It also includes the Hypothesis testing. The explanation of model performance parameters i.e. R^2 , RMSE and RSR are covered in this chapter. At the end, the summary of the chapter is included.

Chapter-6 shows the summary of key findings of the research. It also covers the conclusion and research contribution of the thesis. The limitations, suggestions and application of research work are mentioned in the chapter.

The later sections of the thesis are references, list of published papers and appendices. The IEEE referencing style is used in the thesis. Two review papers and one research paper are published in various journals. In the appendices, data collection forms and screen shot of data excel sheets are included.

Chapter- 2

Literature Review

2.1 General

Several scholars have conducted studies to analyse the effects of construction work zone. The work zone's impact on traffic flow, delay, and noise level is described here from a rigorous literature assessment.

2.2 Impact of work zone on traffic flow and capacity

Construction and maintenance work zones have historically been considered hazardous sites on highways. According to studies, accident rates during road construction are often greater than during routine traffic operations. Work zone operations may pose a number of issues because work zones often shut down one or more of the available traffic lanes. Some work zone activities, such as resurfacing pavements, cannot be carried out without disrupting traffic. The lane closure could ensure the safety of workers. However, lane reductions may disrupt regular traffic flow and induce speed reductions, resulting in a reduction in road capacity and an increase in traffic delay. Vehicles in the closed lanes must merge into the next available lanes, which may increase the number of traffic conflicts and cause significant traffic safety issues. Highway construction zones impede mobility and disrupt traffic operations. To reduce travel time lost due to work zone-induced traffic congestion, it is critical to arrange temporary traffic control (TTC) at work zones efficiently.

In order to mitigate the negative impacts of work zones, many advanced traffic management systems, such as dynamic lane merging traffic control systems, have been studied.

Venugopal & Tarko studied the Indiana Lane Merge System, which included a sequence of dynamic signs to help in merge operations [14]. Grillo et al. employed the dynamic late-lane merge system (DLLMS) to establish a definite merging point in motorway construction work zone to boost traffic throughput in work zones. The DLLMS was discovered to significantly shorten queue lengths in travel lanes [15]. Adeli & Jiang proposed a new model that is integrated into an intelligent decision support system to

rationally estimate work zone capacity, to perform scenario analysis and to investigate the impact of various factors influencing work zone capacity [16].

It should be mentioned that estimating work zone traffic flow, capacity and delay are important factors of planning work zone traffic control systems. They are the key indicators for determining whether traffic control systems are effective. As a result, accurate assessment of flow, capacity and traffic delay in work zones is critical, and estimating methodologies must be reviewed.

2.2.1 Factors affecting work zone capacity

Work zone capacity might be affected by work zone geometry such as the obstructed road length and width, the location of obstructed road width, and the unobstructed road width. Due to the construction work zone, the existing lanes are closed or partially closed. That leads to congestion and reduction in speed. Various factors affecting the traffic flow under work zone conditions are as follows [17].

- Obstructed road width and unobstructed road width
- Location of obstructed road width
- Traffic and roadway condition
- Effect of heavy vehicles.
- Driver population
- Entrance ramp volume
- Lateral distance to the open travel lanes
- Length & grade of work zone
- Intensity of work activity
- Work duration
- Weather conditions
- Work time
- Hourly traffic volume

Kim & David investigated various independent factors such as closed lanes, the proportion of heavy vehicles, grade, and the intensity of work activity that contribute to work zone capacity reduction. They gathered traffic and geometric data from 12 work zone locations in order to create a new capacity estimation model. According to the findings of their research, traffic and roadway conditions are significant parameters affecting the capacity [18]. Stromgren & Olstam included parameters such as proportion of heavy traffic, lane

width, number of closed lanes, closed road shoulder, proportion of commuter traffic and length of roadwork zone from Swedish capacity manual for the operation and maintenance of roadwork [19]. Using traffic data from the Alabama Department of Transportation, Saha & Sisiopiku studied the operational consequences of temporary traffic control (TTC) options for work zones with 3-to-1 lane drop configurations. Adopting a 3-to-1 lane closure layout, the two rightmost lanes were blocked off, leaving the leftmost lane open through the work zone. The study concluded that the 3 to 1 lane-drop design should not be used for an extended period. Maintenance work can be scheduled from midnight to early morning, and the performance of early and late merge traffic control is compared under the 3-to-1 lane closure scenario [20].

Cheng et al. presented a traffic model with a construction area and results showed that when the length of the work zone, i.e., the main part of the construction area, is appropriate, the traffic flow will reach its maximum value. The authors defined the traffic injection rate as traffic regulations near the construction area, which vehicles must comply with. They also demonstrated that when the injection rate was high, the construction area had a significant negative impact on traffic flow, resulting in severe traffic congestion. The variation tendency of the total traffic flow and the delay time with increasing length of the work zone and injection rate are analysed in order to optimise the traffic flow [21].

Adeli & Jiang considered seventeen different factors affecting the work zone capacity. They are percentage of truck, pavement grade, number of lanes, number of lane closures, lane width, work zone layout i.e. lane merging, lane shifting, and crossover, work intensity, work zone type, length of closure, work zone speed, interchange effects i.e. proximity of ramps, work zone location i.e. urban or rural, work zone duration i.e. long term or short term, work time i.e. daytime or night, work day i.e. weekday or weekend, weather condition i.e. sunny, rainy or snowy, pavement conditions i.e. dry, wet, or icy, driver composition i.e. commuters or non-commuters such as tourists [16].

Sarasua et al. considered terrain, work zone activity, and weather as factors that could influence work zone capacity. Weather-related effects could not be measured because short-term work is generally postponed during inclement weather. They developed the relation between capacity (q) and speed (s) as shown in equation 2.1.

$$q = -2.447 s^2 + 140.920 s \dots\dots\dots (2.1)$$

They also concluded that traffic streams with a high proportion of heavy vehicles would have a significantly lower volume than a stream with mostly passenger cars [22].

Heiden & Geistefeldt estimated work zone capacity by considering parameters such as work zone's traffic, geometrics, and control conditions the number of lanes, lane widths, the presence of divided lanes, the longitudinal gradient, and the proportion of commuters and heavy vehicles on German highways. They concluded that for short-term work zones, the lane closure side (left or right lane) had an effect on capacity [23].

Work zone traffic safety in inclement weather has been a major worry for drivers and transportation organisations. Hou & Chen proposed an integrated methodology for assessing traffic safety in work zones under unfavourable driving conditions, taking into account unique work zone configuration, weather, and road surface characteristics. A new risk index was developed to evaluate the traffic safety risk of work zones by combining the hazards of multi-vehicle incidents and single-vehicle crashes [24].

To study the impacts of construction work zone, it is required to study the driving behaviour especially in the lateral direction. Raju et al. carried out study of traffic flow parameters for before the construction and during the construction stage of Mumbai metro rail. Several variables were used to analyse driving behaviour, such as longitudinal following behaviour, following times, lateral amplitude, and lateral placement, followed by lateral direction [25]. Razaeei et al. showed that due to the narrowing of the lane because of construction work zone, reduction in flow was observed. Lane closures caused disturbances and wave propagation on freeway traffic characteristics, affecting traffic flow [26]. It would be difficult to model the effects of the work zone on mixed traffic flow. Various tools, techniques and approaches were employed to model the impact of work zone on traffic flow parameters. Kim & David proposed a new method for estimating work zone capacity. They developed a multiple regression model by taking into account various work zone parameters i.e., number of closed lanes (N), lane closure location (LOCCL), heavy vehicle percentage (HV), lateral distance (LD), work zone length (WL), work intensity (WI) and work zone grade (WG) as shown in equation 2.2 [18].

$$C = 1857 - 168.1 \text{ NUMCL} - 37.0 \text{ LOCCL} - 9.0 \text{ HV} + 92.7 \text{ LD} - 34.4 \text{ WL} - 106.1 \text{ WI} - 2.3 \text{ WG} \times \text{HV} \dots\dots\dots (2.2)$$

Stromgren & Olstam presented their findings on capacity reduction in roadwork zones. The paper provided a cutting-edge description of the effects of roadwork on capacity. The authors compared a composite model of correction factors from Germany, the United States, and Denmark to the Dutch model for capacity reduction computation. The

comparison demonstrates that the two models produced essentially the same results. The results showed that the empirically estimated capacity reduction matches the reduction calculated with the new model for the various road work designs evaluated. The model developed appears to be valid for capacity reduction estimations of road works on Swedish highways, but empirical evidence is required to ensure general validity [19].

Saha & Sisiopiku carried out investigations using the VISSIM simulation platform. For long-term and short-term lane closures, the experimental design examined two temporary traffic controls [20]. Cheng et al. presented a three lane cellular automata on traffic model with a construction area, using the traffic flow on the Hangzhou Bay Bridge as a case study [21]. Adeli & Jiang had shown a novel adaptive neuro-fuzzy logic model estimation of the freeway work zone capacity. A neural network was employed to estimate the parameters associated with the bell-shaped Gaussian membership functions used in the fuzzy inference mechanism. The authors showed comparisons with two empirical equations and demonstrated that the new model provided a more accurate estimate of the work zone capacity, especially when the data for factors affecting the work zone capacity are only partially available [16]. Sarasua et al. developed methodology to estimate interstate highway capacity for short-term work zone and investigated a variety of factors influencing capacity of interstate work zones in South Carolina. The traffic characteristics of freeway work zones were studied using traditional macroscopic traffic flow modelling methods. The relationships between speed, density, flow, and time headway were derived under the assumption that density and speed have a linear relationship. The passenger car equivalents (PCEs) derived for speed ranges when flows were at or below capacity compared to those outlined in the HCM 2000 for level to rolling terrain [22]. Weng & Meng developed a model to estimate work zone capacity using a decision tree-based approach. To grow the decision tree, the F-test splitting criterion and the post pruning approach were used. Statistical comparison results showed that the decision tree-based model outperformed existing short-term and long-term freeway work zone capacity estimation models, particularly when the input values of influencing factors for the existing models were only partially available [27].

Weng & Meng provided a review of approaches for estimating work zone operational issues such as capacity and traffic delay. Various factors influencing work zone capacity and delay were examined using various approaches such as parametric, non-parametric, and simulation approaches to estimate work zone capacity. The authors concluded that the

simulation approach is appropriate when data is only partially available [28]. Work zones have a significant impact on the quality of traffic flow. Because of narrower lanes, fewer traffic lanes, and unfavourable roadway geometry, capacity can be significantly reduced in work zones. Models to estimate work zone capacity are required to evaluate the impact of work zones on congestion occurrence and resulting delays, as well as to allow for consideration of alternative work zone layouts in the planning process. Heiden & Geistefeldt presented findings from a thorough study of work zone capacity on German highways. A large number of short-term work zones with temporary lane closures and long-term work zones with and without lane reductions were considered. Deterministic and stochastic approaches were used to estimate the capacity of long-term work zones. Based on the empirically estimated capacities, standardized capacity values for work zones were estimated. Due to the relatively small number of samples covering a large number of different work zone characteristics, a statistical analysis with regression models wasn't applicable. Instead, an existing capacity model from the German work zone management guidelines was modified and recalibrated [23]. Road maintenance and reconstructions are carried out to keep freeway network in good condition. For proper traffic management measure, it is required to determine the capacity of road and travel time for the road users.

2.2.2 Various approaches for estimation of work zone capacity

Zheng et al. had compared various prediction models for estimation of freeway work zone capacity. The conventional models are based on the assumption of a linear relationship between the capacity of a work zone and its configuration variables. Then three prediction models were introduced, namely the model in the Highway Capacity Manual, two multi-linear regression models, and a fuzzy logic based artificial neural network model. These models were tested for Dutch cases. The authors had shown that comparing to the widely applied linear regression models; the neuro-fuzzy model has the highest average accuracy. They also concluded that the prediction error can be reduced as large as 20% [29]. Because the true value of work zone capacity is difficult to determine with absolute certainty, it should be represented by a probability distribution. Weng & Yan proposed a method for calculating work zone capacity distribution based on probabilistic speed-flow relationships. To begin, the flow and traffic speed were modelled as random variables with lognormal distributions. Then, under congested and uncongested traffic conditions, the lognormal distributed speed-flow functions were established to formulate the probabilistic

speed-flow relationships. The probabilistic speed-flow relationships were used to derive a work zone capacity distribution model as shown in equation 2.3 [30].

$$\ln(C_{wz}) = 2.72 - 0.23 \ln(n) + 1.21 \ln(V_{limit}) - 0.0018 A + \frac{0.063}{n} + 0.71 \varepsilon_u + 0.92 \varepsilon_c \dots \dots \dots (2.3)$$

Where, C_{wz} work zone capacity in passenger cars per hour per lane (pcphpl) is function of number of construction sites per work zone (n), geometrical alignment in degree (A), speed limit (V_{limit}) (km/h), ε_u and ε_c normally distributed random error associated with logarithm of traffic speed under uncongested and congested traffic condition respectively.

The ability to effectively estimate work zone capacity is critical since accurate estimates are a crucial input to work zone queue length and traffic delay predictions. Work zone capacity is an important consideration when planning road construction activities. Knowing how different definitions of capacity affect the numbers derived from field data will lead to better lane closure planning and scheduling. Edara examined three alternative methodologies i.e. maximum sustained flow, rescaled cumulative flow curves, and 85th percentile flow using field data from short-term work zones in Missouri [31]. Raju et al. carried out the work on a mid-block road section and then macroscopic traffic characteristics were evaluated. They have studied the traffic flow parameters for both the conditions i.e. before the construction and during the construction stage of Mumbai metro rail. Further to understand the impact, vehicular trajectory data were collected over three distinct traffic-flow levels on road sections [25]. Understanding of work zone traffic behaviour is critical for work zone planning and operation. Racha et al. created a mathematical model of work zone traffic flow elements for 22 work zone locations along South Carolina interstate routes that may be used to predict work zone capacity by evaluating the interactions between speed, flow, and density. The scatter plots of the collected data showed that the speed-density relationship does not follow Greenshields' linear model. To represent the link between speed and density, a non-linear hyperbolic model was devised. Using this approach, a work zone's capacity was predicted to be 1550 passenger cars per hour for 2-lane to 1-lane closures using the equation 2.4 [32].

$$C_{wz} = (C_B + I) * f_{HV} * N \dots \dots \dots (2.4)$$

Where, estimated work zone capacity of a short term work zone (veh/hr) is a function of base capacity C_B , adjustment factor (I) for type, intensity, length and location of the work activity, heavy vehicle factor f_{HV} , number of lanes open through work zone area (N).

Other than traffic impact, the construction work zone affects the construction activities both on and close to a freeway, reducing construction efficiency, especially by delaying the delivery of materials [33]. The implementation of metro rail projects opens the door to construction activities, and long-term construction work zones are unavoidable. Long-term work zones on urban roads cause a variety of problems, including reduced capacity, increased travel time delays, increased queue length, more fuel consumption, the number of forced merges, and road accidents. As a result, it has become necessary to investigate and quantify the impact of mass rapid transit system construction work zones on the traffic environment, which will aid in estimating the economic loss caused by metro rail construction work zones. Bhutani et al. studied the impact of metro rail construction work zones on traffic environment and quantified these impacts for the current situation. The effect of intersection in a work zone was studied using Vissim 6.0 software. Queue lengths were calculated in both work zones and non-work zones [34]. It would be difficult to model the effects of the construction area on mixed traffic flow. It must determine which traffic regulations must be followed near the construction site. Meanwhile, it is necessary to depict the various driving behaviours of cars and trucks when they collide within the construction zone [21]. Weng & Meng evaluated the speed-flow connection and merging behaviour of drivers in work zone merging locations. It initially proposed lane-based speed-flow models that included traffic conflicts between lanes. They developed a desired merging location model, which determines where drivers begin to consider merging. They also developed a binary logit model, which is used to predict the likelihood that vehicles will merge into current nearby gaps. Acceptable results suggested that the merging behavioural models can forecast drivers' merging behaviour competently, and that the merging distance model could provide accurate information for traffic engineers to compute the merge lane length [35]. Tracz & Gaca investigated traffic flow-speed relationships. The structure of these relationships is typical of empirical data, where the dispersion of recorded values is indicative of randomness and the effects of local factors. The road conditions and roadside factors have a major influence on speed in free-flow traffic. The most essential of these

criteria are the type of cross section, the intensity of roadside growth, and the road's accessibility [36].

Average traffic flow speed is determined not only by the geometrical alignment of a road cross section, but also by local conditions like speed limitations. The speed-flow relationship in work zones has been relatively an uncommon research issue. Avrenli et al. investigated the speed-flow connection in a specific work zone with no lane closure. A step-by-step technique for developing the work zone speed-flow curve as a three-regime model with free flow, transition, and congested regimes was described. The speed-flow curve's congestion regime was built in the form of a power function. Correct prediction of work zone capacity leads to more efficient operation in a real-time system, more appropriate travel pattern information, more accurate diversion and traveller information for alternate routing, and increased transportation system reliability [37].

Maze et al. worked on Iowa work zones with limited data collection and capacity that ranged from roughly 1,400 to 1,600 passenger car equivalents depending on the lane closure condition. On 80 stretches, data were collected using an automated traffic recording system. They compared historical and current traffic data based on traffic volume and capacity. They also forecasted when congestion will occur and what type of traffic management strategy will be used. They identified potential strategies such as diversion routes and informing drivers well in advance so that they can choose alternative routes or travel times [38].

Accurate traffic flow prediction is critical for enhancing traffic network operational efficiency. With the continuous expansion of traffic networks, providing reliable and efficient multi-step traffic flow prediction for large-scale traffic networks with a large number of sensors deployed has become a challenging issue. Sun et al. proposed a multi-step many-to-many traffic prediction model for large-scale traffic networks, called Spatio-Temporal Shared Gated Recurrent Unit (STSGRU), which receive inputs from multiple sensors and provides predictions for all sensors simultaneously. They firstly modelled the weekly pattern of traffic flow, using periodicity to explore long-term temporal features and provide smooth traffic flow to reduce the impact of data volatility. Second, different from existing models, they proposed a shared weight mechanism to achieve many-to-many prediction without mapping traffic networks to images or graph structures. The authors proposed a model that strikes a delicate balance between complexity and accuracy [39].

Richard created a basic theory of traffic flow by substituting individual vehicles with a continuous "fluid" density and employing an empirical speed-density relationship. The influence of a traffic signal on traffic streams was studied, and it was discovered that there is a threshold effect in which disturbances are modest for light traffic but abruptly grow to substantial values when a critical density is exceeded. [40].

2.2.3 Summary

From the literature review, it is observed that new techniques such as artificial neural network fuzzy logic, genetic algorithm are used for capacity estimation but the traditional method of speed flow relationship is also important to study the capacity. In the study, speed-flow relationships are established for the flow analysis. Furthermore, the traffic flow models are developed using regression technique for during and after construction stage. Various approaches and parameters used for traffic flow analysis and modelling are summarised in the table 2.1.

Table 2.1 Various approaches for work zone flow/capacity and affecting parameters

Reference	Approach/ tool	Parameters/ Variables considered for work zone flow/capacity																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Maze et al. [38]	Speed flow relationship	✓	✓		✓																	
Kim & David [18]	Multi-regression					✓						✓						✓	✓			
Adeli & Jiang et al. [16]	Neural-fuzzy logic					✓	✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
Sarasura et al. [22]	Speed flow relationship	✓	✓	✓													✓	✓				
Zheng et al. [29]	Neural-fuzzy logic	✓				✓	✓	✓		✓		✓		✓			✓		✓		✓	✓
Weng & Meng et al. [27]	Decision tree	✓				✓		✓				✓	✓	✓			✓		✓	✓		✓
Weng & Meng et al. [35]	Speed flow relationship	✓	✓	✓																		
Bhutani et al. [34]	Speed flow relationship	✓	✓																			
Stromgren & Olstam et al. [19]	Empirical					✓	✓	✓											✓			✓
Heiden & Geistefeldt et al. [23]	Deterministic & stochastic					✓	✓					✓							✓			✓

1-Speed, 2- Flow, 3-Density, 4-Queue length, 5- No of open & closed lane, 6-Lane width, 7-Work zone area Length, 8-Transition Area Length, 9-Lateral distance, 10-Road curve radius, 12- work zone duration (short /long term), 13-Work Time (Day/Night), 14-Pavement conditions (dry/wet/ icy), 15- Work day (weekday/week end), 16- Weather condition, 17- Intensity of Work, 18-% Heavy Vehicle / Composition, 19- Work zone location (urban / rural), 20- Presence of Traffic sign & signal, 21- Driver Population(commuters)

2.3 Impact of work zone on delay

Delays are inconvenient and thus reduce the quality of transportation. Delay can be defined as extra time taken by drivers compared to the expected travel time. Delay is of many forms based on various locations. Travel time delay is the difference between the travel time of vehicle traversing through a section of street or highway when traffic is in free flow nature and the average time required to travel through congested condition. It includes operational delay due to deceleration of vehicles in existing traffic and stopped delay. Congestion, insufficient carriageway width, mixed traffic conditions, on street parked vehicles, and heavy pedestrian flow are the factors that contribute to delay.

In traffic work zone, the delay may be operational delay or moving delay. Work zones cause traffic delays, which should be estimated in order to provide better transportation. Travel time is a critical factor that is directly related to delay. It has a direct impact on the cost, quality, and comfort of travel. Saving in travel time is also very beneficial for transportation projects. The main factors affecting work zone delay are vehicle composition, percentage of heavy vehicles, activity area length, and available lane width. In many cases road gradient, pavement unevenness, category of road also has significant impact on delay. Congestion is also responsible for delay.

2.3.1 Literature review on factors affecting delay

Chung et al. estimated non-recurrent traffic congestion using the capacity and the number of closed lanes in work zones and the upstream traffic demand of work zones and concluded that the effect of number of closed lane is not significant due to additional lane of shoulder area is included in the traffic lane as a strategy to mitigate traffic congestion [41]. Dowling et al. studied non-recurrent congestion and annual vehicle hours of delay caused by various parameters such as weather, work zones, incidents and capacity [42]. Anusha et al. focused on the Passenger Car Units (PCU), vehicle composition and their travel time for estimation of travel time at urban arterials under mixed traffic conditions [43]. Meng & Weng considered work zone configuration, traffic flow, heavy vehicle percentage, activity area length and transition area length to assess the effect on work zone traffic delays. To explain traffic delays at work zones, two indices were used i.e., average traffic delay per work zone and average traffic delay per 100 m [17].

They have shown that average traffic delay per work zone (D) in sec/veh/zone is a function of traffic flow (f) in vehicle per hour, activity area length (L_a), transition area length (L_t), percentage of heavy vehicle (h_v) as shown in equation 2.5.

$$D = 55.25 - 4.97 \ln(f) + 3.68 \times 10^{-3} f - 1.52 \times 10^{-2} L_a + 2.38 \times 10^{-5} f L_a + 2.76 \times 10^{-5} f L_t + 15.73 \ln(h_v) \dots\dots\dots (2.5)$$

Chitturi & Benekohal presented a methodology for quantifying mobility impacts that takes into account the effects of roadway and traffic on car and heavy vehicle speeds and delays separately. Several factors, such as speed variation, roadway width, and differences in speed of cars and heavy vehicles, were taken into account when calculating delay using the equation 2.6 [44].

$$EDV = V * (1 + P_{HV} (D_PCE - 1)) \dots\dots\dots (2.6)$$

Where, equal-delay-volume (EDV in passenger car) is function of volume of mixed traffic V (vehicle per hour), percentage of heavy vehicle in fraction P_{HV}, and delay based PCE (D_PCE).

The majority of urban areas are constructing multimodal facilities to support both motorised and non-motorized traffic. The resulting transportation system is vulnerable to complicated interactions among modes and users. These complex relationships are difficult to assess and describe on a consistent basis. To replicate such real-world scenarios and estimate future conditions, a microsimulation platform is required. There is a need to rely on a microsimulation platform to replicate such real-world scenarios and forecast future conditions. Kodupuganti & Pulugurtha carried out a study on assessing the effect of heterogeneous traffic conditions involving multiple modes like Light Rail Transit (LRT), walking, bicycling, and motorized traffic on vehicle delay at intersections using Verkehr in Stadten Simulations Model (Vissim), a traffic simulation software. Base simulation model was developed by replicating the traffic scenario for the year 2018 (without LRT and non-motorized traffic). They proposed framework to assist the planners to assess the impact of adding a new transit system like LRT and associated non-motorized traffic on the urban corridor [45].

Traffic congestion is one of the biggest impediments to developing economies' economic progress, resulting in severe social and economic consequences. More thought provoking

than harmful obstacles is the intensity of traffic congestion in port and industrial districts. Fattah et al. carried out an on-site survey technique to collect data from regular road users, which included administering questionnaires, conducting volume count surveys, and monitoring travel time, delay time, and vehicle speed throughout the day. According to the study results, excessive vehicles, small roads, poor public transportation modes, and the attitudes of bus operators are producing congestion, resulting in high to extreme stress levels for road users [46]. Wei et al. used real-time big data to investigate the spatio-temporal pattern of traffic congestion performance in 77 Chinese large cities. Based on hourly real-time data of traffic performance index collected between August 27, 2019, and September 27, 2019, four clusters of cities were identified based on their urban traffic congestion pattern on different days of the week. They discovered that cities with advanced urban road network planning and delivery, as well as a well-developed urban public transit system, have higher traffic performance [47]. During the COVID-19 pandemic, there was a significant decrease in traffic demand, resulting in considerable reductions in traffic delays, energy consumption, and emissions. Du et al. looked into how reducing the number of automobiles on the transportation network may help the environment. Traffic on seven different networks was modelled using microscopic modelling. They concluded that reduced traffic demand greatly leads to reduced delays and emissions, particularly in congested urban regions. [48].

2.3.2 Literature review on methods for estimating delay

Chung et al. developed a method to quantify non-recurrent traffic congestion caused by freeway work zones based on traffic flow data and spatio-temporal work zone information on major freeways in Korea [41]. Dowling et al. presented an approach for measuring and forecasting total annual traffic congestion due to recurring and nonrecurring congestion. Highway Capacity Manual speed-flow curves and data on facility demands, free-flow speeds, and capacities are used to estimate recurring congestion. The annual vehicle hours of delay induced by weather, construction zones, and incidents were used to estimate non-recurrent congestion using the equation 2.7. Weather and work-zone-related delays are assessed on the basis of frequency of occurrence and estimations of capacity decreases during periods of adverse weather and work-zone activity [42].

$$DWZ(I, H, S) = V(H, S) * P(I, H, S) * [TT(I, H, S) - TT(I=0, H, S)] \dots\dots\dots(2.7)$$

Where, Vehicle hours of delay of work zone type I on segment S during analysis hour H, $DWZ(I, H, S)$ is function of probability of work zone $P(I, H, S)$, no of vehicles $V(H, S)$, estimated mean travel time $TT(I, H, S)$ and estimated mean travel time in no work zone condition $TT(I=0, H, S)$.

Schnell et al. worked with the Ohio Department of Transportation (ODOT) on maintenance of traffic (MOT) to ensure that traffic flows efficiently through work zones. The Highway Capacity Software (HCS), Synchro, CORSIM (corridor simulation), NetSim (Network simulator) and a macroscopic model named QueWZ92 were utilised for traffic modelling and forecast. The queue length that formed in the actual world was underestimated by the calibrated microscopic simulation tools. The macroscopic QueWZ92 package gave more precise estimations than the microscopic packages [49]. Wirasinghe applied the traffic shock-wave theory of Lighthill and Whitham to a general incident, i.e., a moving incident with filtering (overtaking). He calculated individual and total delay by graphical method [50].

Travel time prediction study has demonstrated its value and research significance in rational planning of travel arrangements and reducing road congestion. To anticipate taxi journey time, existing models need effective traffic information, particularly traffic condition. This will have an impact on passenger travel arrangements. Sheng et al. has defined urban congestion and taxi flow to represent traffic condition. They used traffic condition and trajectory data for analysis and model development for congestion. They integrated factors of departure time and travel date to improve the accuracy of the model. The experimental results show that model has some advantages over some classical models in travel time prediction [51]. Anusha et al. carried out a study on the travel time estimation on urban arterial mid-block section. The travel time was estimated using a weighted average speed-based method. The effects of heterogeneity and limited lane discipline in the traffic stream of mixed traffic were considered using model formulation [43]. Shen et al. proposed an innovative path-finding algorithm to achieve on-time arrival reliability on road networks under uncertainty with stochastic delays at signalized intersections [52].

Because of their critical roles in hazard planning, emergency response, and urban community recovery, urban traffic networks with partially obstructed roads must frequently stay open to traffic before, during, and after disasters. Effective traffic Transportation networks planning is largely dependent on precise prediction of journey

time on partially obstructed highways, which differs greatly from that on intact roads. Travel time prediction techniques established for intact highways have been directly applied to partially obstructed roads due to a lack of adequate models. That results in incorrect travel time estimations. Unrealistic travel time predictions for partially blocked highways, as well as the entire transportation network, have a negative impact on traffic planning, emergency response, and other decision-making processes that rely largely on travel time prediction. Hou et al. developed a new approach for travel time functions for partially blocked roads in urban areas using gap based on microscopic traffic simulation under various scenarios with different demand flow rates, truck ratios and blockage ratios [53]. Martinelli & Xu gave a comprehensive and precise estimation of traffic delay caused by a motorway work zone where the roadway in one direction is closed and traffic is routed to share the roadway in the opposite direction. The overall delay was divided into two parts: speed reduction delay and congestion delay. They developed a model to calculate the length of the queue upstream of a work zone, and a process was created to calculate the daily congestion delay [54]. Li et al. investigated congestion control in a network with delay sensitive/insensitive traffic. They created a model by explicitly including delay components in the utility function that measures customer satisfaction with the Quality of Service (QoS) [55]. Laval described the Kinematic Wave model with triangular fundamental diagram. He used Self-organized criticality (SOC) for traffic flow and concluded that conventional traffic management strategies are required to maximize the traffic flows [56].

Due to its ease of implementation and scalability to large network situations, Liu & Gayah developed a unique travel-delay-based Max Pressure (MP) algorithm for regulation of arbitrary transportation networks with signalized crossings. The MP framework used a point queue model to depict vehicle transition between connections, which did not take vehicle location into account, despite the fact that this may have a considerable impact on control performance. However, implementing the Original-MP Max Pressure algorithm in practice may be problematic due to the substantial measuring infrastructure required to estimate the number of vehicles at junctions [57].

Congestion on road transportation networks is a recurring issue in big metropolitan cities worldwide. For sustainable transportation, it is vital to leverage underutilized road capacities in a network in order to reduce congestion on over utilized links while also

satisfying the system optimal flow assignment. Bayraktar identified four congestion mitigation strategies based on deviation and relative deviation of link volume from the corresponding capacity. Consequently, four bi-objective mathematical programming optimal flow distribution (OFD) models are proposed. The case study results demonstrate that all the proposed models improve system performance and reduce congestion on high volume links by shifting flows to low volume to capacity links [58].

Estimating arterial link travel time and delay using vehicular positioning data remains a difficult task. Allocating the travel time between two consecutive AVL (Automatic vehicle location) reports of a vehicle to each traversed link is difficult, especially when the data sampling frequency is low, and determining the proportion of traffic delay in link travel time is difficult. Meng & Wang estimated link travel time and traffic delay caused by intersections or alighting and boarding at bus stops using transit buses with 30-second sampling interval AVL data. Travel time is divided into three components in the proposed model: free flow travel time, congestion time, and stopping time at signalized intersections and bus stops, which are then given to each road connection. To solve for the most likely traffic delays along the route, the proposed approach developed a likelihood function that is maximized. According to the results, the suggested model provided effective and accurate traffic delay estimate, which can be applied to transit-based or probe vehicle-based traffic applications such as journey time estimation and travel speed estimation [59].

Haseman carried out a survey of a 12-week collection of 1.4 million travel time records that were utilized to evaluate and express quantitative travel mobility measures for a rural I-65 work zone in North-western Indiana. They included collecting and processing automated probe data from several field collection sites, communicating trip delay durations to motorists, analysing driver diversion rates, and producing proposed matrices for a state transportation agency to evaluate work zone mobility performance [60].

When traffic cannot be rerouted, the freeways are subject to rebuilding and restructuring as congestion levels rise. It has already been stated that traffic simulation is a better approach to freeway reconstruction analysis than the traditional Highway Capacity Manual (HCM). The standard HCM procedures cannot evaluate users' delays on a freeway under construction when traffic flow is limited. The effects on existing traffic patterns are significant. In terms of direct reconstruction costs, every attempt to reduce user costs raises the direct costs of rebuilding. As a result, there is a clear trade-off between lowering direct

costs and lowering costs to travellers and economic activities. Astarita et al. assessed the delay experienced by users of two-lane freeways when only one lane is available. The delays for various flow levels and reconstruction area lengths are evaluated using a tailored new developed microscopic traffic simulation model [11].

Meng & Weng created a model for work zone traffic delays. The HCA (Heterogeneous cellular automata) model developed by Meng and Weng was used to estimate traffic delays in work zones. In terms of estimation accuracy, the HCA model outperformed Paramics (traffic simulation software) for estimating traffic delay [17].

Chitturi & Benekohal proposed to calculate the capacity-at-operating-speed from the speed-flow curves developed for work zones by determining the impact on the operating speeds of vehicles in work zones. Delay and queue length were calculated using speed and capacity. Delay was classified as queue delay or moving delay. For work zones, the moving delay was calculated using delay-based passenger car equivalent (PCE) values. The queue delay was calculated using the capacity determined in this study and an input-output analysis approach [44]. Lee et al. created WZCAT (Work Zone Capacity Analysis Tool) analytical software to predict delays and queues for short-term (daily) work zone closures. WZCAT predicts queue lengths using a simple input/output model [61].

Work zone related traffic delay is an important cost-component on freeways with maintenance activities. Using the deterministic queuing theory, Chien et al. created a method for approximating delays by combining limited simulation data using corridor simulation (CORSIM) model. They also developed the concept of deterministic queuing theory by considering various geometric conditions and time-varying traffic distribution [62].

For the Illinois Department of Transportation (IDOT), Benekohal conducted a state wide assessment and discovered that incentive/disincentive and lane leasing systems were more effective in reducing work zone duration and delay. The Highway Capacity Manual (HCM) technique was used to estimate capacity; QUEWZ, Quick Zone, and the HCM technique were used to estimate queue length and delay; and QUEWZ and spreadsheets were used to estimate road user charges. The results of FRESIM, QUEWZ, and QuickZone software were compared to field data. A new methodology was developed to determine capacity, speed decrease, delay, queue length, and user expenses [10].

There should be a management system to reduce the travel time in work zone. Peak travel times contribute to congestion formation at work zones. Advanced Traveller Information Systems (ATIS) can inform drivers in real-time about the delays and travel times on route and can provide information about an alternative route to a destination. Reinolsmann et al. conducted a driving simulation study with 80 drivers in the State of Qatar to investigate drivers' behaviour and voluntary route choices when encountering total travel time (default setting) or delay time updates for two freeway routes on Variable Message Signs (VMS) and Graphical Route Information Panels (GRIP). The GRIPs are a graphical alternative to conventional VMS that can provide drivers with a visual map of the most direct route or an alternative less congested route to a destination using different colour schemes. The results showed that the display of zero delays for a detour did influence 74–83% of the drivers to take the alternative route when being displayed on a VMS and a GRIP with free flow attribute framing. When displaying equal total travel times, the GRIP did influence 25% more drivers to follow the alternative route than the VMS [63] .

Various methods and techniques are available to measure travel time. Floating car and loop detector-based methods are two different types of methods frequently used to collect travel time delay information across a freeway network. Wang used both floating car method and loop detector-based methods in the Highway Congestion Monitoring Program in the California Department of Transportation. It was found that these two types of methods do not estimate similarly in terms of total segment travel time delay. The mean absolute relative difference (MARD) can be as high as 78% [64] .

The enormous development in the availability of mobile phones in societies all over the world, is prompting numerous groups to investigate how these devices might be used effectively as part of large-scale data collection activities in a variety of sectors such as transportation. Congestion has occupied a prominent position on the transportation agenda in recent decades. Fulponi suggested to use cell phone for traffic flow data collection. The combination of both techniques, GPS and GIS, allows for the analysis of people movements, their origins, destinations, routes taken, and even the rates at which they circulated. In this context, the generation of enormous amounts of data offers up new avenues for mobility management and urban transportation planning. The authors have shown the possibility of replicating the methodology used in planning to mitigate the effects of congestion [65] .

Travel time is critical information for traffic management and planning. Automated vehicle identification (AVI) systems have been used for decades to obtain reliable trip time data. Bluetooth and Wi-Fi-based devices, for example, have become a more cost-effective way of gathering interval travel time information in urban areas. Ma et al. focused on developing a trip time prediction system that can take into consideration both online and historical measurements due to the increasing availability of such data. To combine online trip time with historical trends, an extended Kalman Filter (EKF)-based method is used. The method takes into account the system latency caused by vehicle re-identification in particular. The approaches are tested using data from Stockholm's Automated Number Plate Recognition (ANPR). According to the results, the prediction performance is good and trustworthy in catching main trends during congestion building and dissipation [66]. Mallem et al. used GPS enabled test vehicle for collection of travel time and delay data. They developed journey time maps, which provide a visual representation of the road network around a reference location for a given period [67].

2.3.3 Summary

From the literature review, the major factors affecting work zone delay are traffic flow, work zone configuration, proportion of heavy vehicles and work zone length etc. Regression analysis has been used in the present study to estimate delay. Various approaches and parameters used for delay analysis and modelling are summarised in the table 2.2.

Table 2.2 Summary of literature review for work zone delay

Reference	Parameters considered for work zone delay	Method/ approach/tool
Meng et al. [59]	free flow travel time, congestion time, and stopping time at signalized intersections	Probabilistic approach
Astarita et al. [11]	Length of free road section, traffic flow, work zone lay out, percentage of heavy vehicles, distribution of speed of light vehicles, speed distribution of heavy vehicles	Microscopic simulation model

Meng & Weng [17]	work zone configuration, traffic flow, and heavy vehicle percentage, area length, transition area length, traffic flow, and heavy vehicle percentage	Heterogeneous cellular automata (HCA)model
Chitturi & Benekohal [44]	roadway width, speed variation, and differences in speed of cars and heavy vehicles	Input-output approach based on speed flow relationship
Lee et al. [61]	Speed, volume, location of lane closure, time of lane closure, work zone length, work zone activity, work zone intensity	WZCAT (Work Zone Capacity Analysis Tool) analytical software program
Chien et al. [62]	Flow, speed, queue length, work zone length	Simulation using CORSIM

2.4 Impact of work zone on noise level

Urban noise pollution has risen to the top of the list of issues related to the human health in recent years. Automobiles are the primary source of noise in cities.

The sound pressure level is calculated as shown in the equation 2.8

$$L_p = 10 \log_{10} (P/P_r)^2 \dots\dots\dots (2.8)$$

Where, L_p = Sound pressure Level in dB

P = root mean square sound pressure usually in $\mu\text{N}/\text{m}^2$

P_r = reference sound pressure

The reference sound pressure P_r has an internationally agreed value of $20 \mu\text{N}/\text{m}^2$ (CPCB 2001) [68].

L_{eq} (equivalent continuous sound level): Sound levels often fluctuate over a wide range with time. Equivalent sound level can be obtained from variable sound pressure level L , over a time T , by using the equation 2.9

$$L_{eq} = 10 \log_{10} [1/T \int_0^T 10^{\frac{L}{10}} dt] \dots\dots\dots (2.9)$$

Leq is the preferred method to describe sound levels that vary over time, resulting in a single decibel value, which takes into account the total sound energy over the period of time of interest. This is where the L_{eq} or equivalent continuous sound level meter comes in. This meter faithfully follows all the fluctuations, stores them in its memory and at the

end of the measurement calculates an 'average energy' or Leq value. The word average refers to the logarithmic average. So sound level meter converts the dB values to sound pressure levels, adds them all up then divides by the number of samples and finally converts this equivalent level back to decibels - dBs. Table 2.3 shows the noise level standard in various countries [69].

Table 2.3 Noise level standard in different countries.

Countries	Industrial (dB)		Commercial (dB)		Residential (dB)		Silent zones (dB)	
	Day	Night	Day	Night	Day	Night	Day	Night
India	75	70	65	55	55	45	50	40
Australia	55	55	55	45	45	35	45	35
Japan	60	50	60	50	50	40	45	35
US, EPA WHO	70	60	60	50	55	45	45	35

(Source: Sagar and Rao, 2006) [70]

2.4.1 Literature review on factors affecting noise level

The major factors that affect the noise level in urban area include various conditions such as traffic condition, pavement condition, environment and surrounding condition. Here are some parameters, which are included by various researchers for the noise modelling.



Figure 2.1 Factors affecting traffic induced noise level

(Source: Vyas et al., 2022) [69]

Traffic condition: Vehicular composition, percentage of heavy vehicles, speed, volume, traffic density, occurrence of honking events, peak hours of the day, type of fuel, age of vehicle. Pavement condition: Pavement unevenness, potholes, type of pavement, gradient, road geometry, road width. Surrounding & environmental condition: Type of land use, intersection, presence of signals, building height, green cover. Yang et al. showed that the level of noise in the city is higher during off-peak hours than during rush hours, owing to quicker speeds and more traffic flow. Land use and the surrounding neighbourhood also influence the overall noise level in the area [71]. There is heterogeneous traffic in developing countries like India, which leads to an increase in noise levels due to mixed traffic, congestion, honking, and a lack of awareness. According to Gilani, the traffic noise system is composed of the road traffic subsystem, the human subsystem, the environment subsystem, the traffic network subsystem [72]. The type of fuel has a significant impact on noise generation. When compared to conventional fuel, electrified vehicles have the potential to reduce traffic noise. Laib et al. demonstrated that using electric buses on routes with a high bus share of total traffic, low average travel speeds, and a low percentage of other heavy traffic, particularly at bus stops, has a high potential for noise reduction [73]. There is also significant impact of noise level on the price of real estate. Lozhkina et al. have shown that the price of the apartment on the heavy trafficked road is 10 % less compared to the apartment in quiet area. They also studied that the traffic noise creates an extreme risk of cardiovascular disease among senior citizens (aged over 65) that live in apartments with high noise in surrounding area [74]. For the model development, Gozalo et al. considered urban variables such as street location, street geometry, urban land use, road traffic control, and public and private transportation. They discovered that there are very significant correlations between noise levels and the variables [75].

2.4.2 Literature review on methods for estimating noise level

Many researchers throughout the world have utilised various approaches and strategies to anticipate noise levels, such as the parametric approach, the non-parametric approach, and simulation. When regulatory road traffic noise data is partial, incorrect, or missing, it is required to classify and qualify the data by prioritising certain sources of information and criteria above others. Chen et al. developed a per-vehicle noise prediction model for hilly areas using a multilayer feedforward ANN model. The ANN-based noise prediction model outperformed the empirical predictive equations in terms of accuracy [76]. Using the Morris screening method, Aumond et al. performed an overall sensitivity analysis of the

common noise assessment methods in Europe (CNOSSOS-EU) model [77]. Due to predictability and precision, soft computing approaches such as fuzzy logic, ANN, adaptive neuro-fuzzy inference system (ANFIS) and others are becoming more popular in comparison to classic statistical regression techniques. AlKheder and Almutairi used an ANFIS to predict traffic noise level on a ring road in Kuwait, considering different variables such as noise level in traffic, number of light and heavy vehicles, road width, average speed, building height, pavement condition, and air temperature and pavement temperature [78].

Gilani & Mir used a graph theory technique to build road traffic noise models that included factors relating to the road traffic subsystem. Vehicle speed, width of carriageway, number of heavy vehicles traffic volume, number of heavy trucks, and number of honking incidents were among the road traffic subsystem variables chosen for modelling. The parameterization of traffic noise prediction models varies, and as a result, different estimations of noise levels may be produced based on the geographical context in terms of emission sources and propagation field [72].

Petrovici et al. applied a multifractal approach to the propagation of acoustic waves. The approach's uniqueness originates from the freedom of the multifractal model, which allows for the simulation of a wide range of acoustic wave behaviours utilising the fractality degree [79]. Thakre C. et al. conducted a study on one of Nagpur's minor roads for two years, from 2012 and 2019. They used a MLR model that took into account parameters such as traffic volume, honking, and speed versus noise equivalent levels as shown in the equation 2.10. Noise level L_{eq} is function of light vehicles (lv), medium vehicles (mv), heavy vehicles (hv), and no of honks (hn).

$$L_{eq} = 62.5 + 0.0561(lv) + 0.1238(mv) + 0.7947(hv) + 1.6860(hn) \dots\dots\dots (2.10)$$

They found a 5–6 dB(A) increases in noise level and a 65.9 % and 81.9 % increase in sound pressure during morning and evening sessions, respectively [80].

Chang et al. monitored 24-hour average road traffic noise levels and analysed the frequency components over the course of a year to develop noise exposure land-use regression models. To create land-use regression models, noise measurements were combined with land-use types, road and traffic statistics, meteorological data, and geographic information systems [81].

In Shanghai, China, Xu et al. recorded noise levels over several seasons and developed a LUR (land use regression) model to assess the spatial variability of intra-urban noise and

identify potential sources. To create LUR models, noise measurements were combined with land-use types, transportation networks, socioeconomic data, and geographic information systems. The model's performance was evaluated using ten-fold cross-validation. LUR can be a reliable strategy for expressing noise variability in megacities where noise maps are not accessible, according to the researchers [82].

Lan et al. proposed a method for obtaining representative road traffic noise maps of different periods using an urban road traffic noise spatiotemporal distribution mapping method. The proposed noise spatio-temporal distribution model with two time-dependent variables - traffic density and traffic speed and spatiotemporal features generated from multisource data are used in this method [83].

For the period 1995 to 2014, Merchan et al. modelled the spatio-temporal variations in road traffic noise pollution in an Ecoregion of roughly 66,000 km². To expand noise modelling across the entire ecoregion, they used MLR (multilinear regression). They speculated that noise pollution levels from road traffic may not rise in lockstep throughout wide geographic areas, possibly due to the concentration of high and fast traffic volumes on modern highways connecting cities [84]. Changes in traffic noise levels (L_{eq}) at the eco regional scale is function of dimensional Euclidean distances from each centroid to roads R, motorways M, towns with more than 10,000 inhabitants T and to the coastline C as shown in the equation 2.11

$$L_{eq} = 6.285 + 9.310 \times 10^{-4} R + 1.009 \times 10^{-5} M - 9.401 \times 10^{-5} T - 5.119 \times 10^{-5} C \dots \dots (2.11)$$

Uribe et al. examined the impact of vehicular traffic on the environmental noise spectrum throughout a 12-km road stretch of Santa Marta's tourism route having five locations in urban and suburban areas. It demonstrated that low frequencies had more energy than high frequencies and were influenced by the time of day, according to the noise spectrum. During the day, all types of vehicles influenced low frequencies, but high frequencies were influenced by both day and night [85]. Using common noise metrics, diverse traffic noise patterns across road networks remain generally undifferentiated. Peng et al. developed two supplementary noise indicators for road traffic noise to address this issue. The first supplemental indicator distinguishes between the effects of noise exposure during the day and at night. The second supplemental indication distinguishes commuter traffic noise from heavy truck noise. Both indicators are expressed as hourly contributions of light and heavy vehicle noise, as well as typical traffic noise indicators [86].

One of the land uses that is susceptible to road noise is schools. While schools are required to be quiet zones, many are located in metropolitan areas and are subjected to excessive levels of noise. During school hours, Shaaban & Abouzaid carried out an assessment of traffic noise around different schools in Doha, Qatar. The findings revealed that noise levels are positively connected with traffic volume near the schools, implying that areas with larger traffic volumes have higher noise levels [87].

The influential variables and their contribution to generated noise level at signalised T-intersections, cross-intersections, and roundabouts were determined using regression modelling by Khajehvand et al. The findings revealed that the total traffic volume, as well as the number of cars, pavement condition index, and speed, have a substantial impact on noise levels. Furthermore, traffic noise levels are higher at roundabout exit approaches than at roundabout entrance approaches. Furthermore, unforeseen events and non-lane-based behaviour resulted in a dramatic increase in the maximum sound level as departure approaches [88]. Asensio et al. proposed a method of computation that allows us to isolate the contribution of a specific vehicle to overall noise pollution in an urban setting, and they used the CNOSSOS-EU framework as a base for compatibility with the European noise mapping plan [89]. For the CBD of Ondo, Nigeria, Ibili et al. investigated traffic noise levels and produced models. Traffic noise models for the measurement of equivalent noise levels (L_{eq}) at the CBD of Ondo were developed using the empirical methods of the calculation of road traffic noise (CoRTN) model and statistical multilinear regression (MLR) modelling methodology. They have shown that noise level L_{eq} is function of traffic volume Q in vph, traffic speed V in kmph, no of heavy goods vehicles per hour HGV as shown in the equation 2.12.

$$L_{eq} = 44.83 + 8.152 (Q) + 0.031 (V) + 0.085 (HGV) \dots\dots\dots (2.12)$$

With acceptable coefficients of determination (R^2) values of 0.943 and 0.963, respectively, the correlation between CoRTN and MLR models demonstrated reliable efficiency relative to observed noise levels, indicating that the method is robust and accurate in estimating the level of noise from road traffic for the study area [90]. Reidel et al. investigated the sensitivity of older citizens to road traffic noise. They studied 1691 people aged 60 to 90 years old who filled up questionnaires about their exposure to road traffic noise at the most exposed façade. A path model with linear regressions on engagement-specific self-efficacy and communal mastery measures and Probit regressions on binary planned and performed engagement variables was used to test the assumed relationships. The findings revealed a

few group-specific vulnerabilities, such as the link between engagement-specific self-efficacy and performed engagement among participants living in higher-social-welfare neighbourhoods who were also exposed to greater levels of exposure [91].

Ihemeje & Onyelowe et al. presented a state-of-the-art review on the assessment and modelling of traffic noise intensity on roadside inhabitants in Port Harcourt, Nigeria. They looked at a variety of strategies and proposals for reducing noise intensity for the health of people living near traffic lanes that had been recommended in earlier studies [92].

On an original dataset gathered in Patiala, India, Singh et al. developed a machine learning-based prediction of sound pressure level (SPL). Data on vehicular traffic and SPL was collected at several locations throughout the city. The obtained data is augmented to ten times its original size using Monte Carlo simulation, and ANN for vehicular traffic noise prediction are trained and compared to other Machine learning approaches [93].

De et al. created an adaptive traffic noise model for a noise-prone zone's susceptible society. To assess the risk of noise, they devised a fuzzy logic system. They took into account the normality and non-normality of participation for various noise parameters, such as noise intensity, exposure period, and the impacted age group of people in a specific location, and graphical depictions were created for the model's overall rationale [94].

Ranpise et al. measured ambient noise levels along key arterial roads in Surat, compared them to mandated criteria, and developed a noise prediction model for arterial roads based on an ANN with a feed-forward back propagation method for training [95]. Machine learning (ML) modelling approaches were utilised by Khalil et al. to estimate roadway traffic noise. Regression decision trees, support vector machines, ensembles and ANN were among the machine learning approaches used. A conventional regression model produced earlier under the same conditions was compared to the best developed ML model. The cross-validated results show that the best machine learning model surpassed regression modelling [96].

Gundogdu et al. created two prediction models based on genetic algorithms (GA) that can be used to restructure traffic flow within cities. Some of the noise data was used to validate the models [97]. Szwarc & Czy used GA to describe an innovative method of noise prediction for the railway [98]. Rao & Tripathi investigated the noise produced in bauxite mines by various noise sources. They used MATLAB to test the applicability of a genetic method. They came to the conclusion that GA can converge faster and discover the best values in a reasonable amount of time [99]. The sound quality of each operation condition

and position of the tractor was evaluated using the rating scale approach by Chen et al. The authors developed a back propagation neural network (BPNN) and a support vector regression (SVR) model, which were then improved using a GA. The GA was found to increase the model's prediction accuracy and greatly minimise the severe errors when the experimental findings were verified [100].

Debnath et al. investigated noise descriptors for contour plotting and discovered the suitability of ANN for the prediction of traffic noise in the Dhanbad Township, concluding that the ANN approach is far superior to any other statistical method in predicting traffic noise level [101].

In general, urban noise mapping entails modelling noise emission and attenuation in a given area, Lesieur et al. used radial basis functions as interpolators in their Meta modelling for urban noise mapping. Noise Modelling, an open-source software, was used to create the meta-model. The meta-model simulations are almost 10,000 times faster than the model while keeping the core characteristics [102]. To investigate traffic noise at roundabouts and signalised intersections, Li et al. employed a traffic noise simulation method based on microscopic traffic simulation. An experimental method was used to develop a vehicle noise emission model that considers the influence of acceleration. Traffic noise around roundabouts and signalised intersections was simulated at various traffic volume levels [103].

2.4.3. Summary

Various researchers have carried out work in the field of noise prediction model. Based on the prevailing condition, type of noise source, availability of data, various parameters are selected. The traditional approach is regression analysis which is a parametric approach. In the present study regression analysis is carried out for noise level analysis. There are some more approaches such as genetic algorithm, fuzzy logic, artificial neural network and graph theory whose suitability condition is mentioned in table 2.4. Table 2.4 show the inferences of the literature review.

Table 2.4 Summary of literature review for noise level

Approach	Description	Work done by	Parameters/ Attributes
Statistical/ Empirical /Regression	With a set of dependent and independent variables, it is a parametric technique. It is straightforward and simple to comprehend. It is not applicable to a complex problem.	Yang et al. [71]	Traffic volume, speed, land use type
		Gozalo et al. [75]	Street location, street geometry, urban land use, road traffic control, and public and private transportation
		Thakre et al. [80]	Traffic volume, honking, and speed
		Chang et al. [81]	Land-use types, road and traffic information, meteorological data
		Xu et al. [82]	Land-use types, road networks, socioeconomic variables
Graph Theory	It investigates how networks can be encoded and their attributes determined. Insufficiently suitable to large-scale data	Gilani & Mir [72]	Traffic volume, speed, Street width, Number of heavy vehicles
ANN	ANN is the most useful tool in machine learning prediction model. When dealing with complex problems with unclear functional relationships, this tool comes in handy. A black box is difficult to decipher.	Chen et al. [76]	Hilly terrain, gradient, Traffic volume
		Ranpise et al. [95]	Traffic volume, traffic composition,
		Khalil et al. [96]	Distance, Light vehicle volume, heavy vehicle volume, average speed, roadway temperature
		Debnath et al. [101]	Traffic volume, percent of heavy vehicles, Speed, traffic flow, road gradient, pavement, road side carriageway distance
Adaptive Neuro Fuzzy interface system	These systems can handle a variety of inputs, including data that is ambiguous, skewed, or inaccurate. When the situation is unknown and hazy, this is a good tool to	AlKheder & Almutairi [78]	Traffic noise level, light and heavy vehicle count, average speed, road width, building height, pavement condition, and air and roadway temperature

	have the inference inherent in human thinking and the processing of imperfect data Human reasoning is used to create rules.	De et al. [94]	Age of people, exposure time, noise level and noise risk index as an output.
Genetic Algorithm	The genetic algorithm is a heuristic for searching that is based on Charles Darwin's theory of natural evolution. This algorithm is modelled after natural selection, in which the fittest individuals are chosen for reproduction in order to produce the children of the next generation.	Chen et al. [100]	Tractor noise and various operations to run tractor, A-weighted SPL, loudness, sharpness, roughness, and fluctuation strength
		Rao at al. [99]	Engine noise, exhaust noise, transmission, tyre–road interaction, aerodynamics.
Software & Simulation	Simulation can be used to evaluate the performance of an existing system or to predict the performance of a future system by comparing different solutions and designs. It is possible to study a variety of situations and results.	Lesieur et al [102]	Traffic topography, meteorological data
		Singh et al. [93]	Traffic composition
		Li et al. [103]	Light vehicle, medium vehicle, heavy vehicle, their acceleration.

2.5 Summary

Various approaches like parametric approach, non-parametric approach and simulations are available. Also, many tools like Vissim, PARASIM, and CORSIM etc. are available. Based on the availability of data and precision of work, the approach has been selected. For long term work zone, weather condition can affect the traffic significantly specially during rainy season. Vehicular composition plays an important role in traffic analysis (e.g. slow moving vehicle, Non-Motorized vehicle and heavy vehicles). The percentage of heavy vehicles is significant factor influencing capacity and delay. Road condition-unevenness (cracks, potholes) etc. reduce the speed of vehicles and ultimately affect the capacity. From the review it is observed that the neuro-fuzzy model for work zone capacity has the highest average accuracy. The neuro-fuzzy model provides a more accurate estimate of the work zone capacity, especially when the data for factors impacting the work zone capacity are only partially available. From the review it is concluded that the location of the work zone in rural or urban areas is also identified as the relevant parameters influencing the capacity. It is also concluded that the transition area length has much bigger effect than activity area length on traffic delay. Simulation approach gives better capacity estimation accuracy while microscopic simulation gives better estimation of delay as compared to other approaches.

In the field of noise analysis and prediction modelling, various researchers have carried out work using various techniques and parameters. Some of the techniques requires large data while some techniques requires less data. So, based on the availability of the data the techniques have been chosen. Though now a days many soft computing techniques are becoming popular, the importance of statistical techniques cannot be ignored.

In the developed country, the traffic is homogeneous while in developing country like India, there is heterogeneous traffic. There is no proper lane change behaviour in India. There is no enforcement to reduce honking on urban street. Hence, the work done in developed country may not get fit in the condition of Indian streets. In case of highway or freeway, the factors affecting noise are different from the factors affecting noise level in urban area. Majority of the work has been carried out for free way condition and having homogeneous traffic. But this study is carried out for urban area with mixed traffic condition. Moreover in the present study, traffic flow and delay as well as noise parameters are analysed.

Chapter- 3

Methodology & Study Area

3.1 General

Methodology is essential for comprehending the various research processes. A methodology is an ordered, theoretical review of the procedures used in the investigation. The current chapter outlines the process used to attain the objectives. The various procedures used during the research are thoroughly addressed. The current chapter also offers information about the study area.

3.2 Methodology

In a thesis, the methodology section typically provides a detailed description of the methods and procedures used to conduct the research or study. This section outlines the overall approach and framework employed to address the research objectives. Here is a general structure and key components in the methodology description of thesis.

3.2.1 Problem identification

First, the problem is identified in the research due to the metro rail construction work zone. It involves identifying and analyzing the challenges, issues, or impacts that arise because of implementing such projects, i.e., impact during the construction stage and after construction stage. The impacts considered for the analysis are traffic flow, delay and noise level.

3.2.2 Literature Review

The literature review is a critical component of a thesis that involves a comprehensive and systematic analysis of existing scholarly works, research studies, and academic literature relevant to the research topic or problem. It serves multiple purposes, including Establishing the research context, identifying research gaps, evaluating and synthesizing existing literature, selecting the appropriate research methodology and supporting theoretical framework.

In the present study, more than 100 journal articles, conferences proceedings, various relevant reports, Indian standards codes and some books are referred to get direction for the research. The literature was accessed using google search engine. About 120 papers have been accessed from Elsevier, and ASCE e-resources using the key words like

construction work zone, traffic flow, delay, travel time, noise level, capacity etc. About 50 papers have been accessed using the e-resources of Taylor and Francis, and Springer publication.

3.2.3 Data collection

In the study, the primary and secondary data are collected. Traffic data are collected through videography survey and noise level data are collected using the sound level meter. Some reports or data available as open resources are also used as secondary data to support the study.

3.2.4 Data Management and Recording

Systematic approach is applied for organizing, storing, and managing the collected data. It requires a data recording system that ensures accuracy, confidentiality, and proper documentation. MS Excel is used as a basic tool to facilitate data organization and analysis.

3.2.5 Data Analysis

Data analysis in a thesis involves the systematic examination and interpretation of the collected data to derive meaningful insights, answer the research questions and address the research objectives. The collected data are properly organized to ensure its quality and suitability for analysis. It involves pie charts, bar charts and summarized tables of data as per the need of research. The descriptive analysis is done to summarize and describe the main characteristics of the data. It includes frequencies, percentages, means, medians, standard deviations, and correlations to gain an initial understanding of the data.

The thesis mainly involves quantitative data. So the statistical analysis techniques such as: Inferential statistics, hypothesis tests (i.e., t-test, ANOVA test) to examine relationships, differences, or associations between variable are used. Regression models are used to explore relationships and predict outcomes based on independent variables. Visual representation of data is done using charts, graphs, and tables to present data analysis findings effectively. Visual representations are conveying complex information and enhancing the clarity and impact of results.

For the assessment of the impacts, during and after construction stage, the study has been carried out. Various independent variables are identified to get relation with dependent variables i.e., flow, delay and noise level. Regression analysis has been carried to study the impact of work zone. The major factors affecting flow, delay and noise levels are identified using the correlation analysis. The prediction models are developed for the flow, delay and noise level for during and after construction stage. The developed models are validated

using ANOVA test and cross validation technique. Based on the analysis the impact of restricted area of work zone on flow, delay and noise level are quantified.

3.2.6 Conclusion

In a thesis, the conclusion typically serves as a summary and final statement of research findings, analysis, and overall study. It allows reflecting on the objectives and hypotheses of the research, evaluate the significance of results, and draw broader conclusions. This thesis has undertaken an in-depth impact analysis of metro rail construction work zones on the urban traffic and noise level in urban area,. Through extensive data collection, analysis, and evaluation, various aspects related to the effects of metro rail construction on traffic flow, delay and noise level are successfully investigated. The findings of this research contribute to a better understanding of the impacts of construction work zone on the traffic and noise level in urban area.

This entire research is divided in following components/stages. Figure 3.1 shows the methodology chart.

1. Literature Review
2. Identification of study area
3. Data collection (during and after construction stage)
 - a. Primary data
 - b. Secondary data
4. Data extraction from videography
5. Data analysis
6. Impact analysis of work zone
7. Identification of major factors affecting traffic flow, delay and noise level due to traffic work zone
8. Prediction of flow during and after construction stage
9. Prediction of operation delay during and after construction stage
10. Prediction of noise level during and after construction stage
11. Validation of flow, delay and noise level model
12. Conclusion and suggestion

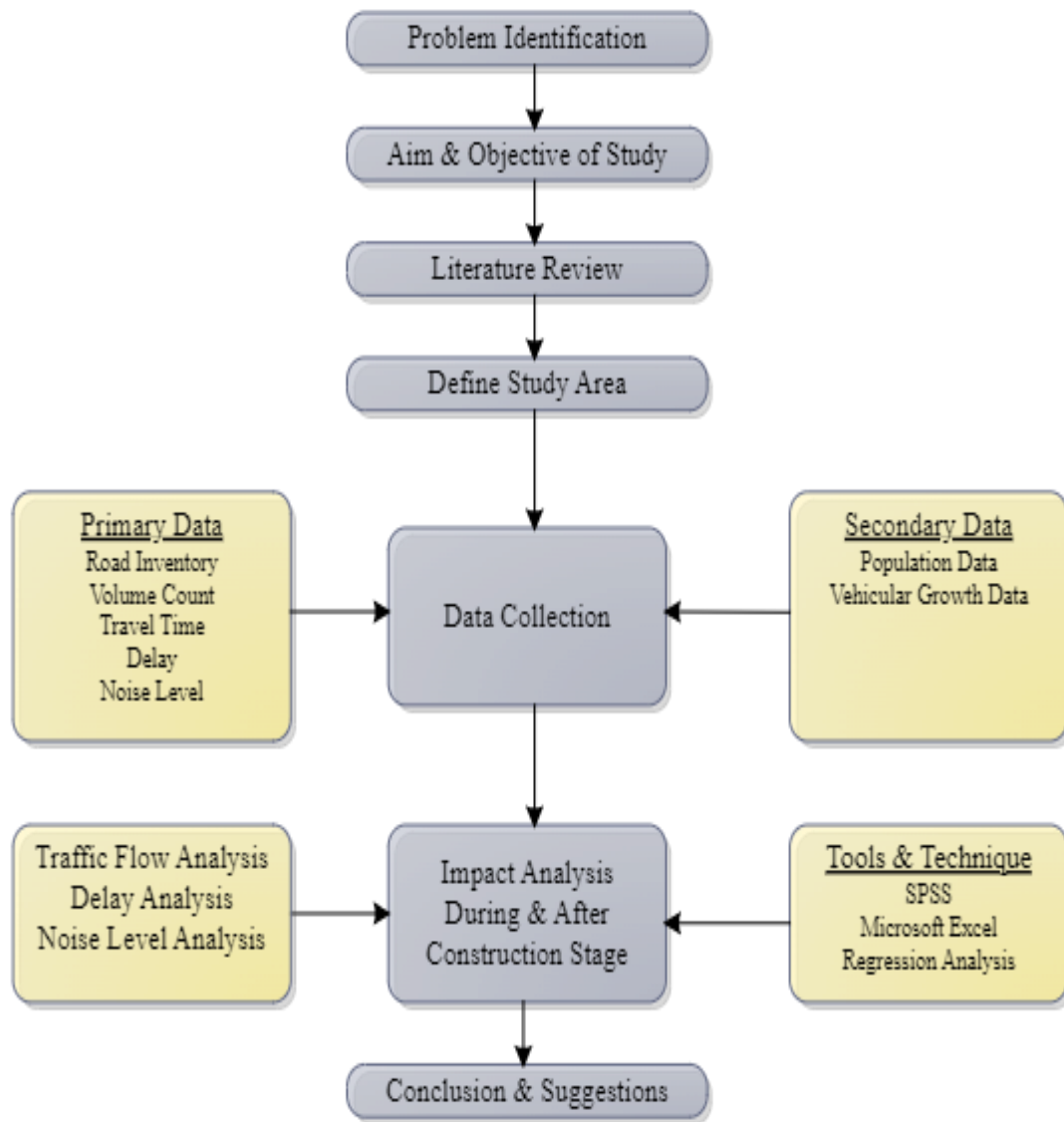


Figure 3.1 Methodology chart

3.3 Study area

Ahmedabad, presently the seventh largest metropolis in India and the largest in Gujarat, was constructed as a walled city on the eastern bank of the river Sabarmati in 1411 AD. Ahmedabad has historically been one of the most prominent trade and commercial centres in western India. It is also a major industrial and financial metropolis, accounting for around 14% of total investments in all stock markets in India and 60% of total state productivity. It is home to a number of national, regional, and worldwide scientific and educational institutes. The city has a rich architectural history, which is reflected in numerous magnificent monuments, temples, and modern structures. Ahmedabad has been

selected as one of 100 Indian cities to be developed as smart cities as a part of the Indian government's flagship Smart Cities Mission [104].

3.3.1 Ahmedabad city profile

Ahmedabad, in demographic-cum-economic terms, is the most developed region of Gujarat. Ahmedabad a 600-year-old city is the district headquarters and the biggest city of the state at present. Table 3-1 shows the demographic details of the Ahmedabad city [104].

Table 3.1 Demographic details of Ahmedabad

Co-ordinates	23.03° N 72.58° E
Area	466 Sq.km (year 2006)
Population	55,77,940 (Year 2011 Census)
Population Density	11,948 / sq. km
Literacy rate	89.60%
Average Annual rain Fall	782 mm
Popularly known as	Amdavad
STD Code	079

The population growth of Ahmedabad is increasingly continuously. The figure 3.2 shows exponential growth of Ahmedabad city [105].

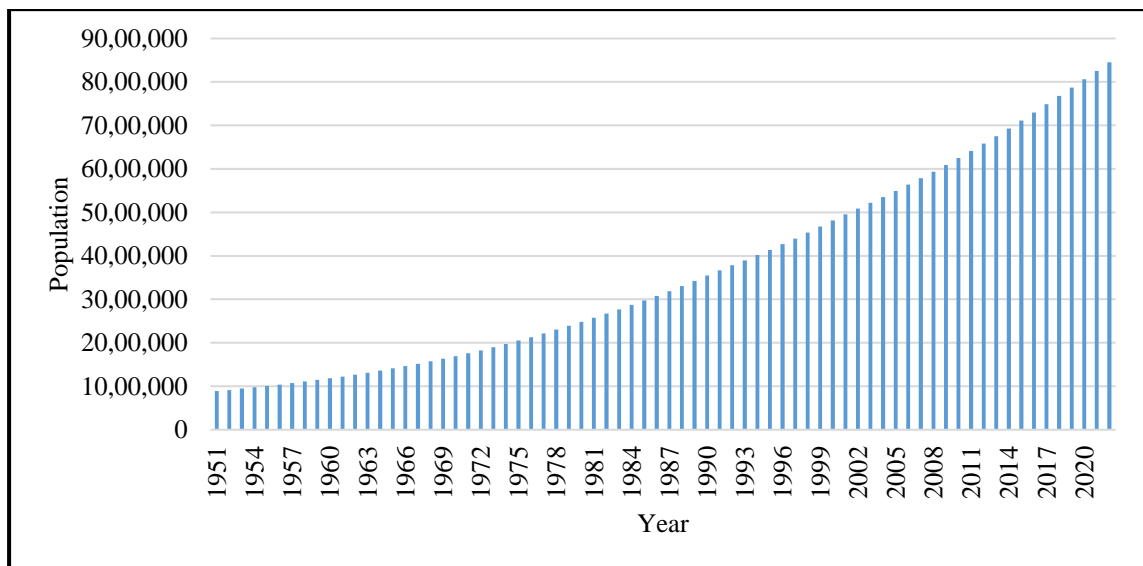


Figure 3.2 Population growth in Ahmedabad

(Source: www.macrotrends.net/cities/)

Ahmedabad is connected to the state's and country's major urban centres via an expressway, many national and state highways, broad-gauge (BG) and meter-gauge (MG) railways, and

an international airport. The city's transportation system is mainly reliant on roadways. Over the previous few decades, population and area growth have been reflected by a significantly faster increase in motorized population [106].

3.3.2 Vehicular growth

In 1971, Ahmedabad had just 45000 registered automobiles. This figure increased to 25 lakh in 2010. According to RTO data, car ownership was around 30 cars per 1000 people in 2010. When two-wheelers are taken into account, the personalised vehicle ownership rate is 230 per 1000 people. Ahmedabad now has 24, 00,000 registered vehicles, with 2, 63,205 of them being cars [107]. The growth of the number of vehicles was phenomenal in the last 2 decades and the city has around 49 lakh registered vehicles as on 31st March 2020 and more than 70% are two-wheelers [108]. Figure 3.3 shows total number of registered vehicles in Ahmedabad.

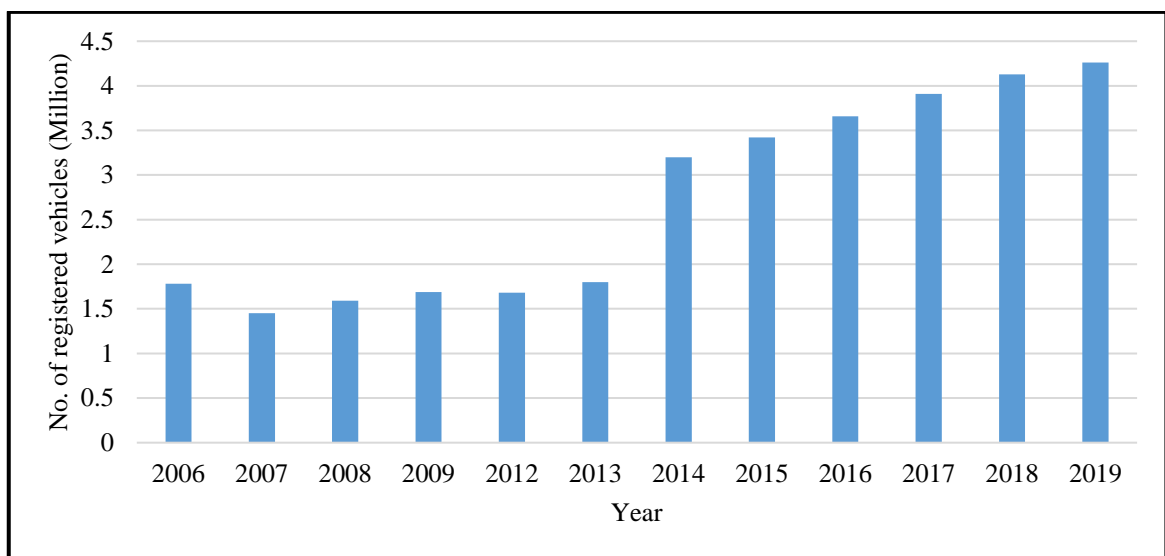


Figure 3.3 No. of registered vehicles in Ahmedabad

(Source: <https://cot.gujarat.gov.in>, RTO Ahmedabad)

3.3.3 Road network

Ahmedabad has grown in the shape of circular rings surrounding the walled city region, which serves as the historic core commercial centre. Historically, the street network was ring-radial in shape, with 5 rings and 19 well-defined radials: 11 in the west and 8 in the east. The Ashram road, which runs along the western bank of the Sabarmati River, acts as a north-south axis. The overall length of the road network inside the Ahmedabad Municipal Corporation (AMC) area is 2399 kilometres. The Sabarmati River divides the city into two parts. Eleven bridges allow easy movement throughout the city. A 106 km long BG line

and a 126 km long MG line run through the city. Several rail-over bridges have been constructed to facilitate movement across railway lines [107]. Figure 3.4 shows map of Ahmedabad showing major road and railway lines. [109]

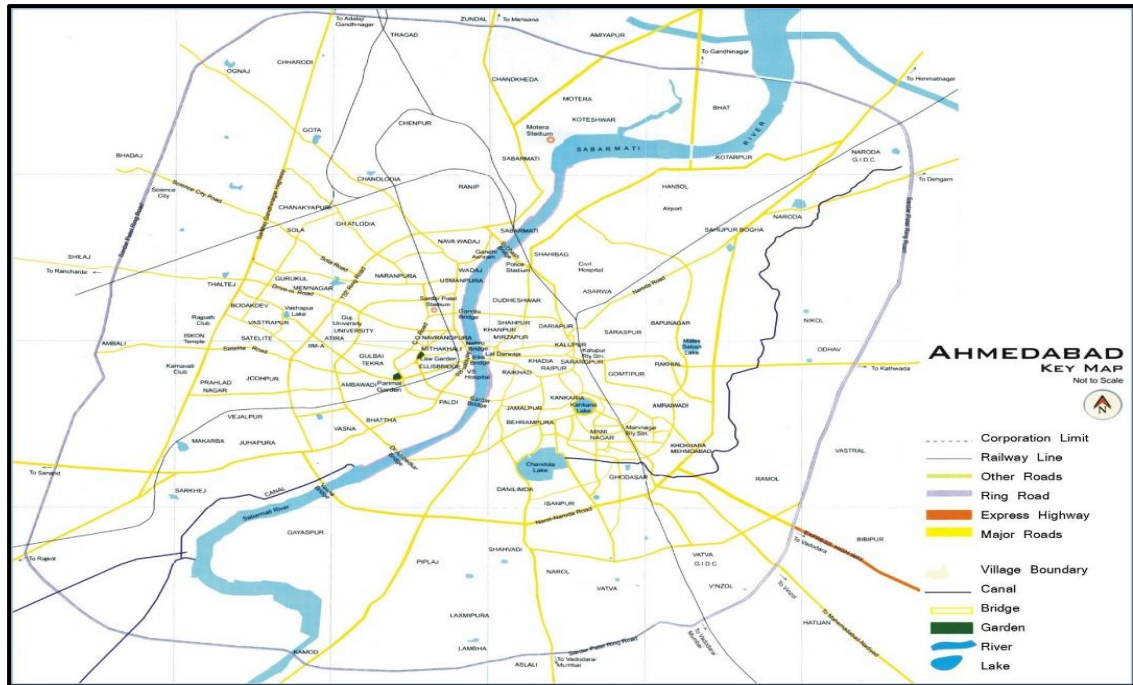


Figure 3.4 Map of Ahmedabad city

3.3.4 Urban transportation system

Ahmedabad Municipal Transport Services (AMTS) and Ahmedabad Janmarg Limited (AJL) provide transit services in Ahmedabad, while Gujarat State Road Transport Corporation caters to regional public transit demand (GSRTC). The BRT system currently has 59 kilometres of network length and serves 1.17 lakh passengers per day. There are nine operational routes with peak headways of approximately 2.5 minutes. Due to dedicated corridors and priority at major junctions, BRT buses reach peak hour speeds of 25kmph, which are comparable to mixed traffic speeds. As Ahmedabad BRTS routes have sharing space on the intersection and fly over bridges. There is a partial separate right of way is dedicated to BRTS. So, average speed is observed as 25 kmph. There are approximately 60000 auto rickshaws in operation in the city. Around 6000-8000 of them work as "Chhakdas" or shared auto rickshaws. They compete with bus services because they run along the BRTS and AMTS routes at comparable fares [107].

3.4 Ahmedabad metro rail project

Ahmedabad Metro is a rapid transit system for the cities of Ahmedabad and Gandhinagar in Gujarat state of India. The total length of the Ahmedabad Metro Rail Project Phase-I is approximately 40.03 kilometres, of which approximately 6.5 kilometres are underground and the remainder are elevated sections. With two corridors and 32 stations, the project will connect four corners of Ahmedabad [110]. Figure 3.5 shows North-South Corridor and Figure 3.6 shows East-West Corridor [111].



Figure 3.5 North-South Corridor

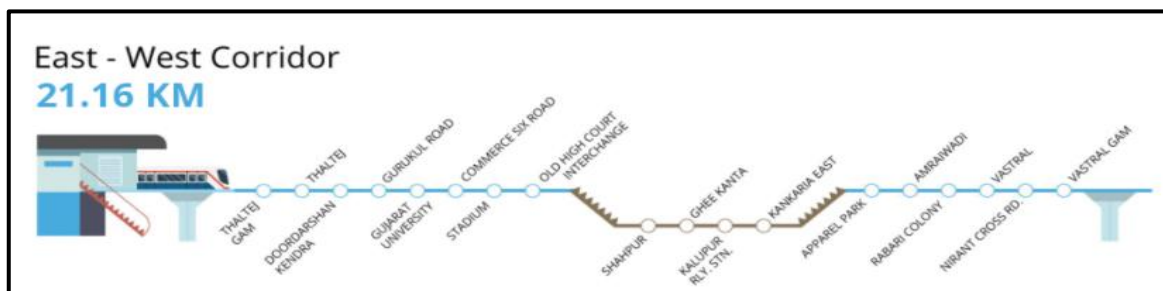


Figure 3.6 East-West Corridor

The East-West Corridor is approximately 21.16 kilometres long, with 17 stations along the way. This corridor will run through Nirant Crossroad, Vastrapur, Rabari Colony, Amraiwadi, Apparel Park, Kankaria East, Kalupur Railway Station, Ghee Kanta, Shahpur, Old High Court, Stadium, Commerce Six Road, Gujarat University, Gurukul Road, Doordarshan Kendra, and Thaltej stations. Approximately 6.5 km of the East-West corridor is underground, with four underground stations, and the rest is elevated, with thirteen elevated stations. The Old High Court station will serve as an interchange for both corridors [112].

Justification of selection of study area segment

For the north-south corridor, on some of the sections, such as APMC to Paldi, construction were finished in 2017 and the remaining segment was on railway land, so the existing traffic was unaffected. For east west corridor i.e., Stadium to Thaltej crossroad, the

construction was started in 2017 and that is why the area has been selected to compare during and after conditions.

3.5 Study area map

Figure 3.7 shows the map of India, Gujarat and location of Ahmedabad city.

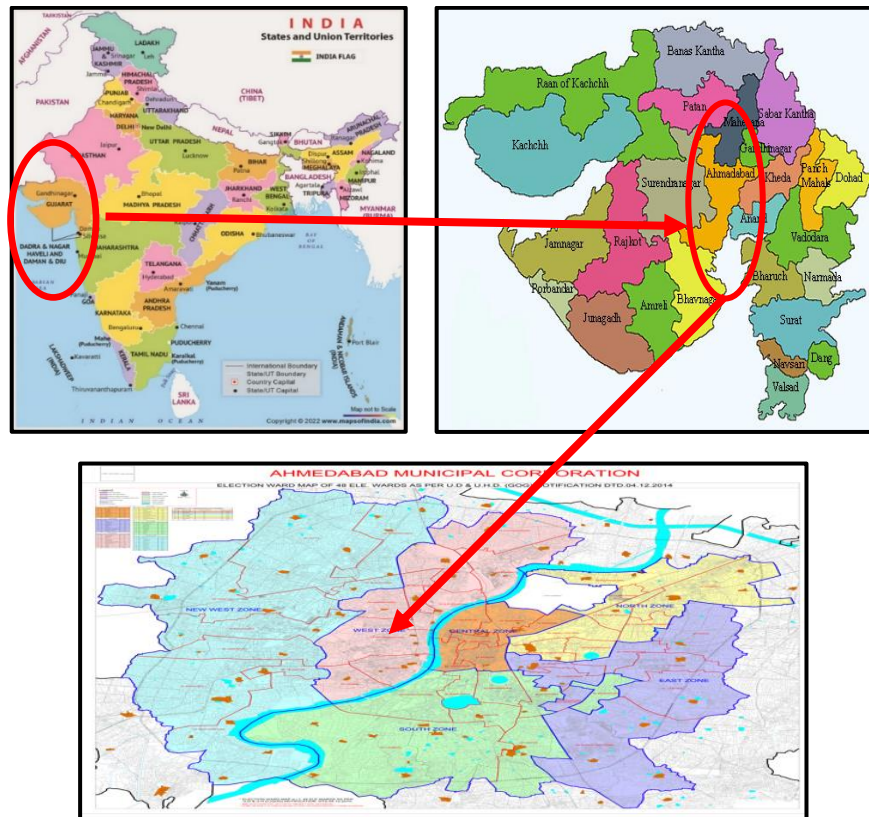


Figure 3.7 Location of study area

The Travel time, delay and noise level are measured on the corridor from Thaltej crossroad to stadium crossroad, while flow and spot speed have been measured on the corridor from Stadium crossroad to Thaltej crossroad (Figure 3.8 A, B and C).

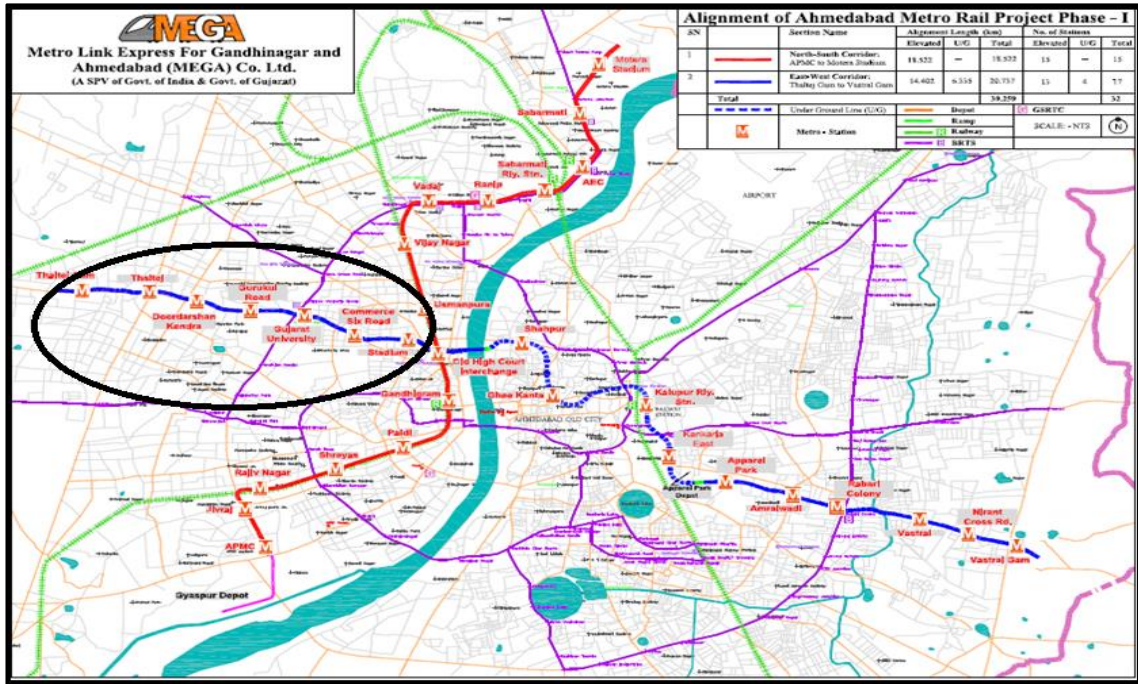


Fig. 3.8-A Ahmedabad metro rail project map phase-1 [111]

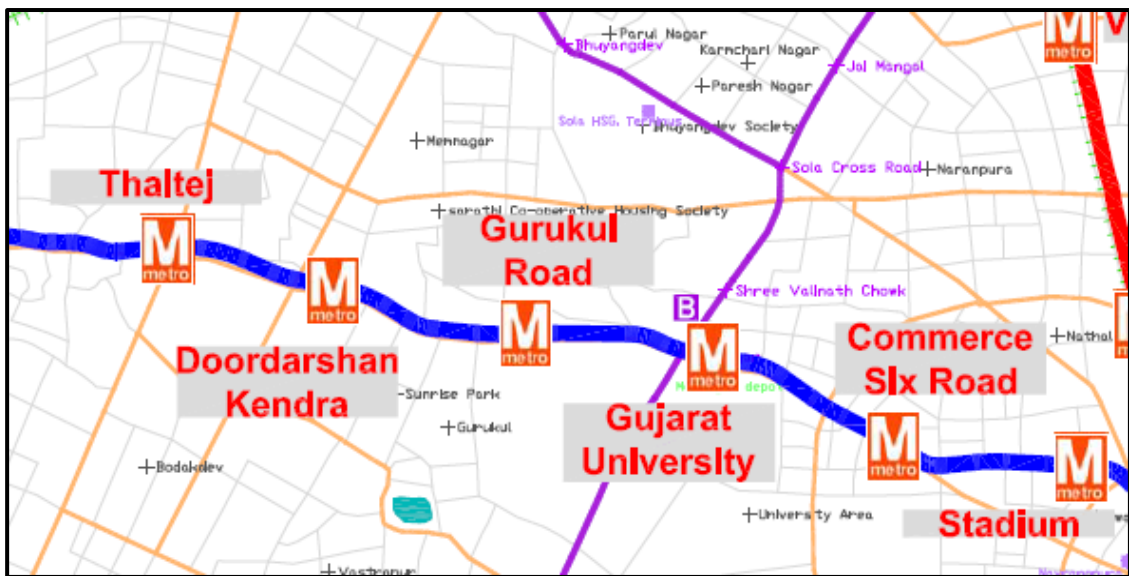


Fig. 3.8-B Segment of East-West corridor phase-1 [111]

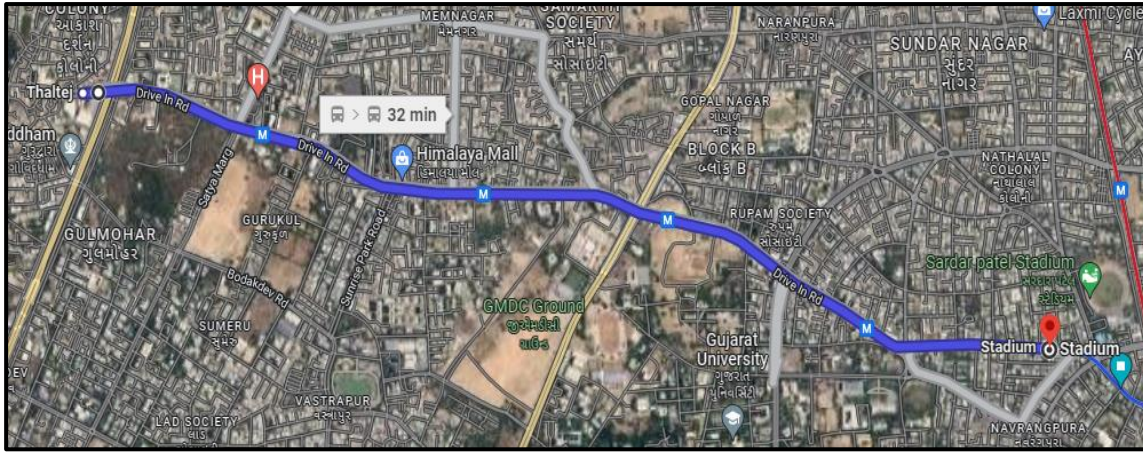


Fig. 3.8-C Image of study area (Google Earth Image)

Figure 3.8 Study area maps

The segment of east west corridor is divided in to no. of links. Many commercial and residential building surround the study area. There are some major hospitals along the corridor such as Nidhi Hospital, May flower women’s Hospital, Sal Hospital etc. The major landmarks on the study area are Sardar Patel stadium, Swaminarayan Gurukul, Himalaya mall, Drive in cinema and Doordarshan Kendra. Table 3.2 shows the detail of the links of study area.

Table 3.2 Study area links

Link	Type of road
Stadium crossroad- Commerce crossroad	4 lane two-way divided road
Commerce crossroad- Vijay crossroad	6 lane two-way divided road
Vijay crossroad- Saurabh crossroad	6 lane two-way divided road
Saurabh crossroad – Helmet crossroad	6 lane two-way divided road
Helmet crossroad- Gurukul crossroad	6 lane two-way divided road
Gurukul crossroad - Sunrise Park crossroad	6 lane two-way divided road
Sunrise Park crossroad - Sal crossroad	6 lane two-way divided road
Sal crossroad-Thaltej crossroad	6 lane two-way divided road

All the images shown in the figure 3.9 to 3.16 are obtained from Google Earth application. Figure 3.9 shows the link of stadium-commerce crossroad. This link lies in the ward of S. P. Stadium and Navarangpura ward. This link is a 4 lane two-way divided road. The major landmarks on this link are Nidhi Hospital, and Saradar Patel stadium.

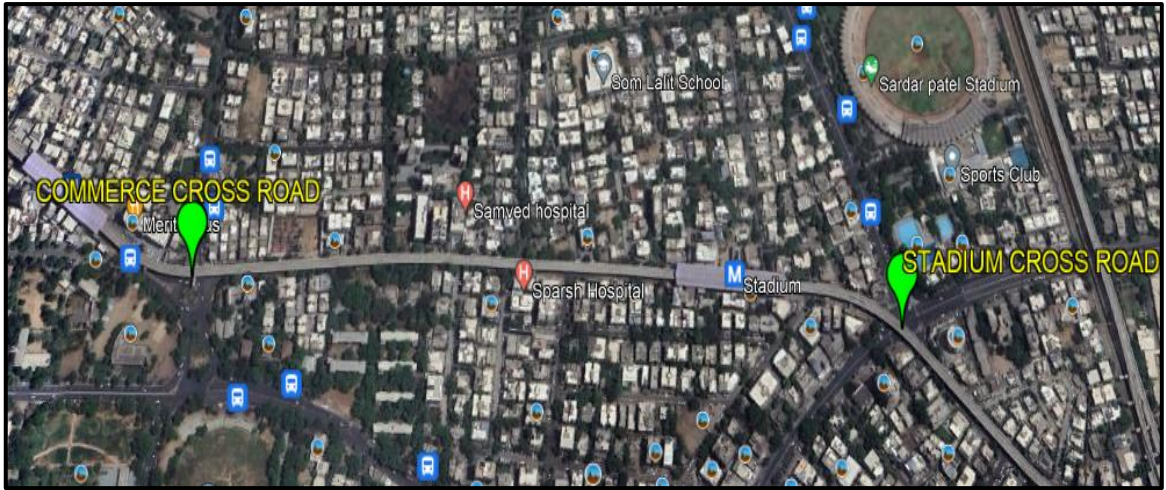


Figure 3.9 Stadium crossroad-Commerce crossroad link

Figure 3.10 shows Commerce crossroad – Vijay crossroad link. This link lies in Navarangpura wad. This link is a 6 lane two-way divided arterial road.

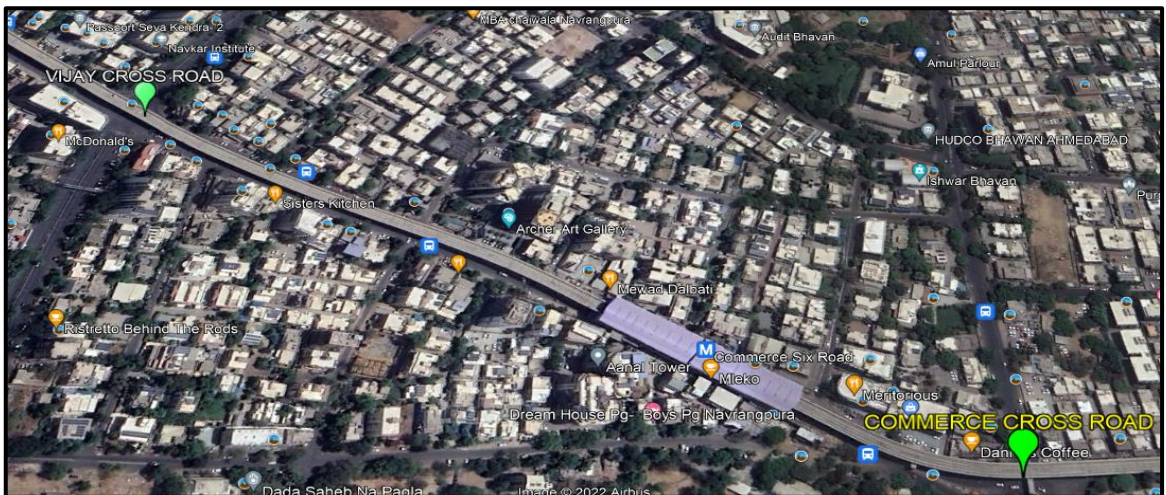


Figure 3.10 Commerce crossroad-Vijay crossroad link

Figure 3.11 shows Vijay crossroad - Saurabh crossroad link. This link lies in Navarangpura wad. This link is a 6 lane two-way divided road. The major landmark on this link is Passport Seva Kendra.



Figure 3.11 Vijay crossroad-Saurabh crossroad link

Figure 3.12 shows Saurabh crossroad–Helmet crossroad link. This link lies in Navarangpura wad. This link is a 6 lane two-way divided road. There is open space long this link. On one side, there is cricket ground and on other side, there is open space under Ahmedabad Education society.



Figure 3.12 Saurabh crossroad-Helmet crossroad link

Figure 3.13 shows Helmet crossroad- Gurukul crossroad link. This link lies in Bodakdev ward. This link is a 6 lane two-way divided road. The major landmarks along this links are Mahatma Gandhi labour institute, Manav Mandir, May Flower women’s hospital etc.



Figure 3.13 Helmet crossroad-Gurukul crossroad link

Figure 3.14 shows Gurukul crossroad- Sunrise Park link. This link lies in Bodakdev ward. This link is a 6 lane two-way divided road. The major landmarks along this link are Himalaya Mall, Sarkari Vasahat and Bahumali Bhavan.

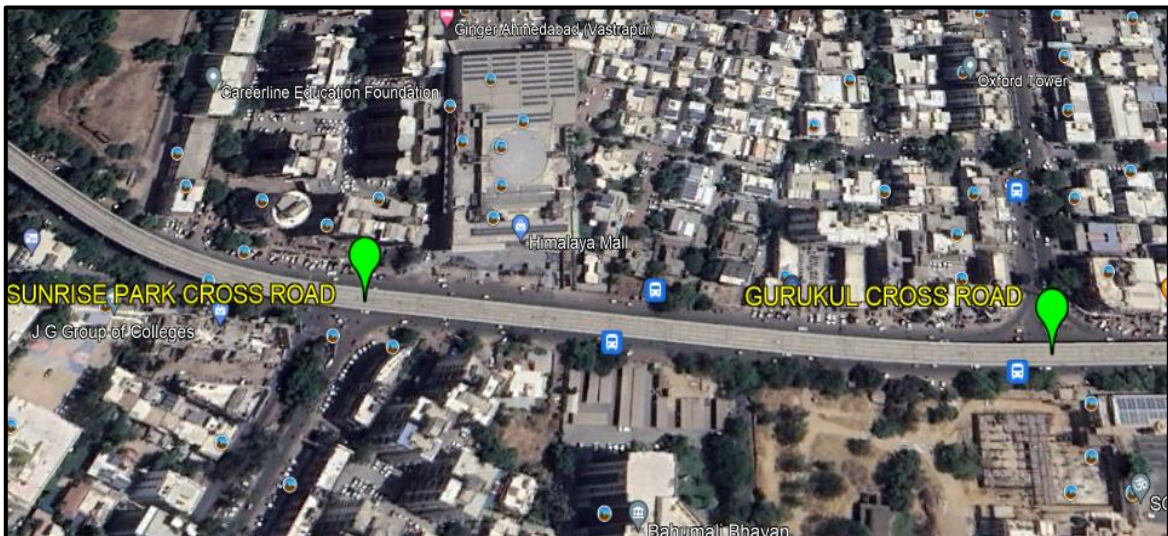


Figure 3.14 Gurukul crossroad-Sunrise Park link

Figure 3.15 shows Sunrise Park- Sal crossroad link. This link lies in Bodakdev ward. This link is a 6 lane two-way divided road. The major landmarks along this links are Doordarshan Kendra, Sal hospital and Drive in cinema.



Figure 3.15 Sunrise Park-Sal crossroad link

Figure 3.16 shows Sal crossroad- Thaltej crossroad link. This link lies in Bodakdev and Thaltej ward. This link is a 6 lane two-way divided road. The major landmarks along this link are Udgam international school and Thaltej electric substation.

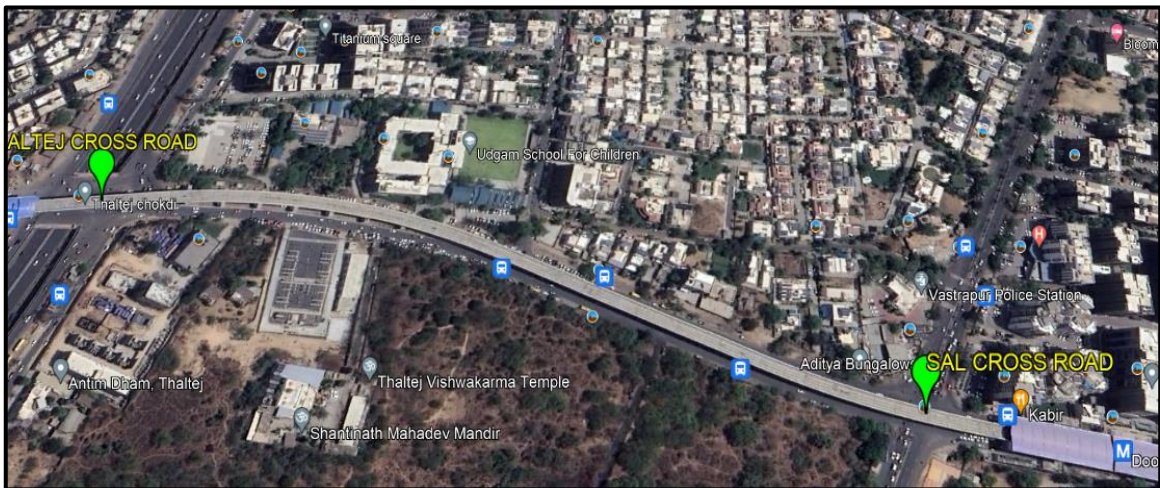


Figure 3.16 Sal crossroad-Thaltej crossroad link

3.6 Summary

The nature and demographic details of Ahmedabad city are covered in this chapter. The criteria for selecting the links for the metro rail construction work zone are also briefly explained. The methodology used in the current study is described. The following chapter describes data collection and analysis.

Chapter- 4

Data Collection and Data Analysis

4.1 General

The data collection is the crucial part to achieve the objective of the research work. The data have been collected twice for the same location to get the idea about the impact of work zone for during and after the construction stage.

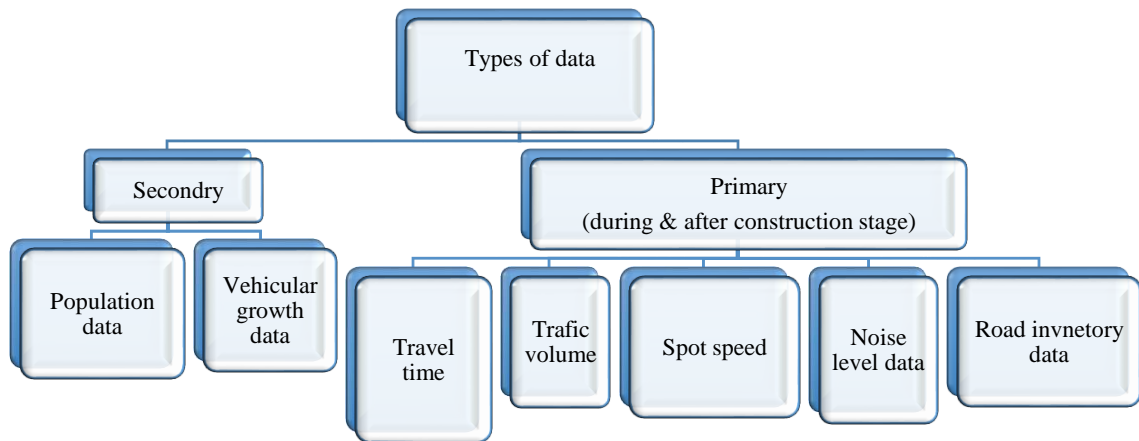


Figure 4.1 Types of data

4.2 Secondary data collection

The data about study area such as demographic details, vehicular growth rate, map of study area etc. have been collected from concerned authority and from online open sources. The traffic flow data and noise level data are collected in the traffic direction from Stadium crossroad to Thaltej crossroad. The traffic flow data are collected in the traffic direction from Thaltej crossroad to Stadium crossroad. Figure 4.2 shows the traffic direction in the study area.



Figure 4.2 Study area traffic direction

4.3 Sample size calculation

The number of observations included in a research study to represent a population is referred to as the sample size which represents the entire population. One of the most important aspects of statistical analysis is determining the appropriate sample size. A small sample size will not produce valid results or adequately represent the realities of the population being studied. On the other hand, while larger sample sizes result in smaller margins of error, an overly large sample size may significantly increase the cost and time required to conduct the research. The sample size has been determined from the equation 4.1 [113] [114].

$$s = \frac{z^2 \times p(1-p)}{\epsilon^2} \dots\dots\dots (4.1)$$

Where,

S is sample size for infinite population

z = Z score,

p = population proportion (Assumed as 50% or 0.5),

ϵ = Margin of error

Here 95% confidence and a margin of error of 5% is considered. Assume a population proportion of 0.5, and unlimited population size. The z value for a 95% confidence level is 1.96.

$$s = \frac{1.96^2 \times 0.5 (1-0.5)}{0.05^2} = 384.16$$

The above equation is applicable for infinite population. The total number of samples are more than the above value. The traffic flow is measured at every 3 min interval during morning, noon and evening time. For the spot speed and travel time measurement, 30% of total volume is measured and noise is also measured at every 3 min interval. Table 4.1 shows the actual number of samples has been considered for the analysis. Here, it is required to mention that the data have been collected during the construction stage and after construction stage.

The traffic flow data and noise level data are the actual number of samples for the data collection, whereas the travel time data for various category of vehicles are taken as more than 10 % of the individual proportion. The spot speed data are also collected for each category of vehicle for more than 10 % of the traffic volume.

Table 4.1 Sample Size

Sr. No.	Parameter	Total no of sample/observations
1	Traffic Flow	1529
2	Travel Time	1074
3	Noise Level	1530

4.4 Primary data collection

In primary data set, road inventory, travel time, delay, classified volume count, spot speed data and noise level data have been collected. In 2018, the whole corridor was under the construction work zone. Barricades were installed on the roads i.e. the road width was partially available for the movement of traffic. In this phase, data have been collected. In 2022, the barricades were removed, and lanes were fully available to the traffic. In this phase, once again the data have been collected.

This corridor is flanked by property uses such as commercial and residential. Because of the barricades put along the stretch owing to metro rail work, the corridor is partially closed at various locations and thus the carriageway width (LW) varies in the study area. For simplicity of data collection, the entire corridor has been divided into number of links.

4.4.1 Road inventory survey

The road inventory data were collected during early morning 5.30 am to avoid conflicts with the traffic. The length and width of the road have been measured using an odometer (a portable handy measuring wheel). The building height is measured by considering 1 floor height is 3.0 m and also verified it with a 30 m tape. These data have been collected for during and after construction stage.

4.4.2 Traffic volume count survey

To get the volume count of the study area, videography survey was carried out. The volume count survey had been carried in October 2018 for during construction stage. Once again, on the same corridor, the volume count survey was carried out in February 2022 for the after-construction stage. Based on the report published by Ministry of Urban development titled “Ahmedabad traffic management and information control centre, operations document”, the morning peak hour is 9:30 a.m. to 10:30 a.m. and evening peak hour is 5:30 p.m. to 6:30 p.m. in Ahmedabad [115].

The volume count is carried out for every 3 min interval on all the links for morning peak hour 9.30 a.m. to 11.30 a.m., noon hour 1.00 p.m. to 3.00 p.m. and evening peak hour 5.30

p.m. to 7.30 p.m. There are signalised intersections on upstream and downstream of the links. The signal cycle time varies from 120 sec to 150 sec on all the intersections. When the signal turns green, vehicle platoon enters to the link. So, the platoon arrival had a variation in the interval of 3 min. To capture the slow down effect due to construction work zone, 5 min interval was not suitable. 3 min was found better to capture the forced flow condition also. To capture the speed variation in smaller interval and to consider the platoon effects, 3 min interval was considered. For statistical check, 20 observations of 3 min interval of Stadium crossroad to Commerce crossroad link were checked. As per Chebyshev's inequality test, 16 observations out of 20 (80%) were lying within 1 standard deviation (121 PCU/hr) from the mean (506 PCU/hr).

4.4.3 Spot speed survey

To get the speed of all kinds of vehicles of the study area, the spot speed survey has been carried out using videography survey. 40 m stretch is taken on the mid-block of the study area for the spot speed data collection. Camera position was fixed in such a way that a clear vision of selected stretch can be taken without any disturbance. From the videography survey, the time taken by the vehicle to cover the distance is used to get the spot speed. The spot speed survey and traffic volume count survey had been carried out at the same time for the selected stretches. From the collected data, space mean speed was calculated.

4.4.4 Travel time and delay survey

To measure the delay caused by construction work zone restriction, travel time and delay survey has been carried out. First, the travel time during the free flow condition has been measured in the early morning hours when free flow condition is available. A vehicle travelling at a time headway 8 seconds or more is considered to be operating under free flow conditions as per Indo HCM (2017) guidelines. This condition was obtained in early morning on the selected links. The travel time during morning and evening peak hour, noon off-peak hour have been measured. The difference between free flow travel time and peak/off-peak hour travel time is considered as the travel time delay. Thus, the travel time delay had been measured for all kind of vehicles for during and after construction stage.

4.4.5 Noise data collection

The data were collected in the month of April 2019 during weekdays. Automobiles are major sources of noise in urban area. So, the data have been collected during the morning and evening peak hours of the day. To consider the off-peak noise level, the data have been collected during noon hours as well. Data have been collected for every 3 minutes interval

in the morning from 9:00 a.m. to 12:00 noon, at midday from 1:00 p.m. to 3:00 p.m. and in the evening from 6:00 p.m. to 9:00 p.m. The time selected for the data collection is based on the rush hour of the day. The morning and evening peak hour and afternoon off peak hours have been selected for the data collection. The data have been collected on the 7 locations of the study area. A sound level metre (SL-4001) is used to measure the noise level. It was positioned at a height of 1.5 metres above the ground at the edge of the lane. Noise level has been recorded at every 3-minute interval along with the traffic data. The data collection are carried out on different traffic direction as shown below.

- For traffic flow parameter analysis, Stadium crossroad to Thaltej crossroad approach was considered.
- For travel time and delay analysis, Thaltej crossroad to Stadium crossroad corridor has been considered.
- For noise level analysis, Stadium crossroad to Thaltej crossroad approach was considered.

Travel time and delay parameters were observed on Thaltej crossroad to Stadium crossroad because there is variation in available carriageway width. So, variation in the speed can be captured. Whereas on Stadium crossroad to Thaltej crossroad stretch, spot speed survey was carried out at various locations because the stretch has comparatively uniform carriage way width.

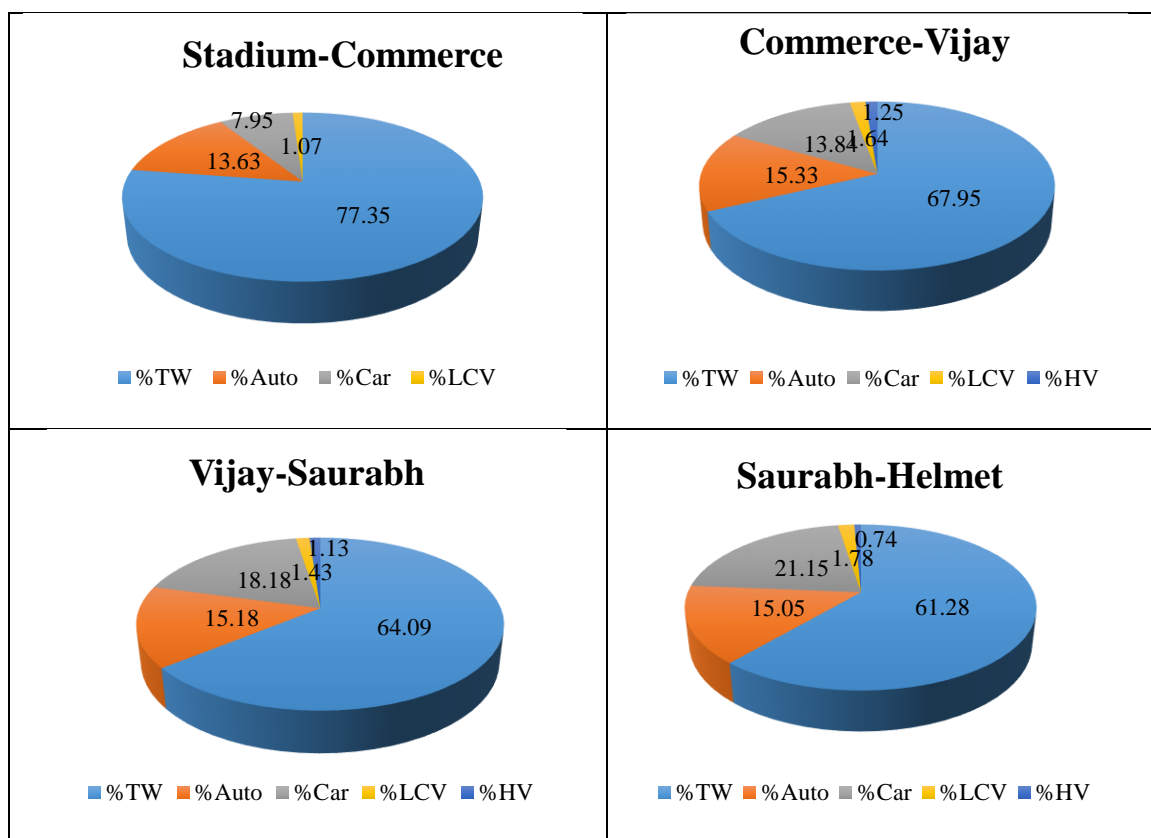
4.5 Traffic flow analysis

To study the Traffic flow parameters, Stadium crossroad to Thaltej crossroad has been divided in to 6 links which is shown in the table 4.2. During construction stage of metro rail project, the carriage way width of the roads were partially closed. Table 4.2 shows the category of road, available carriageway width (ALW) and work zone width during construction stage. Here the link of Stadium crossroad to Commerce crossroad is 4 lane divided two-way road, while rest of the links are 6 lane two-way divided road.

Table 4.2 Inventory data (Stadium crossroad to Thaltej crossroad)

Sr. No	Stretch	Available one way carriageway width (ALW) during construction (m)	Work zone width (WWZ) during construction (m)
1	Stadium crossroad to Commerce crossroad	3.5	3.6
2	Commerce crossroad to Vijay crossroad	5.2	4.8
3	Vijay crossroad to Saurabh crossroad	7	4.3
4	Saurabh crossroad to Helmet crossroad	6.5	5.5
5	Gurukul crossroad to Sunrise Park crossroad	9	2.5
6	Sal crossroad to Thaltej crossroad	7.5	4.0

The traffic flow data have been collected from videography survey. At every 3 min interval, the flow data have been extracted. On each link, the vehicle composition data are collected. Figure 4.3 shows the vehicle composition of all the links during construction stage. From the figure 4.3, it is observed that for all the links, two-wheelers have major proportion. Using the videography method, the flow data were extracted. The flow data have been collected for morning, noon and evening peak hours.



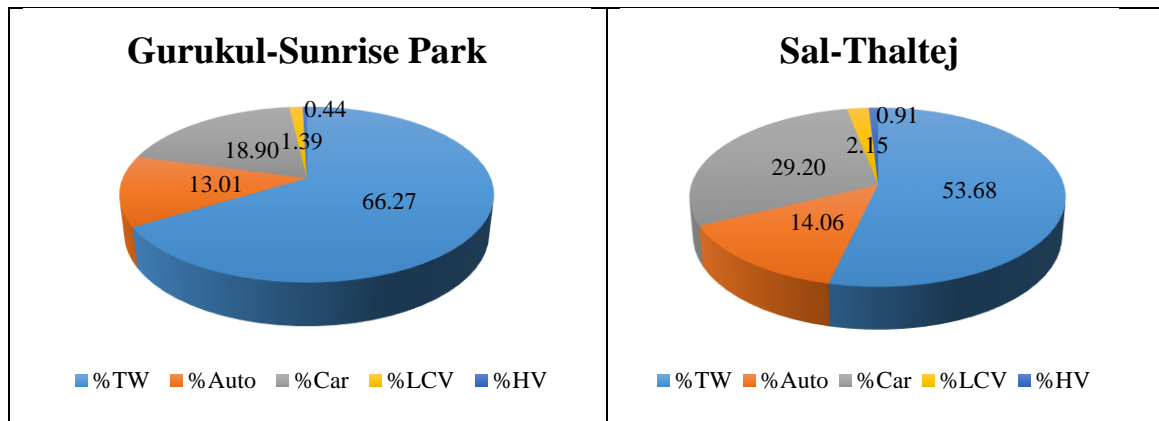


Figure 4.3 Vehicle composition in the study area during construction stage (From Stadium to Sal crossroad)

The PCU values considered for the analysis is taken from Indo HCM 2017 which are shown in the Table 4.3.

Table 4.3 Adopted PCU values

Type of Vehicle	PCU factor
Motorised two wheeler	0.21
Auto rickshaw	0.83
Car	1
Light Commercial vehicles	2.3
Bus *	4.6

*In the study, heavy vehicle (HV) word is used. In this category, number of buses and number of concrete mixers and some other kind of construction vehicles are included. As the proportion of construction vehicles are very low, they are considered along with numbers of buses. Figure 4.4 shows the observed flow rate (PCU/hr) for morning noon and evening hours. Here, the Y axis is average value obtained from conversion of every 3 min traffic flow into 1 hour traffic flow for morning noon and evening hours.

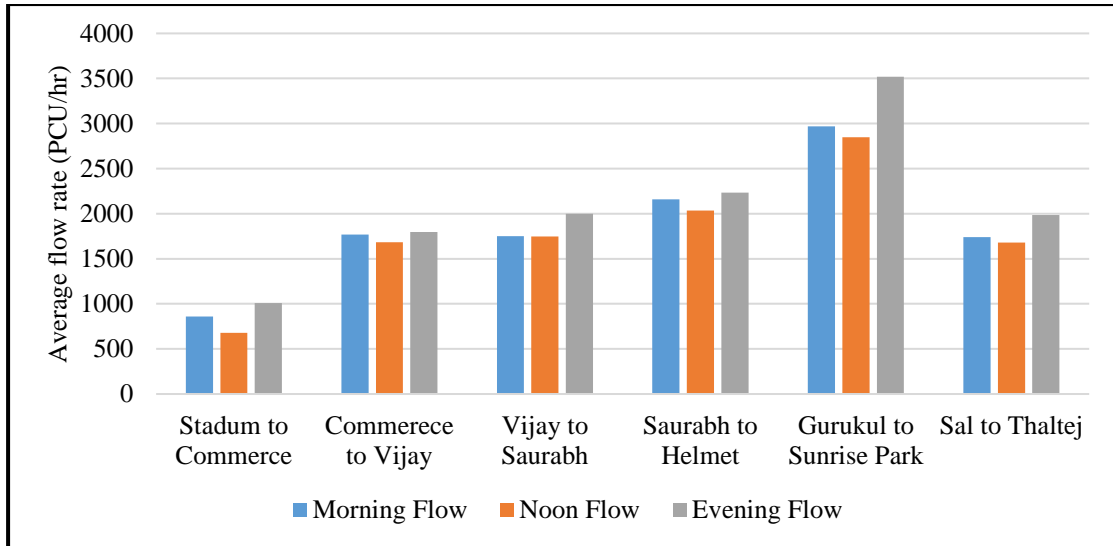


Figure 4.4 Observed flow during construction stage

From the figure 4.4, maximum flow is observed on the link on Gurukul to Sunrise Park. During construction stage, on the link of Stadium crossroad to Commerce crossroad, available carriageway width is 3.6 m which is the lowest as compared to other stretches. Therefore, observed volume and speed are lower than other stretches. On the other links, speed decreases with increase in the average flow rate.

Stadium to commerce link has the minimum flow. The flow and speed are closely related with each other. The spot speed survey is carried out using videography method. 40 m distance is taken on the mid-block for spot speed data collection. From the spot speed data, average travel time is calculated to get space mean speed.

$$\text{Space Mean Speed} = \frac{\text{Distance travelled}}{\text{Average travel time}} \dots\dots\dots (4.2)$$

Figure 4.5 shows the observed space mean speed (SMS) on each link.

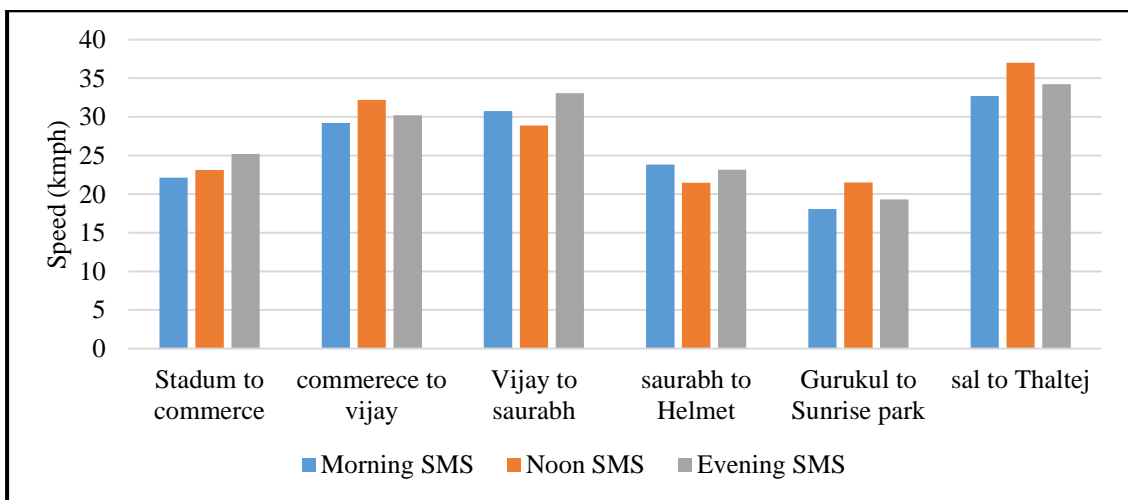


Figure 4.5 Observed speed during construction stage

From figure 4.5, maximum speed 34.63 kmph is observed on the link of Sal to Thaltej crossroad during the noon hours. The minimum speed of 18.17 kmph is observed on the link of Gurukul to Sunrise Park during morning peak hours.

Speed-flow Relationship (During Construction)

The speed-flow relationship has been developed by considering the outer envelope curve and thus maximum flow rate is obtained from the graph (Figures 4.6 to 4.11). The speed-flow relationship is established to get the maximum flow. Outer envelope is only used for obtaining maximum flow rate. Whereas all data points were used to develop regression model. During the data collection few points were observed where "Stop and Go" condition was observed. That is how lower curve points were obtained.

From the figures 4.6 to 4.11, it is observed that the upper envelope is following 2nd order polynomial relationship and lower envelope is following exponential relationship. There is reduction in speed as flow increases. After that, the reduction in flow and speed is observed which is showing forced flow condition of traffic.

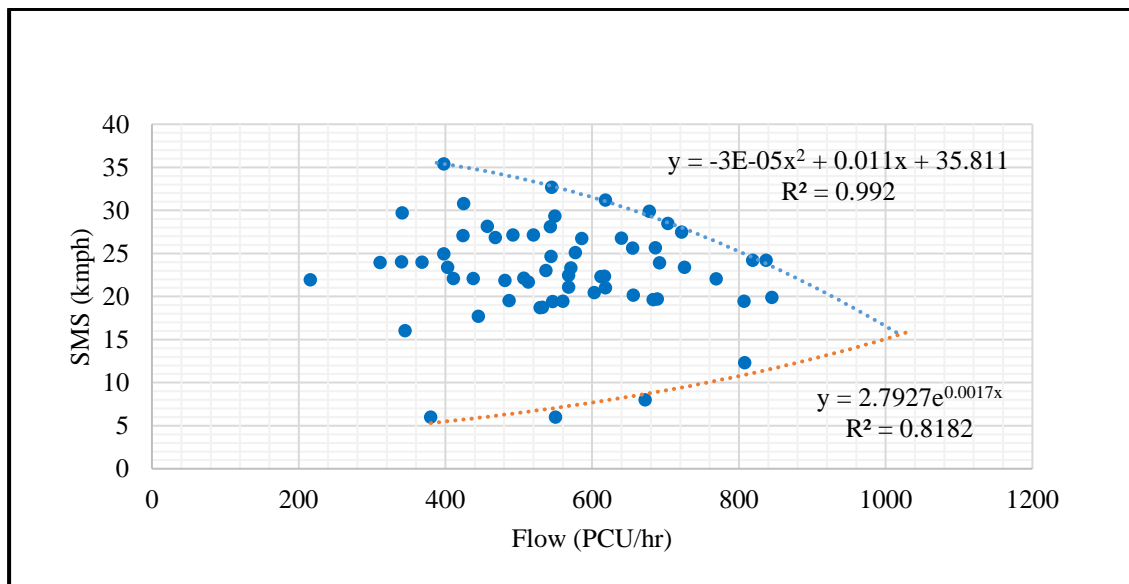


Figure 4.6 Speed-flow relationship during construction stage (Stadium crossroad to Commerce crossroad)

From the figure 4.6, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.992, while lower curve is following exponential relationship having R^2 value as 0.8182.

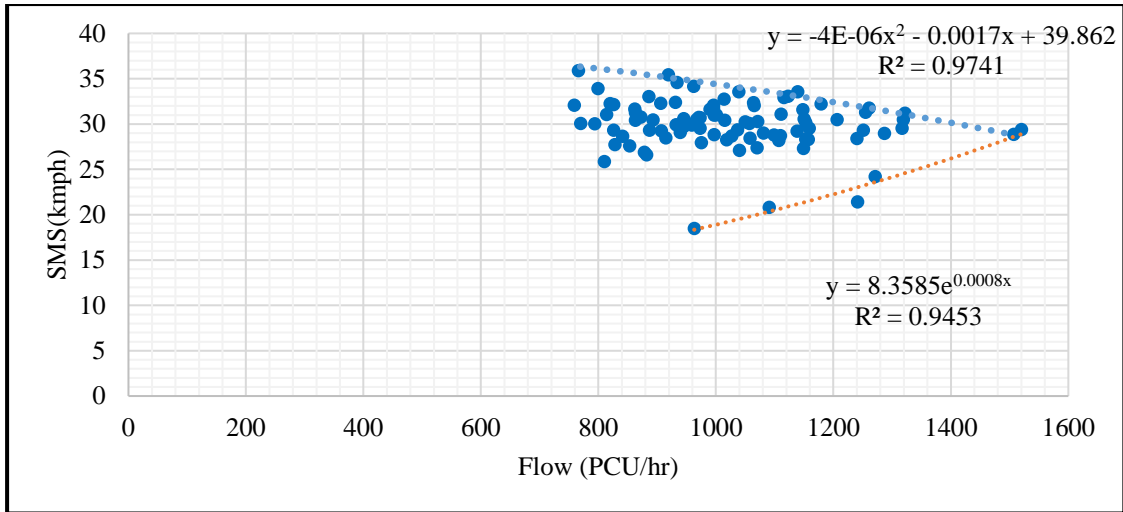


Figure 4.7 Speed-flow relationship during construction stage (Commerce crossroad to Vijay crossroad)

From the figure 4.7, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.9741, while lower curve is following exponential relationship having R^2 value as 0.9453. Speed-flow relation is developed for Vijay to Saurabh crossroad during construction stage which is shown in figure 4.8.

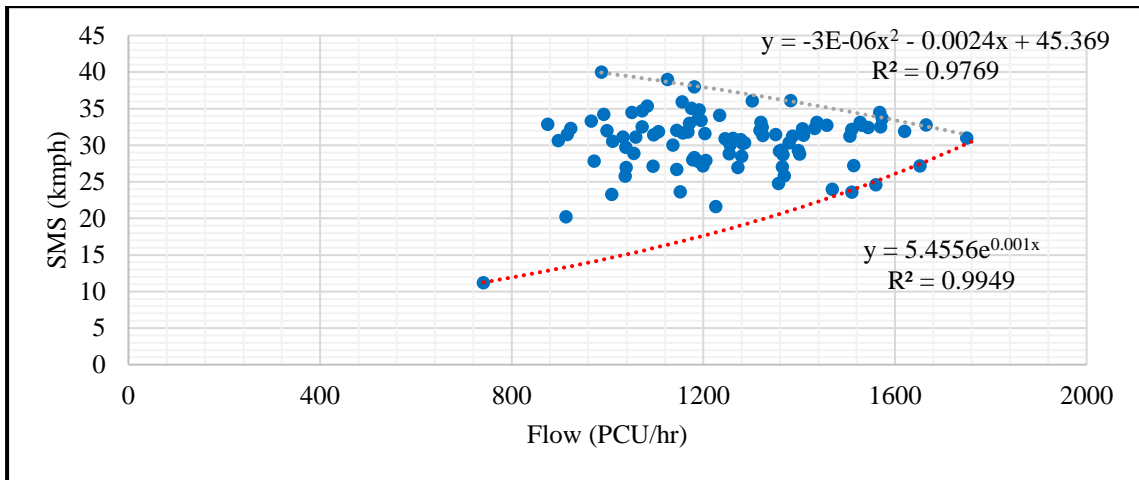


Figure 4.8 Speed-flow relationship during construction stage (Vijay crossroad to Saurabh crossroad)

From the figure 4.8, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.9769, while lower curve is following exponential relationship having R^2 value as 0.9949. Speed-flow relation is developed for Saurabh to Helmet crossroad during construction stage, which is shown in Figure 4.9.

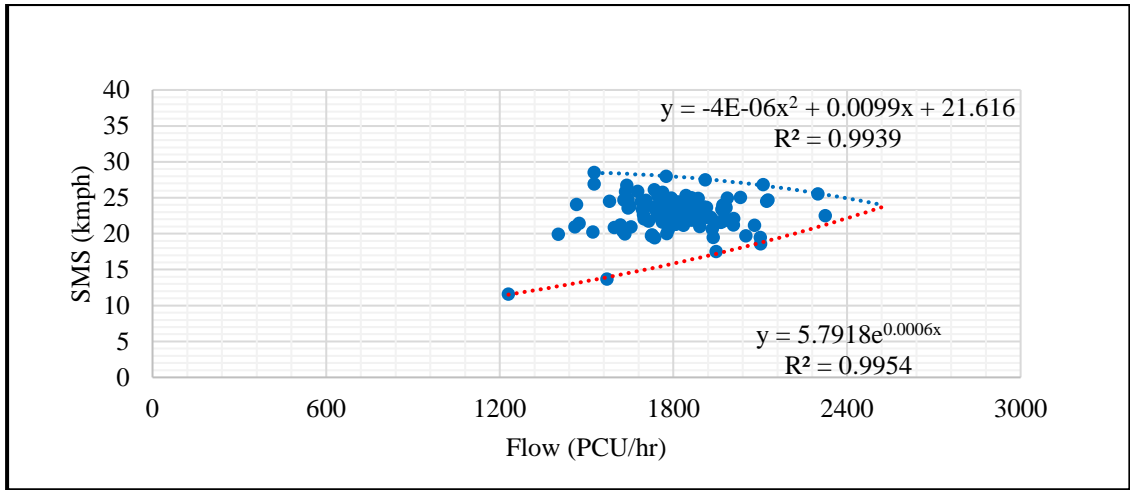


Figure 4.9 Speed-flow relationship during construction stage (Saurabh crossroad to Helmet crossroad)

From the figure 4.9, it is observed that the upper envelope curve is following 2nd order polynomial relation having R² value as 0.9939, while lower curve is following exponential relationship having R² value as 0.9954. Speed-flow relation is developed for Gurukul to Sunrise Park crossroad during construction stage, which is shown in Figure 4.10.

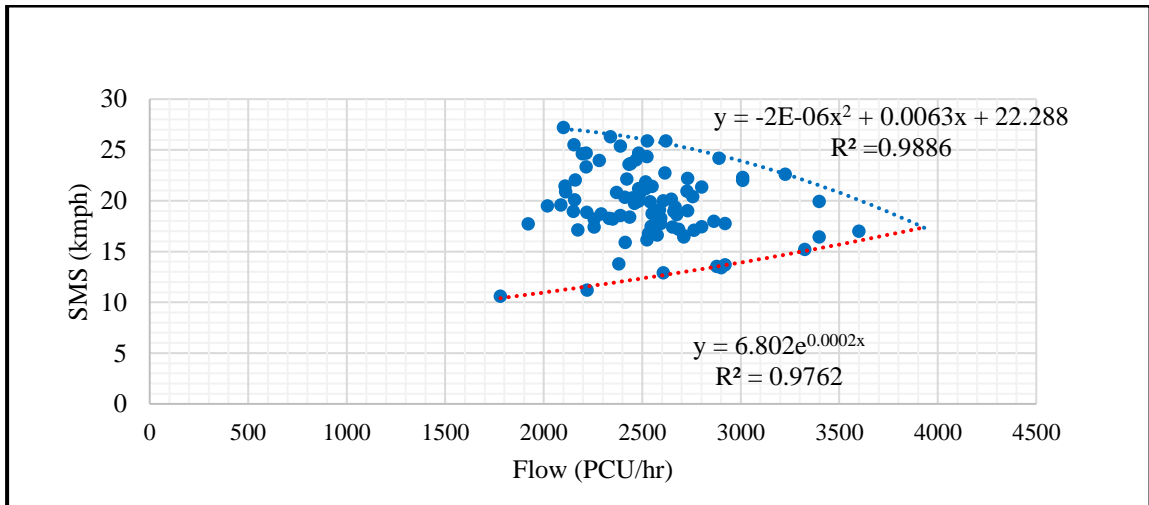


Figure 4.10 Speed-flow relationship during construction stage (Helmet crossroad to Sunrise Park crossroad)

From the figure 4.10, it is observed that the upper envelope curve is following 2nd order polynomial relation having R² value as 0.9886, while lower curve is following exponential relationship having R² value as 0.9762. Speed-flow relation is developed for Sal to Thaltej crossroad during construction stage which is shown in figure 4.11.

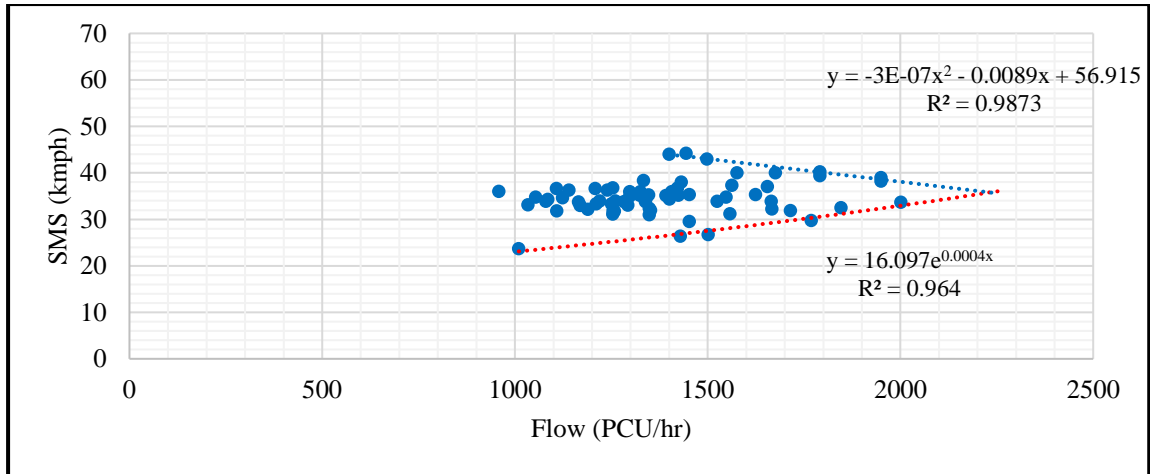


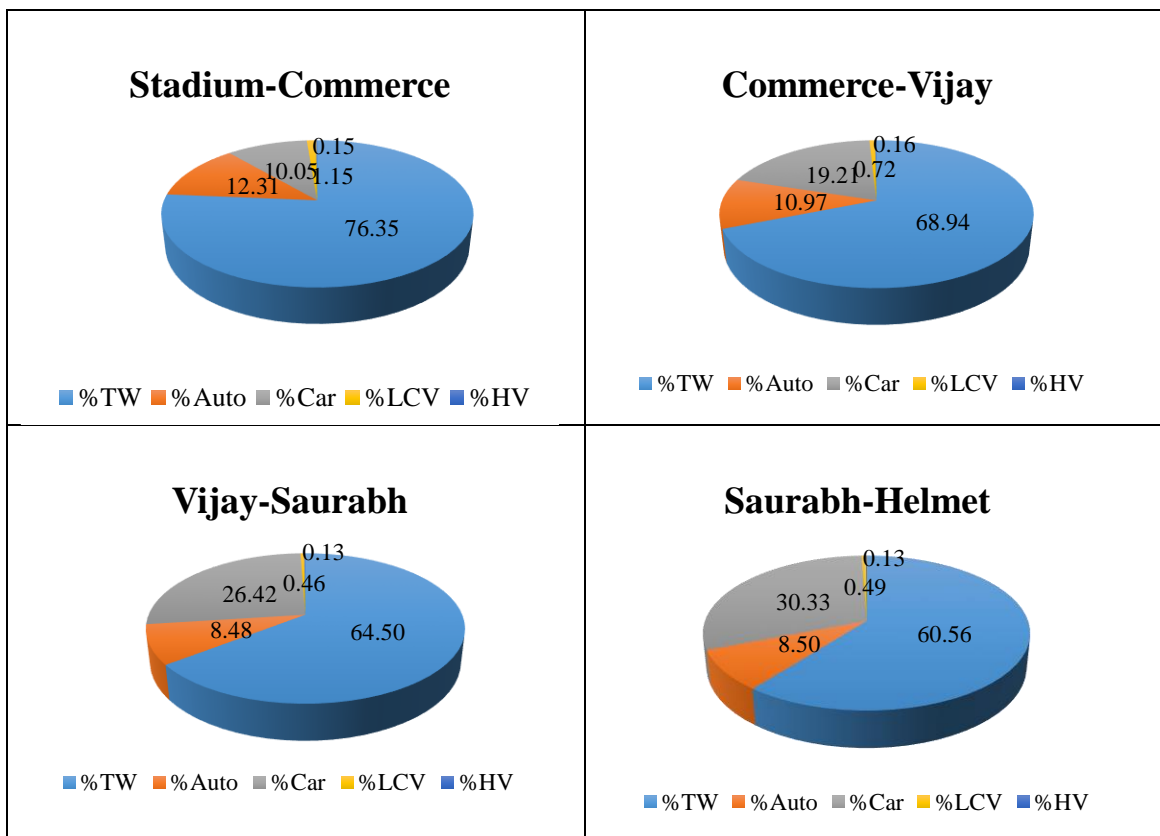
Figure 4.11 Speed-flow relationship during construction stage (Sal crossroad to Thaltej crossroad)

From the figure 4.11, it is observed that the upper envelope curve is following 2nd order polynomial relation having R² value as 0.9873, while lower curve is following exponential relationship having R² value as 0.964. From the speed flow relationship of each link, the maximum flow (Q_{max}) is obtained and the corresponding speed is obtained from the graph. Table 4.4 shows the summary of speed flow relationship of each link.

Table 4.4 Speed-Flow relationship summary during construction stage

Sr. No.	Name of link	Speed- Flow Relationship (During construction stage)	R ²	Q _{max} (PCU/hr)	Speed@ Q _{max} (kmph)
1	Stadium crossroad to Commerce crossroad	$y = -3E-05x^2 + 0.011x + 35.811$	0.992	1015	16
		$y = 2.7927e^{0.0017x}$	0.8182		
2	Commerce crossroad to Vijay crossroad	$y = -4E-06x^2 - 0.0017x + 39.862$	0.9741	1520	29
		$y = 8.3585e^{0.0008x}$	0.9453		
3	Vijay crossroad to Saurabh crossroad	$y = -3E-06x^2 - 0.0024x + 45.369$	0.9769	1760	30
		$y = 5.4556e^{0.001x}$	0.9949		
4	Saurabh crossroad to Helmet crossroad	$y = -4E-06x^2 + 0.0099x + 21.616$	0.9939	2550	24
		$y = 5.7918e^{0.0006x}$	0.9954		
5	Gurukul crossroad to Sunrise Park crossroad	$y = -2E-06x^2 + 0.0063x + 22.288$	0.9886	3900	18
		$y = 6.802e^{0.0002x}$	0.9762		
6	Sal crossroad to Thaltej crossroad	$y = -3E-07x^2 - 0.0089x + 56.915$	0.9873	2200	33
		$y = 16.097e^{0.0004x}$	0.964		

From the table 4.4, it is observed that the maximum Q_{max} value is for link no.5, i.e., Gurukul crossroad to Sunrise Park crossroad. The minimum Q_{max} is observed at Stadium crossroad to Commerce crossroad link. Maximum speed at Q_{max} is observed at Sal crossroad to Thaltej crossroad and the minimum speed at Q_{max} is observed at Stadium crossroad to Commerce crossroad link. Gurukul crossroad to Sunrise Park crossroad link is surrounded by commercial type of land use having the available carriage way width of 9.0 m. Many commercial activities are concentrated here. Stadium crossroad to Commerce crossroad link is surrounded by residential type of land use having available carriageway width of 3.5 m. Sal crossroad to Thaltej cross road link having available carriage way width of 7.0 m, is a connecting link to Sarkhej-Gandhinagar Highway. The traffic data have been collected after constructions stage. Figure 4.12 shows the traffic composition at the links after construction stage.



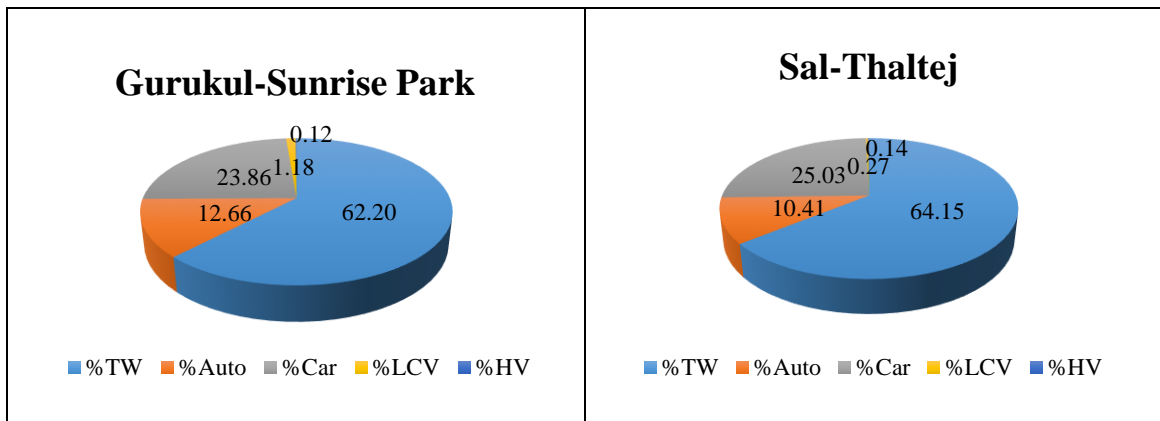


Figure 4.12 Vehicle composition in study area after construction stage (From Stadium crossroad to Sal crossroad)

From the figure 4.12, it is observed that the major composition is of two-wheeler followed by car and auto. Rest of the category of vehicles have low proportion in traffic flow. There is a change in traffic flow and composition due to construction work zone barriers. Due to Construction work zone barriers, available carriage way width was reduced. So, Vehicles might have changed their route to avoid the delay. After removal of the barrier, flow was increased. The observed flow during morning, noon and evening hours are shown in figure 4.13.

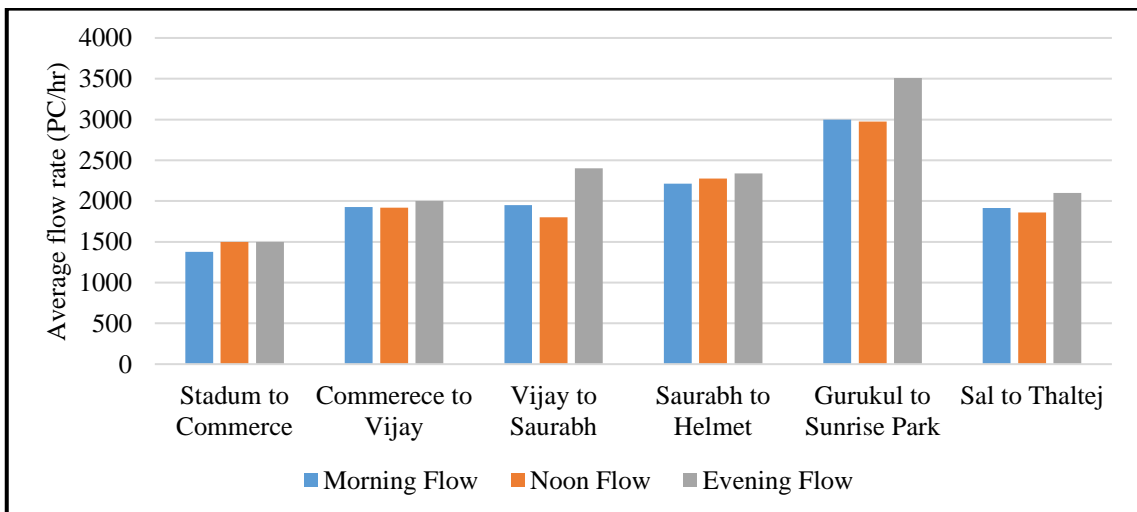


Figure 4.13 Observed flow after construction stage

From the figure 4.13, it is observed that the Gurukul to Sunrise park link has the maximum flow for morning, noon and evening time. The minimum flow is observed on the link of Stadium to Commerce crossroad. The average maximum flow is 3161 PCU/hr on the link of Gurukul to Sunrise Park and the minimum flow is 1458 PCU/hr on the link of Stadium to Commerce crossroad. The space mean speed on each link is calculated from the spot

speed data. The space mean speed on each link for morning, noon and evening hours are presented in figure 4.14.

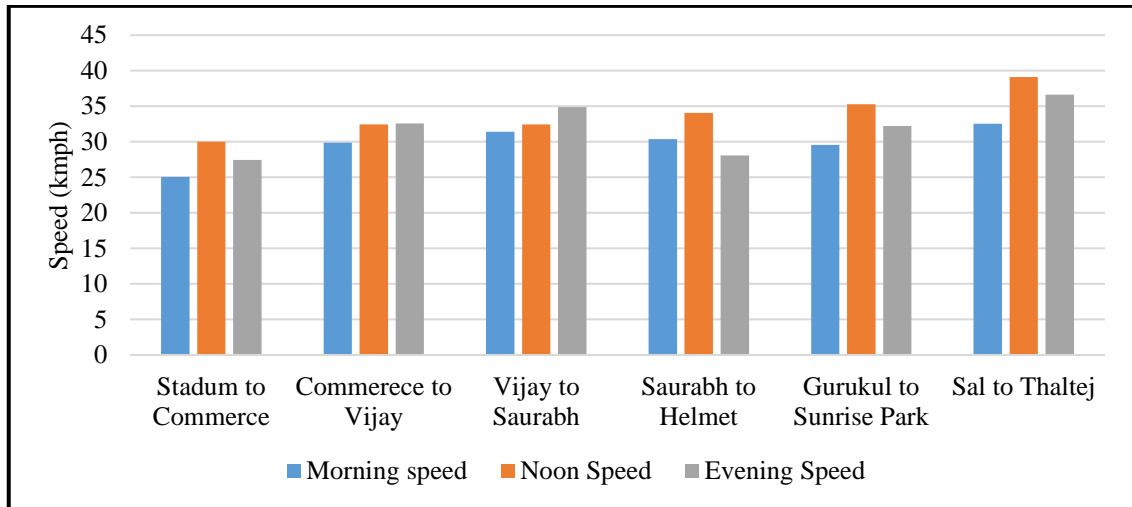


Figure 4.14 Observed speed (SMS) after construction stage

From the figure 4.14, it is observed that the Sal crossroad to Thaltej crossroad link has the maximum speed for morning, noon and evening time. The minimum speed is observed on the link of Stadium crossroad to Commerce crossroad. The observed average maximum speed is 36.09 kmph on the link of Sal crossroad to Thaltej crossroad and the observed average minimum speed is 27.51 kmph on the link of stadium crossroad to Commerce crossroad.

Speed-flow relationship (after construction stage)

The speed flow relation is developed by considering the outer envelope curve and thus maximum flow is obtained from the graph after construction stage. From the figure 4.15 to 4.20, it is observed that the upper envelope is following 2nd order polynomial relationship and lower envelope is following exponential relationship. There is reduction in speed as flow increases. After that, the reduction in flow and speed is observed which is showing forced flow condition of traffic.

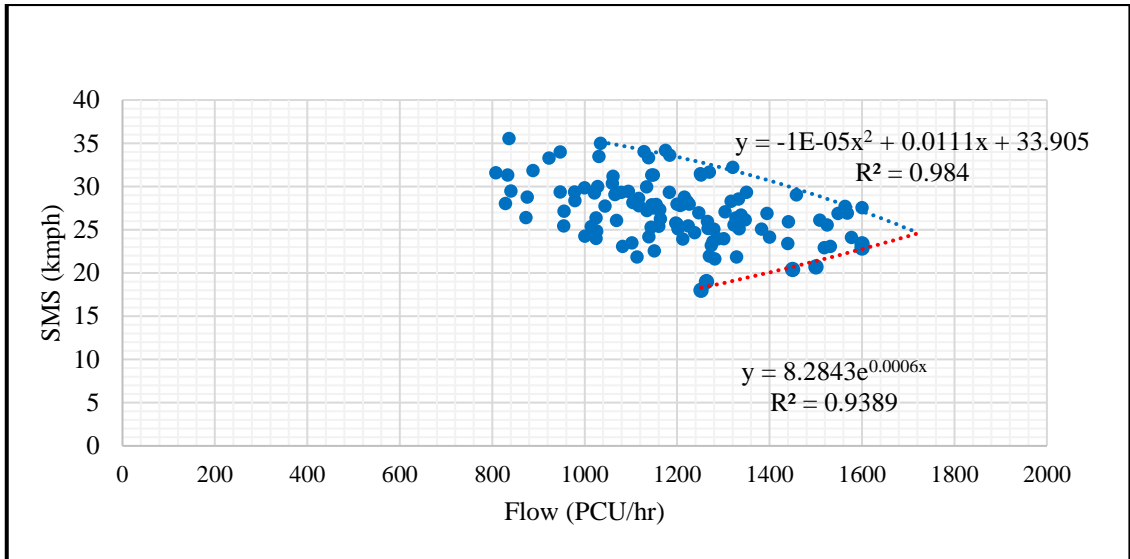


Figure 4.15 Speed flow relationship after construction stage (Stadium crossroad to Commerce crossroad)

From the figure 4.15, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.984, while lower curve is following exponential relationship having R^2 value as 0.9389. Figure 4.16 shows speed flow relationship for the link of Commerce crossroad to Vijay crossroad after construction stage.

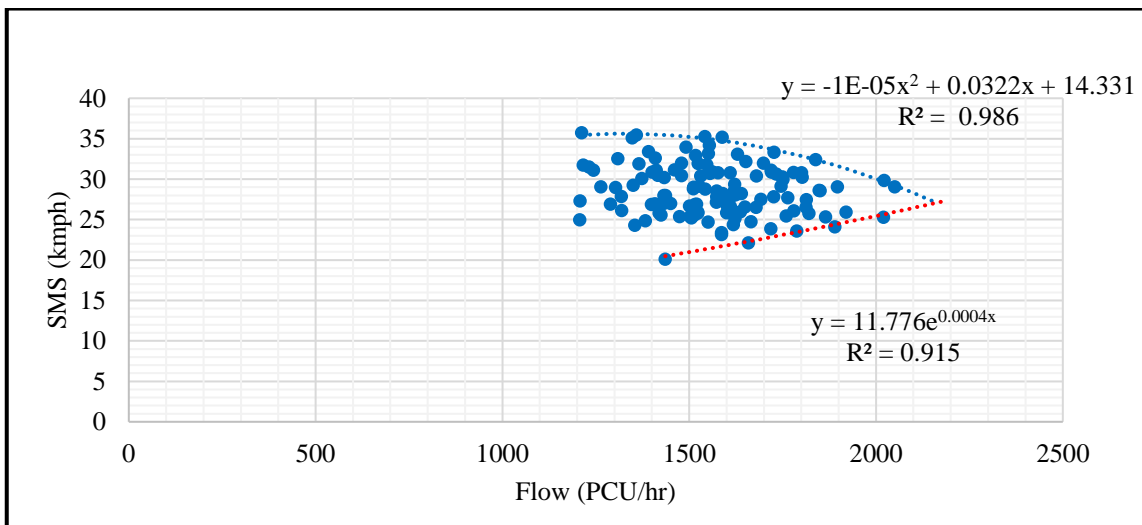


Figure 4.16 Speed flow relationship after construction stage (Commerce crossroad to Vijay crossroad)

From the figure 4.16, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.986, while lower curve is following exponential relationship having R^2 value as 0.915. Figure 4.17 shows speed flow relationship for the link of Vijay crossroad to Saurabh crossroad after construction stage.

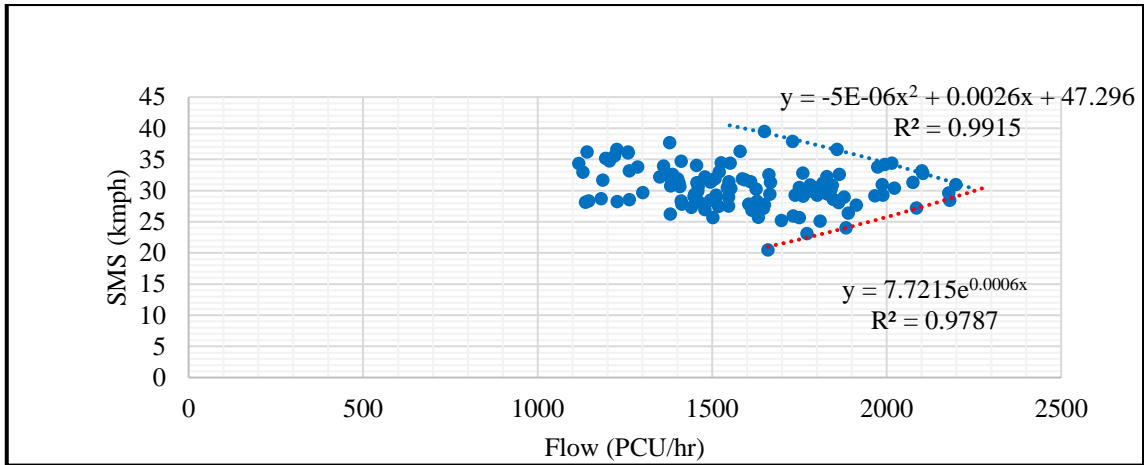


Figure 4.17 Speed flow relationship after construction stage (Vijay crossroad to Saurabh crossroad)

From the figure 4.17, it is observed that the upper envelope curve is following 2nd order polynomial relation having R² value as 0.9915, while lower curve is following exponential relationship having R² value as 0.9787. Figure 4.18 shows speed flow relationship for the link of Saurabh crossroad to Helmet crossroad after construction stage.

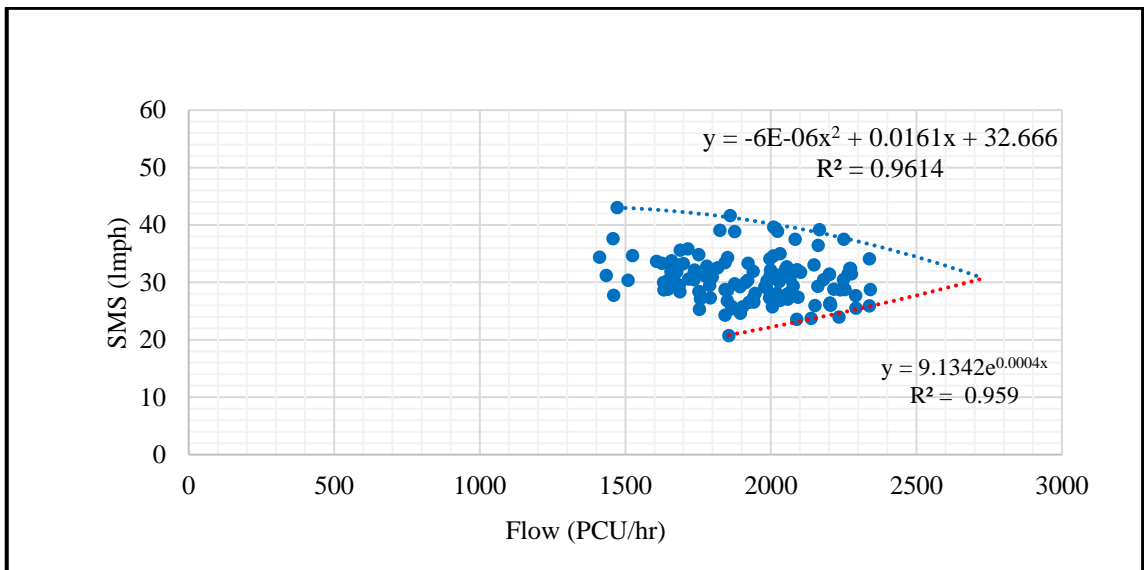


Figure 4.18 Speed flow relationship after construction stage (Saurabh crossroad to Helmet crossroad)

From the figure 4.18, it is observed that the upper envelope curve is following 2nd order polynomial relation having R² value as 0.9614, while lower curve is following exponential relationship having R² value as 0.959. Figure 4.19 shows speed flow relationship for the link of Gurukul crossroad to Sunrise Park crossroad after construction stage.

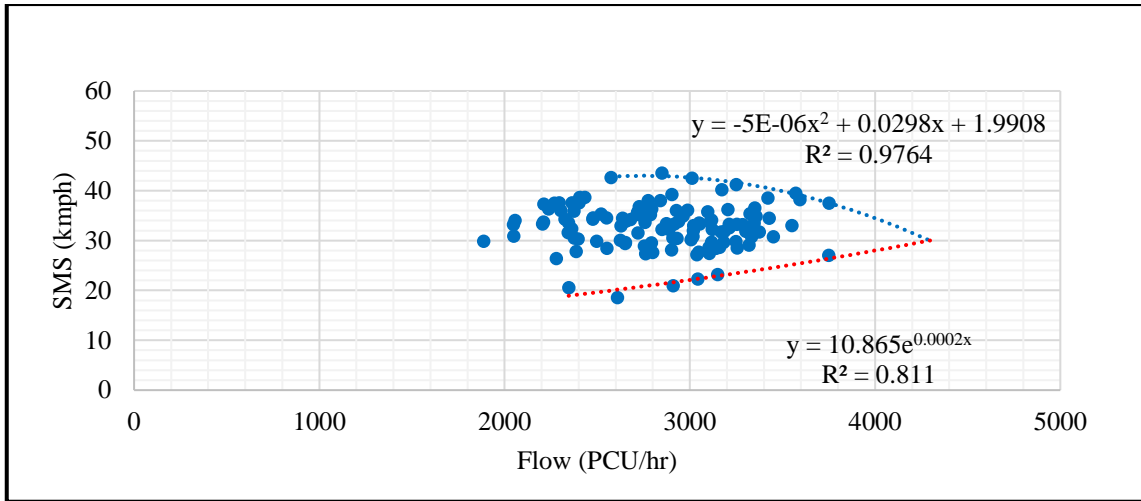


Figure 4.19 Speed flow relationship after construction stage (Gurukul crossroad to Sunrise Park crossroad)

From the figure 4.19, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.9764, while lower curve is following exponential relationship having R^2 value as 0.811. Figure 4.20 shows speed flow relationship for the link of Sal crossroad to Thaltej crossroad after construction stage.

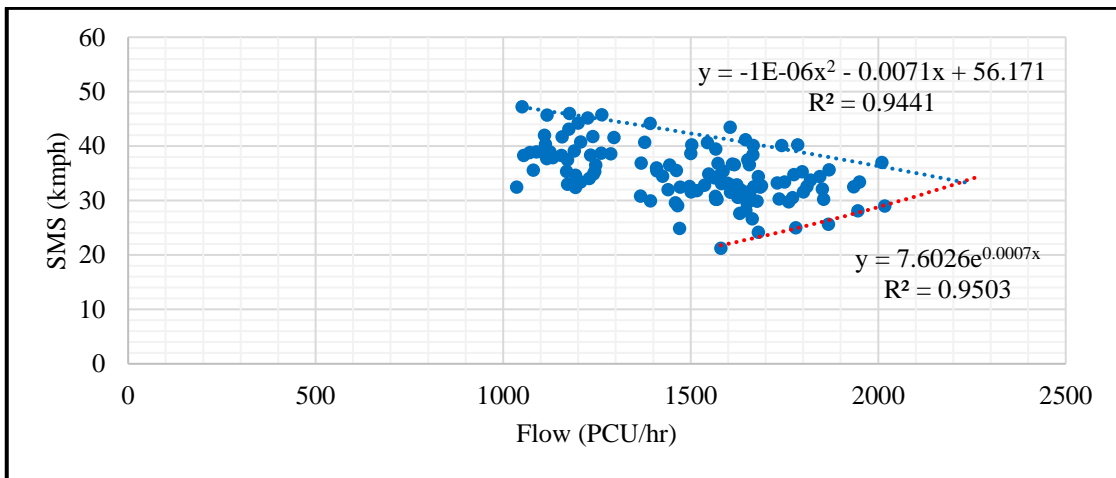


Figure 4.20 Speed flow relationship after construction stage (Sal crossroad to Tahltej crossroad)

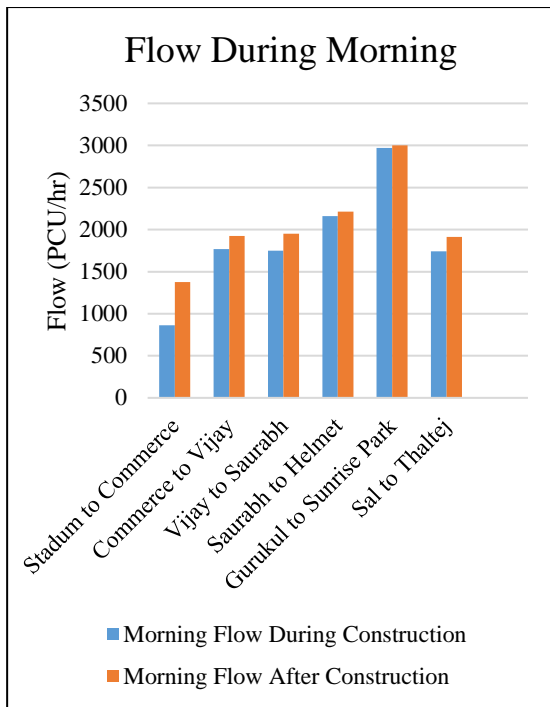
From the figure 4.20, it is observed that the upper envelope curve is following 2nd order polynomial relation having R^2 value as 0.9441, while lower curve is following exponential relationship having R^2 value as 0.9503. From the speed flow relationship of each link, the maximum flow (Q_{max}) is obtained and the corresponding speed is obtained from the graph. Table 4.5 shows the summary of speed-flow relationship of each link after construction stage.

Table 4.5 Summary of speed-flow relationship after construction stage

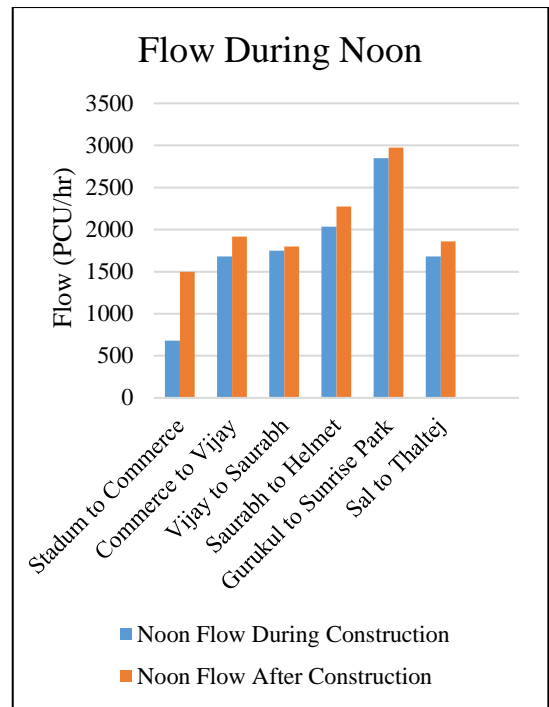
Link	Speed- Flow Relationship (after construction stage)	R ²	Q _{max} (PCU/hr)	Speed @ Q _{max} (kmph)
1.Stadium to Commerce	$y = -1E-05x^2 + 0.0111x + 33.905$	0.984	1700	25
	$y = 8.2843e^{0.0006x}$	0.939		
2.Commerce to Vijay	$y = -1E-05x^2 + 0.0322x + 14.331$	0.986	2150	27
	$y = 11.776e^{0.0004x}$	0.915		
3.Vijay to Saurabh	$y = -5E-06x^2 + 0.0026x + 47.296$	0.992	2250	30
	$y = 7.7215e^{0.0006x}$	0.979		
4.Saurabh to Helmet	$y = -6E-06x^2 + 0.0161x + 32.666$	0.961	2720	31
	$y = 9.1342e^{0.0004x}$	0.959		
5.Gurukul to Sunrise Park	$y = -5E-06x^2 + 0.0298x + 1.9908$	0.976	4250	30
	$y = 10.865e^{0.0002x}$	0.811		
6.Sal to Thaltej	$y = -1E-06x^2 - 0.0071x + 56.171$	0.944	2350	34
	$y = 7.6026e^{0.0007x}$	0.95		

From the table 4.5, it is observed that the upper envelope curve of the speed flow diagram is following 2nd order polynomial while the lower envelope curve is following exponential relationship. It is observed that the maximum Q_{max} value is for link no.5, i.e., Gurukul crossroad to Sunrise Park crossroad is having the carriageway width of 11.5 m. Heavy commercial activities are concentrated here. The minimum Q_{max} is observed at Stadium crossroad to Commerce crossroad link having the carriageway width of 7.1 m. This link is surrounded by residential kind of land use. Maximum speed at Q_{max} is observed at Sal crossroad to Thaltej crossroad having carriageway width of 11.5m. This is a connecting link to Sarkhej-Gandhinagar Highway and the minimum speed at Q_{max} is observed at Stadium crossroad to Commerce crossroad link. It is observed that there is no impact of heavy vehicles on the flow.

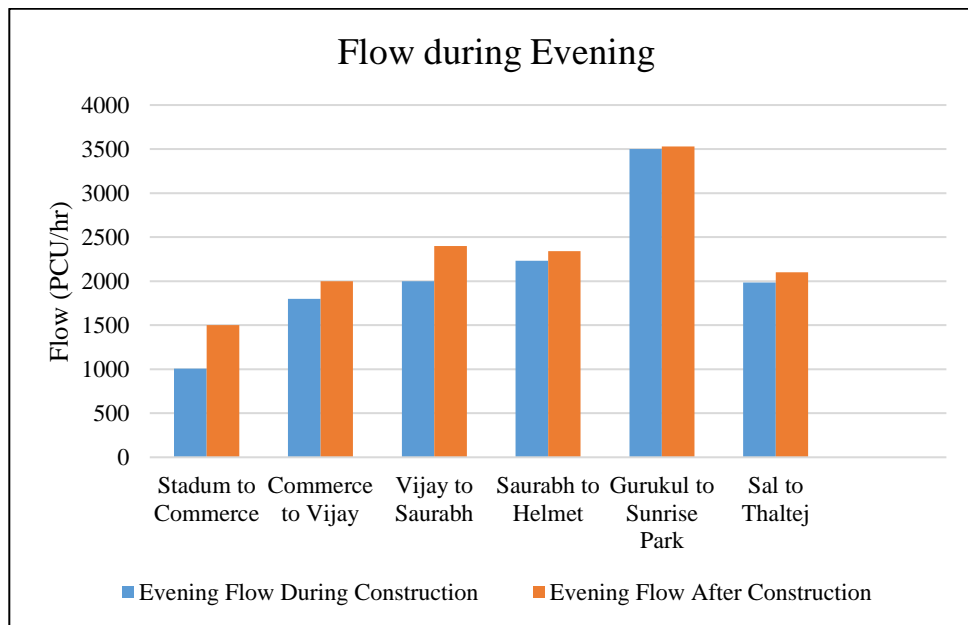
The collected data are compared to study the effects of during construction stage and after construction stage in the study area. Figure 4.21 shows the comparison of flow for during and after construction stage.



(a) Flow comparison during morning



(b) Flow comparison during noon



(c) Flow comparison during evening

Figure 4.21 Flow comparison

From the figure 4.21, it is observed that there is an increase in flow after construction stage, which is summarized in the table 4.5.

Table 4.6 % Increase in flow after construction

Link No	Link Name	% Increase in flow after construction
1	Stadium crossroad to Commerce crossroad	71.63
2	Commerce crossroad to Vijay crossroad	11.33
3	Vijay crossroad to Saurabh crossroad	11.85
4	Saurabh crossroad to Helmet crossroad	6.207
5	Gurukul crossroad to Sunrise Park crossroad	1.56
6	Sal crossroad to Thaltej crossroad	8.65

From the table 4.6, it is observed that there is significant increase in the flow on the link Stadium crossroad to Commerce crossroad and Commerce crossroad to Vijay crossroad. The major reasons for increase in the flow is that there was a significant reduction in the carriage way width during the construction stage. It is observed that other links i.e., Saurabh crossroad to Helmet crossroad, Gurukul crossroad to Sunrise Park crossroad and Sal crossroad to Thaltej crossroad have also increase in the flow after construction stage.

4.6 Delay analysis

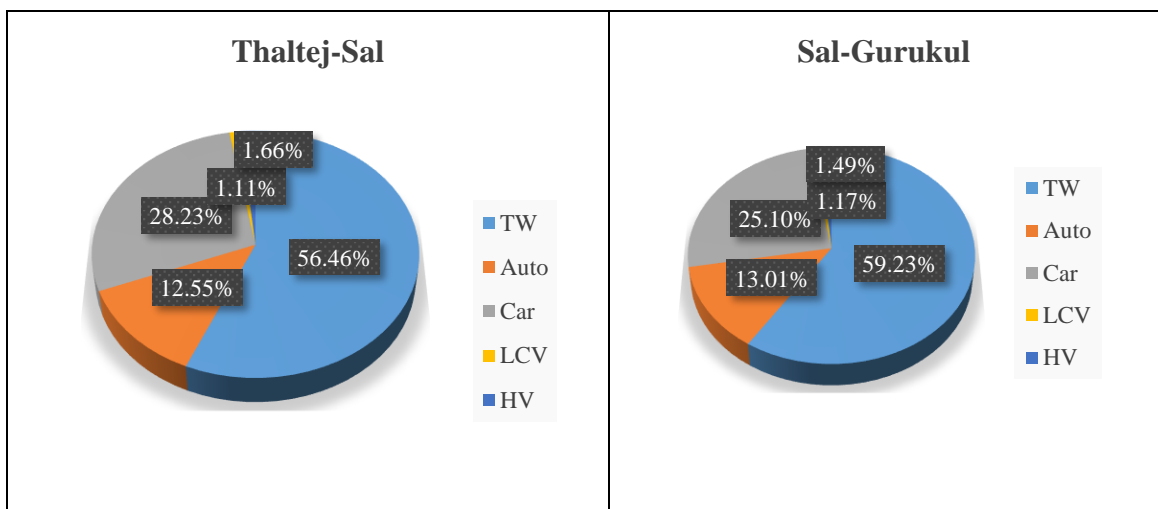
The travel time delay may be defined as difference in travel time between the actual amount of time needed to cross a street or highway and the amount of time equal to the average speed of traffic in an uncongested area [116]. For the delay measurement, license plate survey has been carried out. Firstly, the travel time on links is measured for morning, noon and evening peak hours of the day. Again, the travel time is measured during the early morning time i.e., 6.00 am where free flow condition is obtained. This delay is mainly due to geometric restriction of construction work zone. From the videography survey, average speed and average delay on each link are obtained for during and after construction stage. To study the delay, Thaltej crossroad to Stadium crossroad is divided in to six links. There was very significant variation in the available carriage way width in this corridor, which are shown in the table 4.7.

Table 4.7 Inventory data (Thaltej crossroad to Stadium crossroad)

Sr. No.	Name of link	Length (m)	Available one way carriageway width during construction (m)	Available one way carriageway width after construction (m)
1	Thaltej crossroad to Sal crossroad	455	6	11.5
2	Sal crossroad to Gurukul crossroad	1000	7.5	11.5
3	Gurukul crossroad to Helmet crossroad	205 445	3.3 5.5	12
4	Helmet crossroad to Saurabh crossroad	250 230	5 7.7	11.3
5	Saurabh crossroad to Vijay crossroad	215	5	11.3
6	Vijay crossroad to Commerce crossroad	397 76 107	6 4.4 3.3	10
7	Commerce crossroad to Stadium crossroad	700	3.5	7.1

From the table 4.7, it is observed that the four links i.e., Thaltej crossroad to Sal crossroad, Sal crossroad to Gurukul crossroad, Saurabh crossroad to Vijay crossroad and Commerce crossroad to Stadium crossroad have the same carriage way width throughout the link. But the links i.e., Gurukul crossroad to Helmet crossroad, Helmet crossroad to Saurabh crossroad and Vijay crossroad to Commerce crossroad have varying width throughout the link.

The videography survey is carried out to get the vehicle composition on each link. Figure 4.22 shows the vehicle composition on each link.



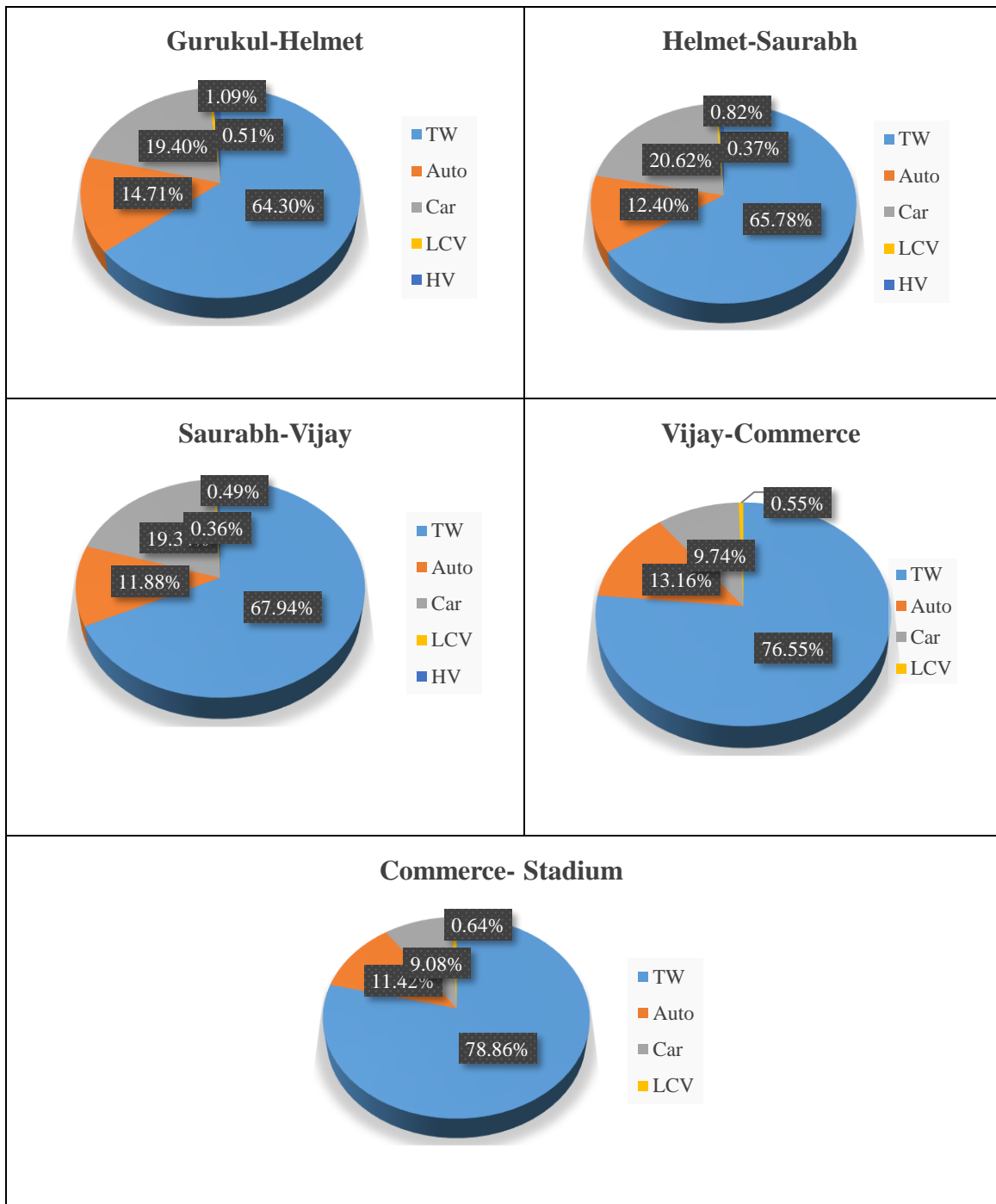
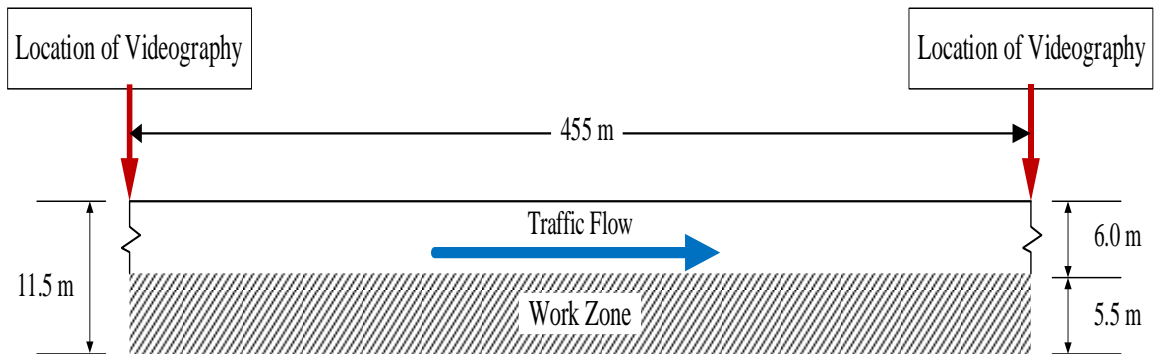


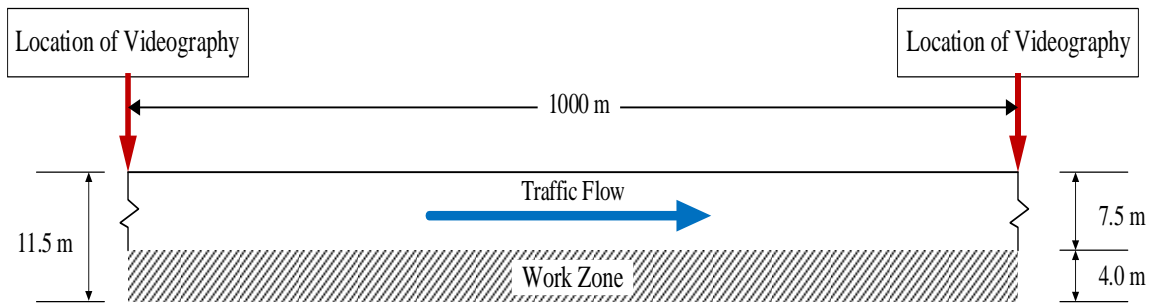
Figure 4.22 Vehicle composition during construction stage on each link (From Thaltej crossroad to Stadium crossroad)

From the figure 4.22, it is observed that the major contribution is of two wheeler, followed by car and auto rickshaw. On the links i.e., Vijay crossroad to Commerce crossroad and Commerce crossroad to Stadium crossroad, the large size vehicles such as bus, HV were prohibited. The available carriage way width in the study area is not uniform. Figure 4.23 shows the layout of the link in the study area.

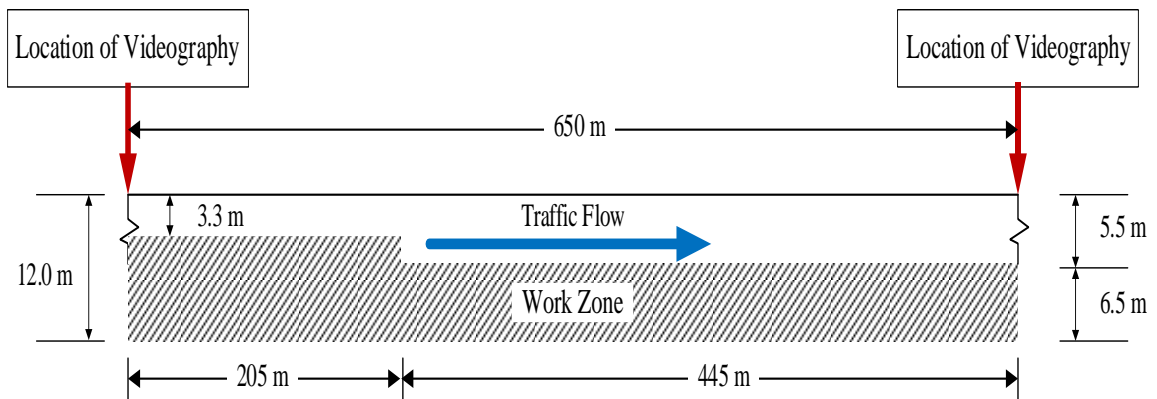
On the approach of Thaltej crossroad to Stadium crossroad, there is significant variation in the available carriage way width of links. Figure 4.23 shows layout of all the links.



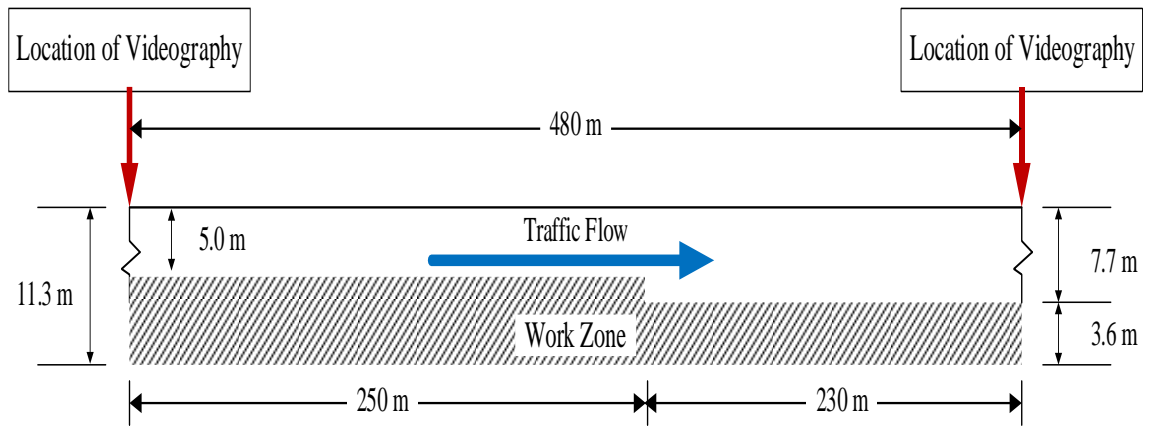
(a) Thaltej crossroad to Sal crossroad



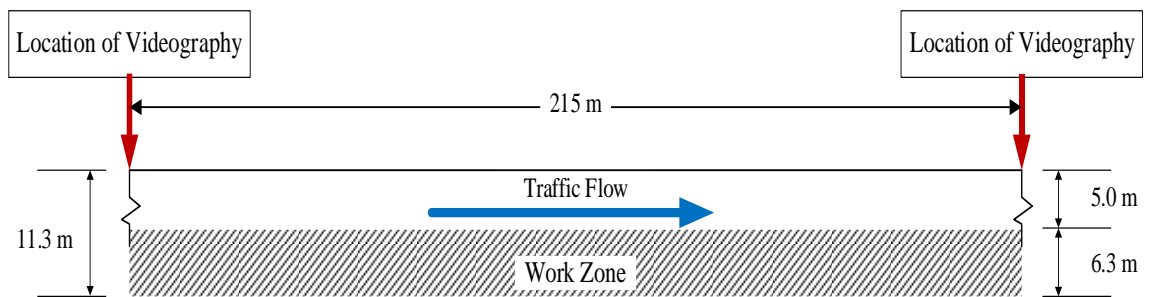
(b) Sal crossroad to Gurukul Crossroad



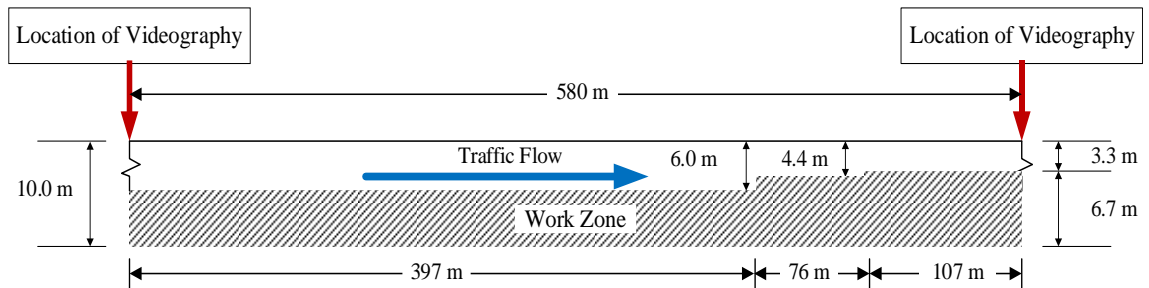
(c) Gurukul crossroad to Helmet crossroad



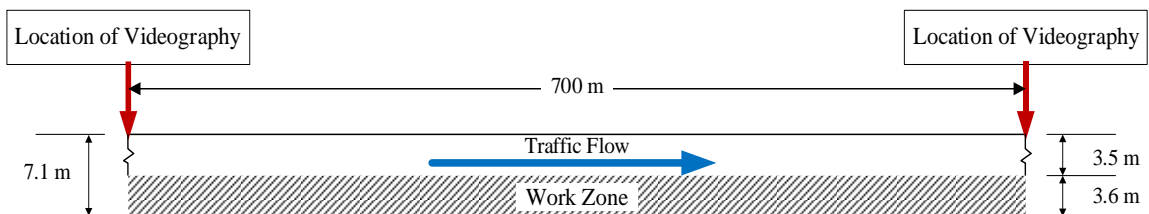
(d) Helmet crossroad to Saurabh crossroad



(e) Saurabh crossroad to Vijay crossroad



(f) Vijay crossroad to Commerce crossroad

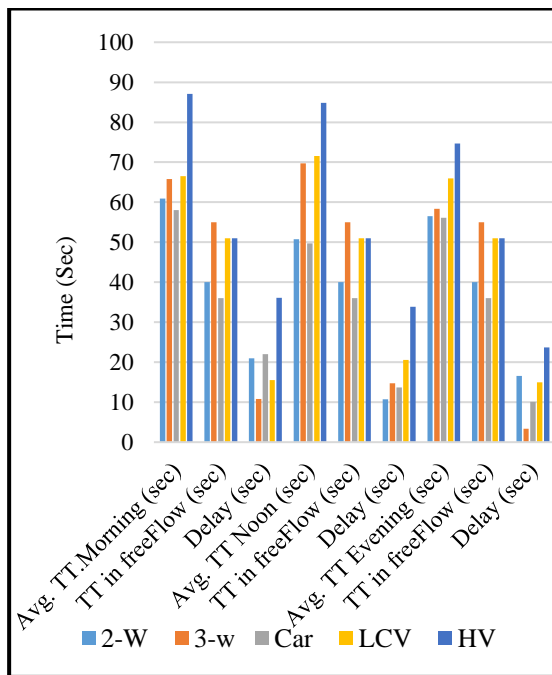


(g) Commerce to Stadium crossroad

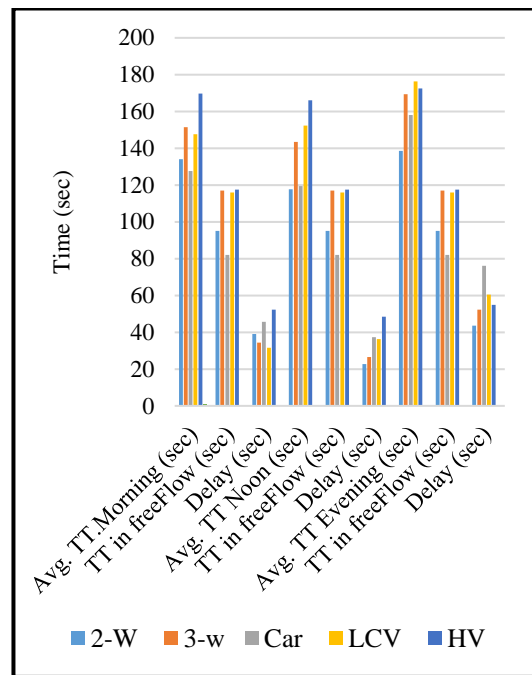
Figure 4.23 Layout of all the links (From Sal to Stadium crossroad)

From the figure 4.23, it is observed that the Thaltej crossroad to Sal crossroad, Sal crossroad to Gurukul crossroad, Saurabh crossroad to Vijay crossroad and Commerce crossroad to Stadium cross road links have the uniform carriage way width. Gurukul crossroad to Helmet crossroad and Helmet crossroad to Saurabh crossroad links have two different widths. Vijay crossroad to Commerce crossroad link has three different widths.

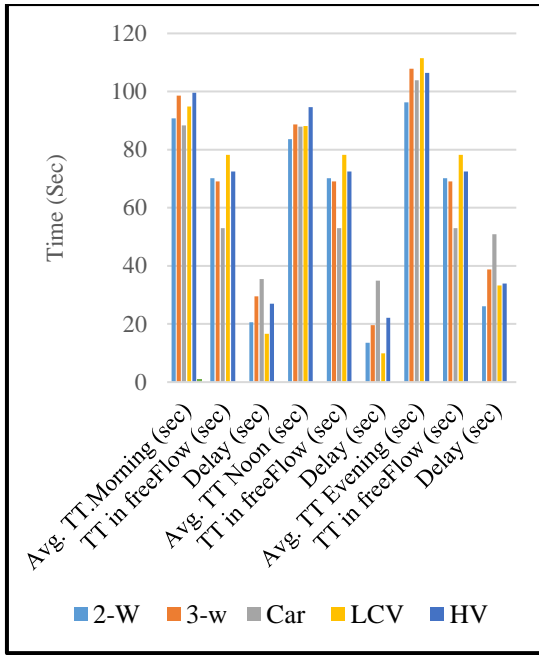
Travel time data have been collected on all the links. Based on the free flow travel time data delay is calculated. Figure 4.24 shows travel time during morning, noon and evening hours, travel time in free flow condition and delay in the study area.



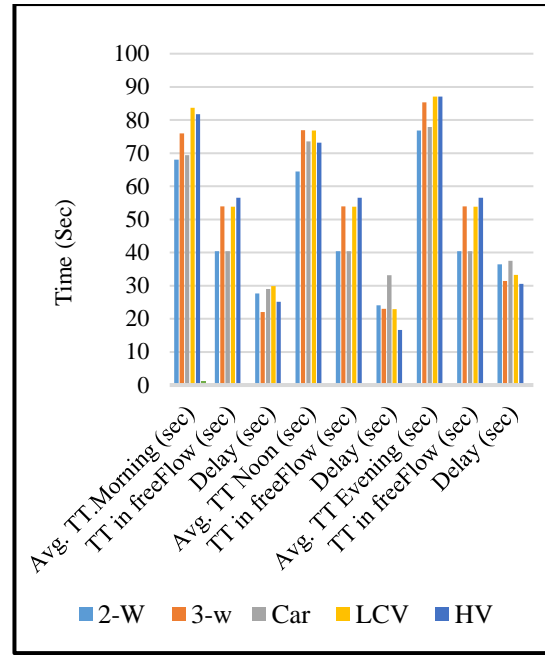
(a) Travel time and delay for Thaltej crossroad to Sal crossroad



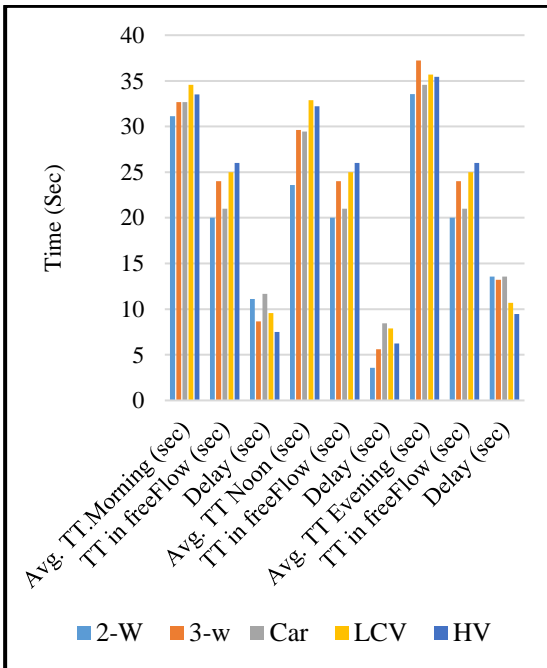
(b) Travel time and delay for Sal crossroad to Gurukul crossroad



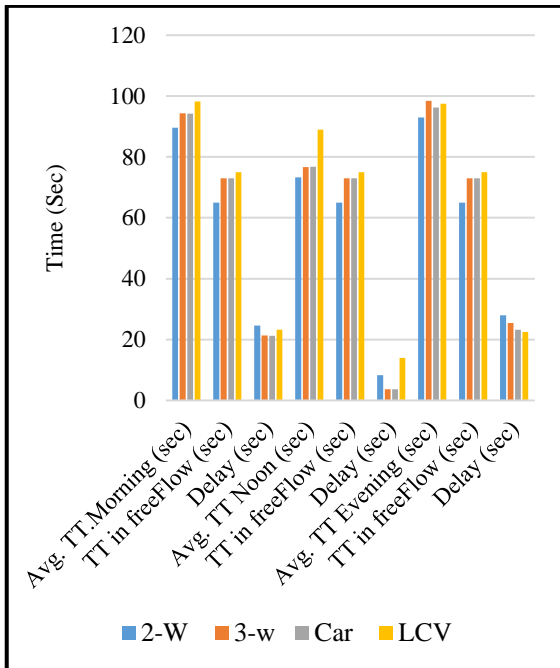
(c) Travel time and delay for Gurukul crossroad to Helmet crossroad



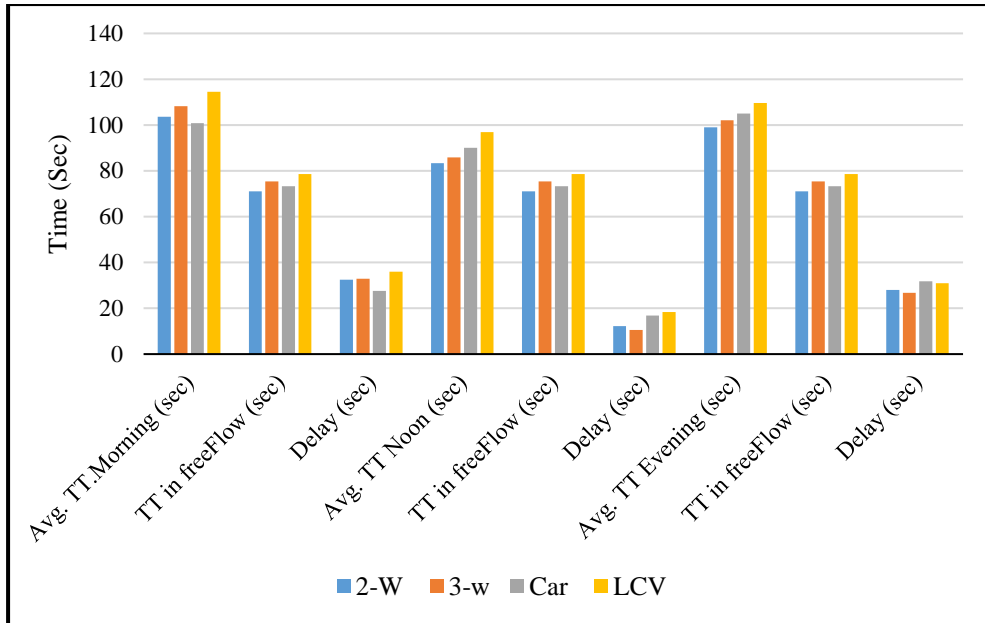
(d) Travel time and delay for Helmet crossroad to Saurabh crossroad



(e) Travel time and delay for Saurabh crossroad to Vijay crossroad



(f) Travel time and delay for Vijay crossroad to Commerce crossroad



(g) Travel time and delay for Commerce crossroad to Stadium crossroad

Figure 4.24 Travel time and delay on each link during construction stage

Figure 4.24 shows the travel time and delay during the construction stage. All the links are having higher delay during evening hours and less delay during noon hours. Figure 4.25 shows the average delay observed in the study area during construction stage.

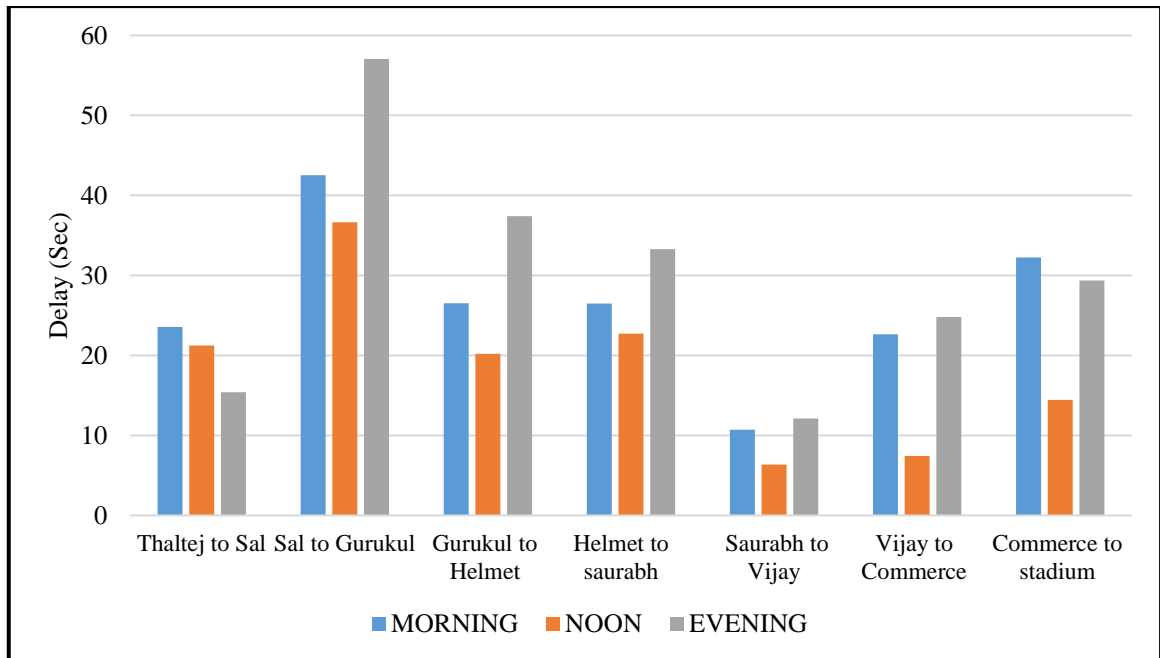


Figure 4.25 Observed delay on each link during construction stage

From the figure 4.25, it is observed that the maximum delay is found during evening on the link of Sal to Gurukul crossroad. Sal crossroad to Gurukul crossroad link is surrounded

by many shopping centres. During evening hours there was a huge shoppers flow on this link. Minimum delay is found during noon on the link of Saurabh crossroad to Vijay crossroad. Saurabh crossroad to Vijay crossroad link has less commercial centres and same carriageway width throughout the segment.

The construction work zone length was considered for delay calculations. Here, the stopped delay at intersection is not considered, but only moving delay is measured. Speed can be better parameter to show the delay on each link. Figure 4.26 shows average speed on each link during construction stage.

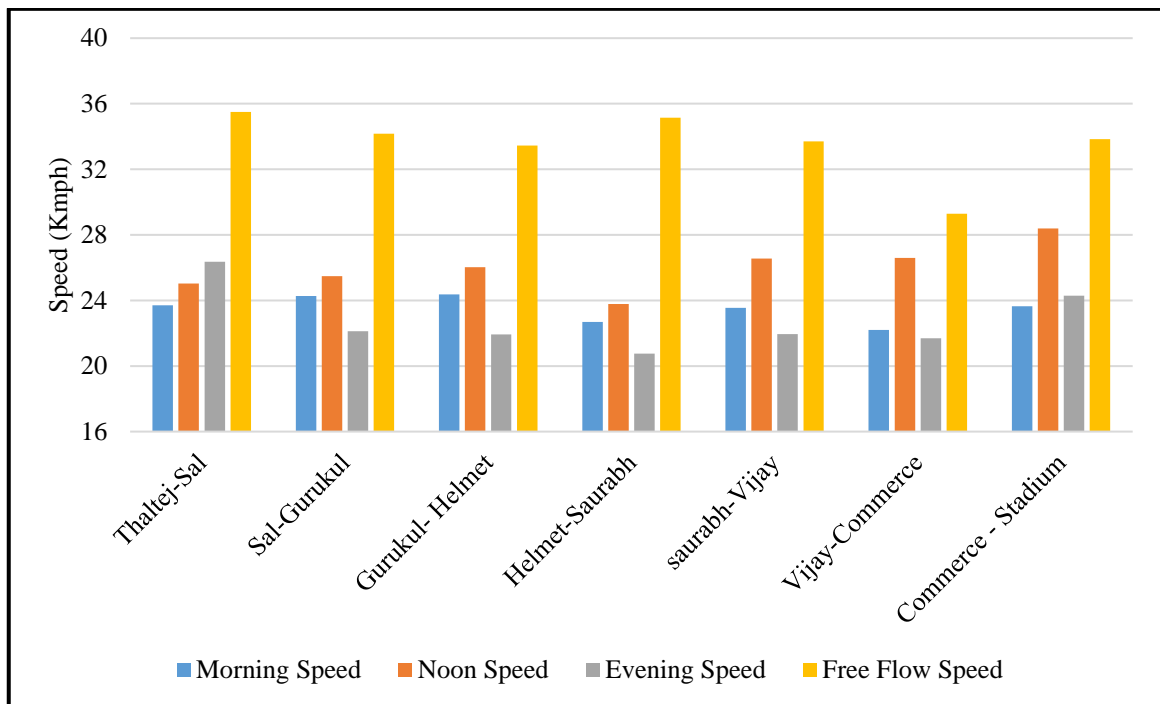
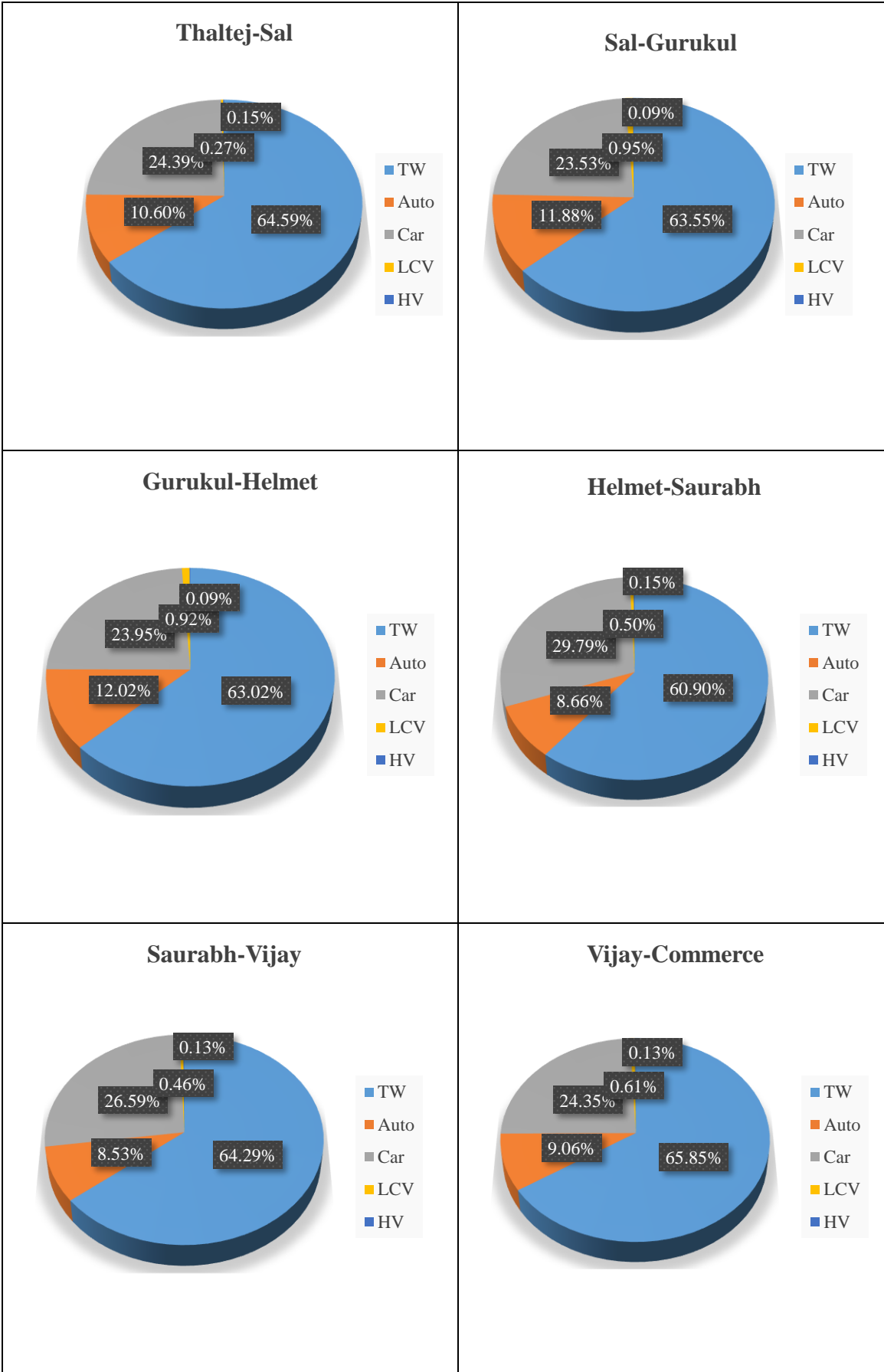


Figure 4.26 Average speed on each link during construction stage

From the figure 4.26, maximum average speed is observed on Thaltej crossroad to Sal crossroad link having value of 26.00 kmph. Minimum average speed is observed on the link of Helmet crossroad to Saurabh crossroad having the value of 22.40 kmph.

The data collection has been carried out after construction stage. Traffic volume count and travel time data have been collected. Figure 4.27 shows the vehicle composition on each link.



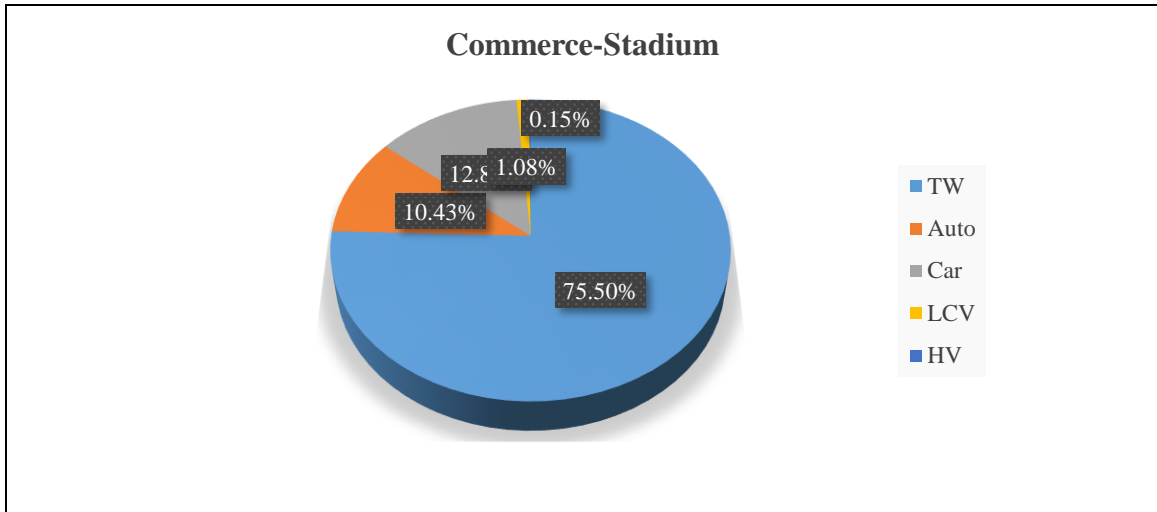
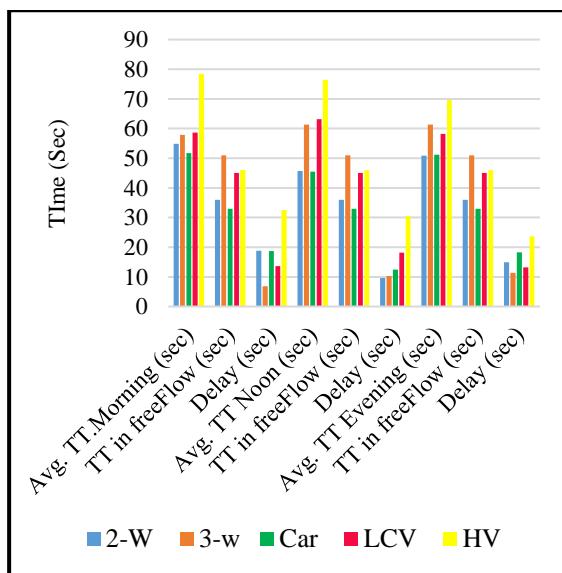
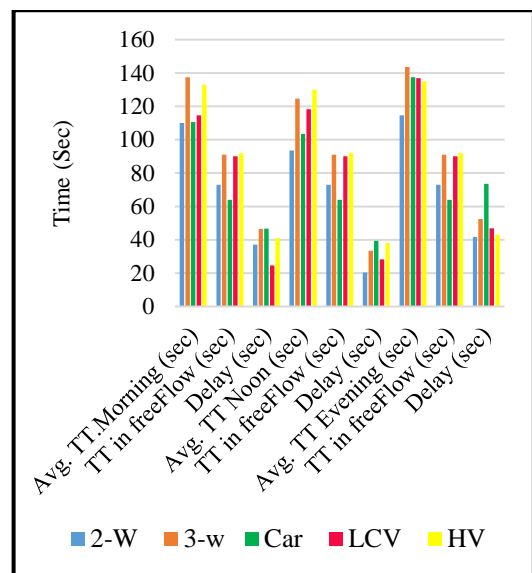


Figure 4.27 Vehicle composition on each link after construction stage (From Thaltej crossroad to Stadium crossroad)

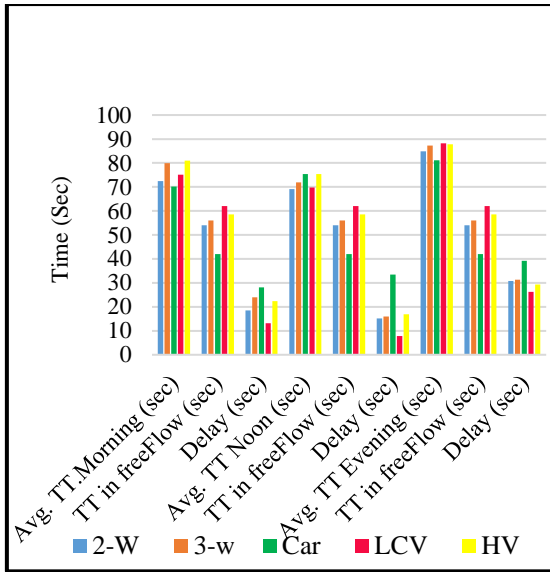
From the figure 4.27, it is observed that the major contribution is of two wheeler, followed by car and auto rickshaw. Travel time data have been collected on all the links after construction stage. Based on the free flow travel time data delay is calculated. Figure 4.28 shows travel time during morning, noon and evening hours, travel time in free flow condition and delay in the study area after construction stage.



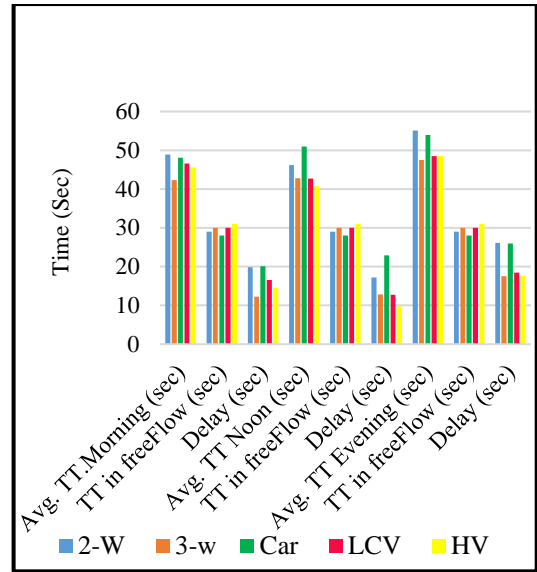
(a) Travel time & delay at Thaltej crossroad to Sal crossroad after construction stage



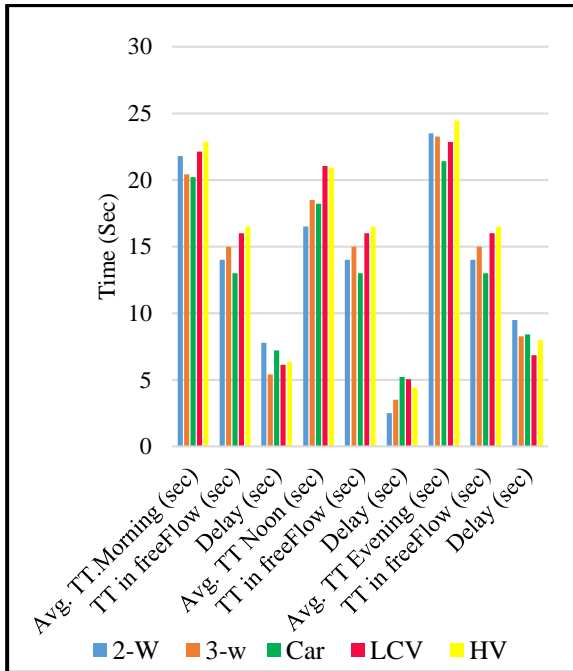
(b) Travel time & delay at Sal crossroad to Gurukul crossroad after construction



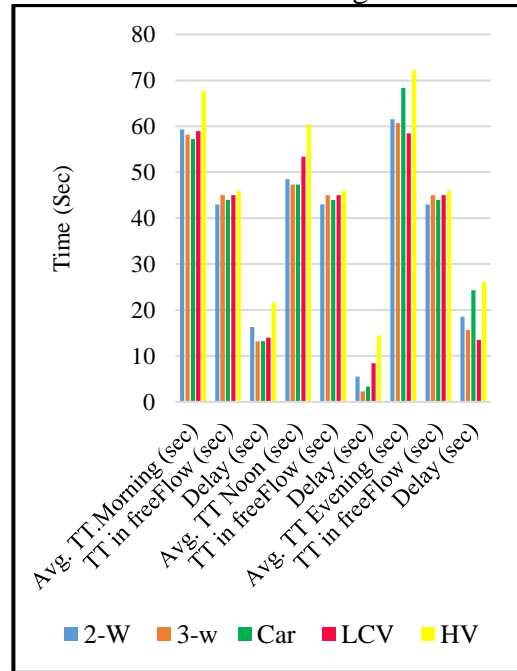
(c) Travel time & delay at Gurukul crossroad to Helmet crossroad after construction stage



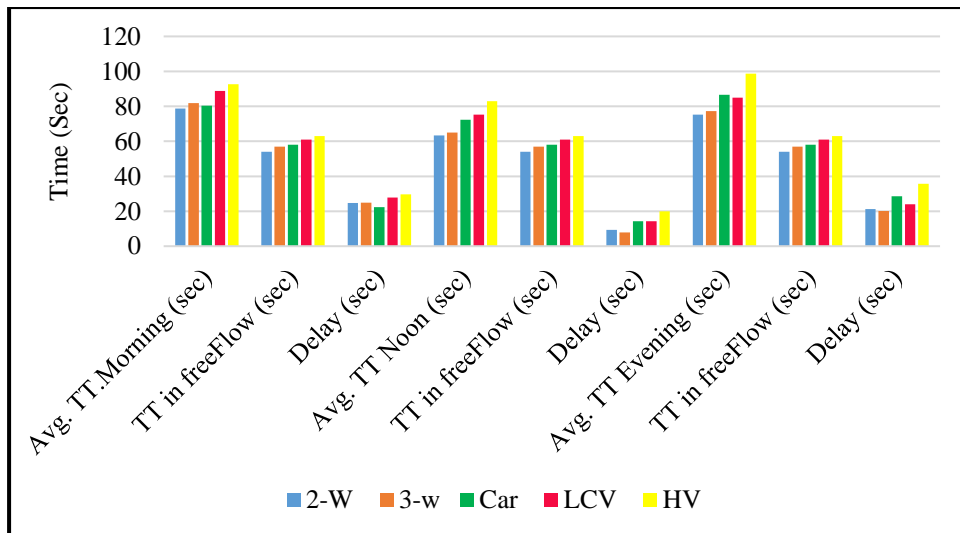
(d) Travel time & delay at Helmet crossroad to Saurabh crossroad after construction stage



(e) Travel time & delay at Saurabh crossroad to Vijay crossroad after construction stage



(f) Travel time & delay at Vijay crossroad to Commerce crossroad after construction stage



(g) Travel time & delay at Commerce crossroad to Stadium crossroad after construction stage

Figure 4.28 Travel time and delay on each link after construction stage

From the figure 4.28, it is observed that the maximum delay is observed during evening and minimum delay is observed during noon for all the links. Figure 4.29 shows average delay on each link during construction stage.

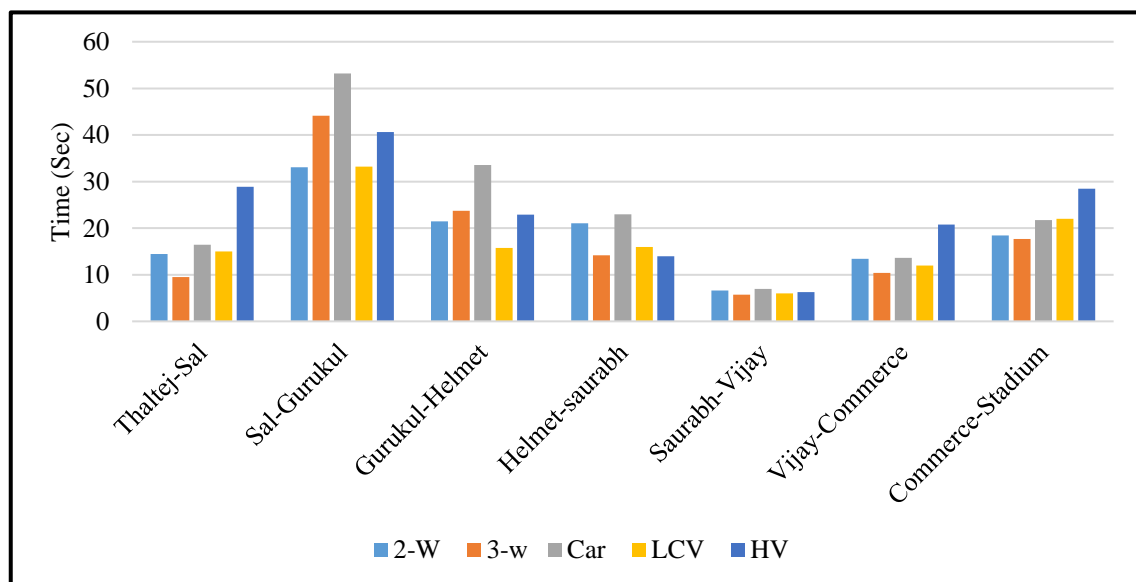


Figure 4.29 Observed delay after construction stage

From the figure 4.29, it is observed that maximum delay is at the link of Sal crossroad to Gurukul crossroad link because this link is surrounded by commercial type of land use.

Minimum delay is observed on the link of Saurabh crossroad to Vijay crossroad. This link is surrounded by vacant government plot and residential area.

Here the links have varying length. So, speed can be a better parameter to show the impact of construction stage. Figure 4.30 shows the average speed on each link.

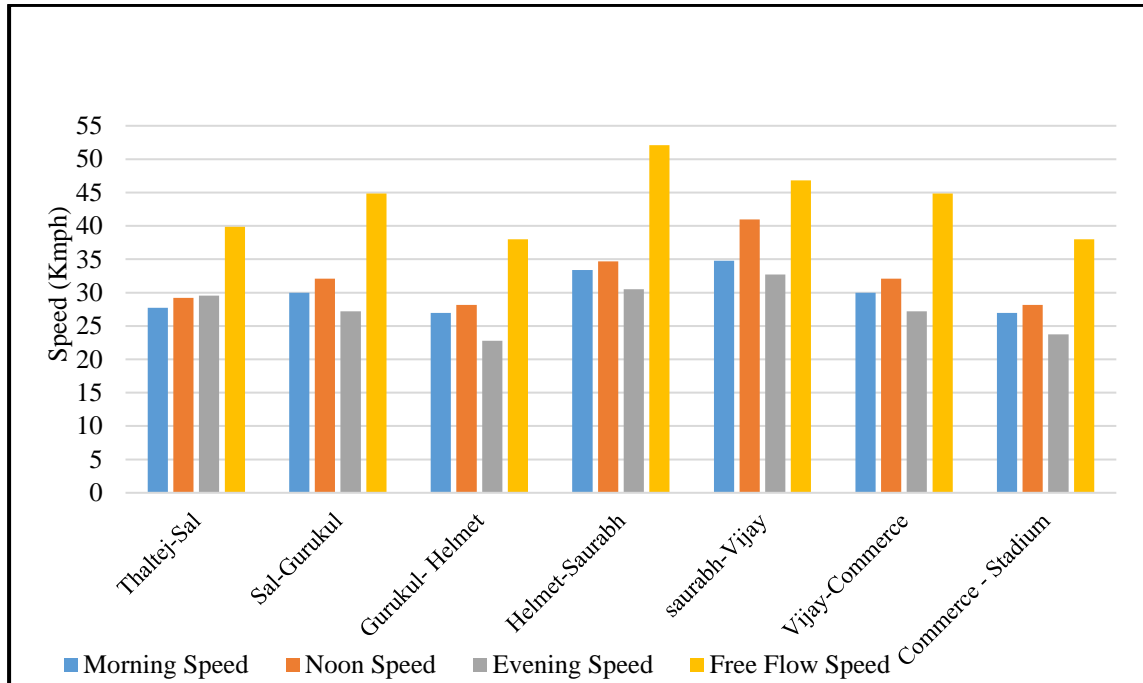
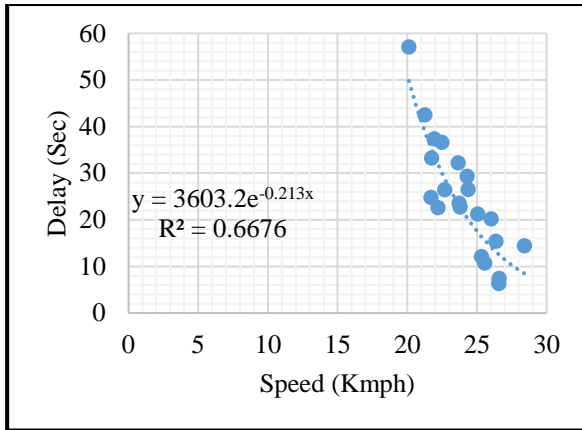


Figure 4.30 Average speed on each link after construction stage

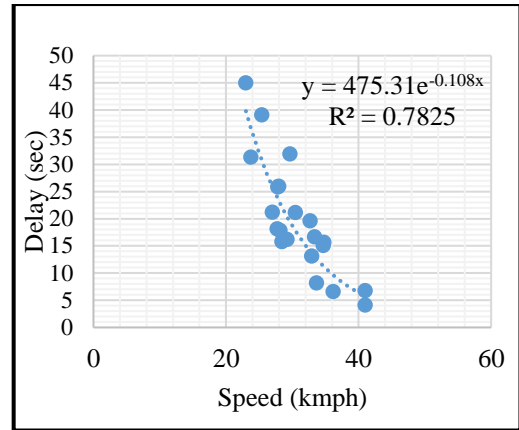
From the Figure 4.30, it is observed that maximum speed for morning, noon and evening hours is at Saurabh crossroad to Vijay crossroad link having the value of 34.77 kmph, 40.98 kmph and 46.84 kmph respectively. It has the carriageway width of 11.3m and it is surrounded by open lands and residential area. Minimum speed for morning, noon and evening is observed at the link of Gurukul crossroad to Helmet crossroad having the values of 26.95 kmph, 28.14 kmph and 22.76 kmph respectively. Though the carriageway width of that link is 12 m, the speed is less. The link is surrounded by mall, two major hospitals and approaching to the major junction of the Navarangpura area.

Relation of delay with speed

The relation of delay with speed is also analysed. The average value of delay and speed of each link are considered. The scatter graph is plotted for delay-speed relationship for during and after the construction stage which is shown in figure 4.31.



(a) During construction stage



(b) After construction stage

Figure 4.31 Speed and delay relationship (during and after construction stage)

From the figure 4.31, it is observed that the relation between average speed and delay is following exponential relation having R^2 value 0.6676 for the during construction stage. For the after construction stage, the relation between speed and delay is following exponential having R^2 value as 0.7825. From the graph, it is observed that as the increase in speed, there is exponential reduction in delay.

Overall delay comparison is carried out for during and after construction stage of metro rail in the study area. Figure 4.32 shows the delay comparison for two wheeler, three wheeler, car, LCV and HV at the study area for during and after construction stage.

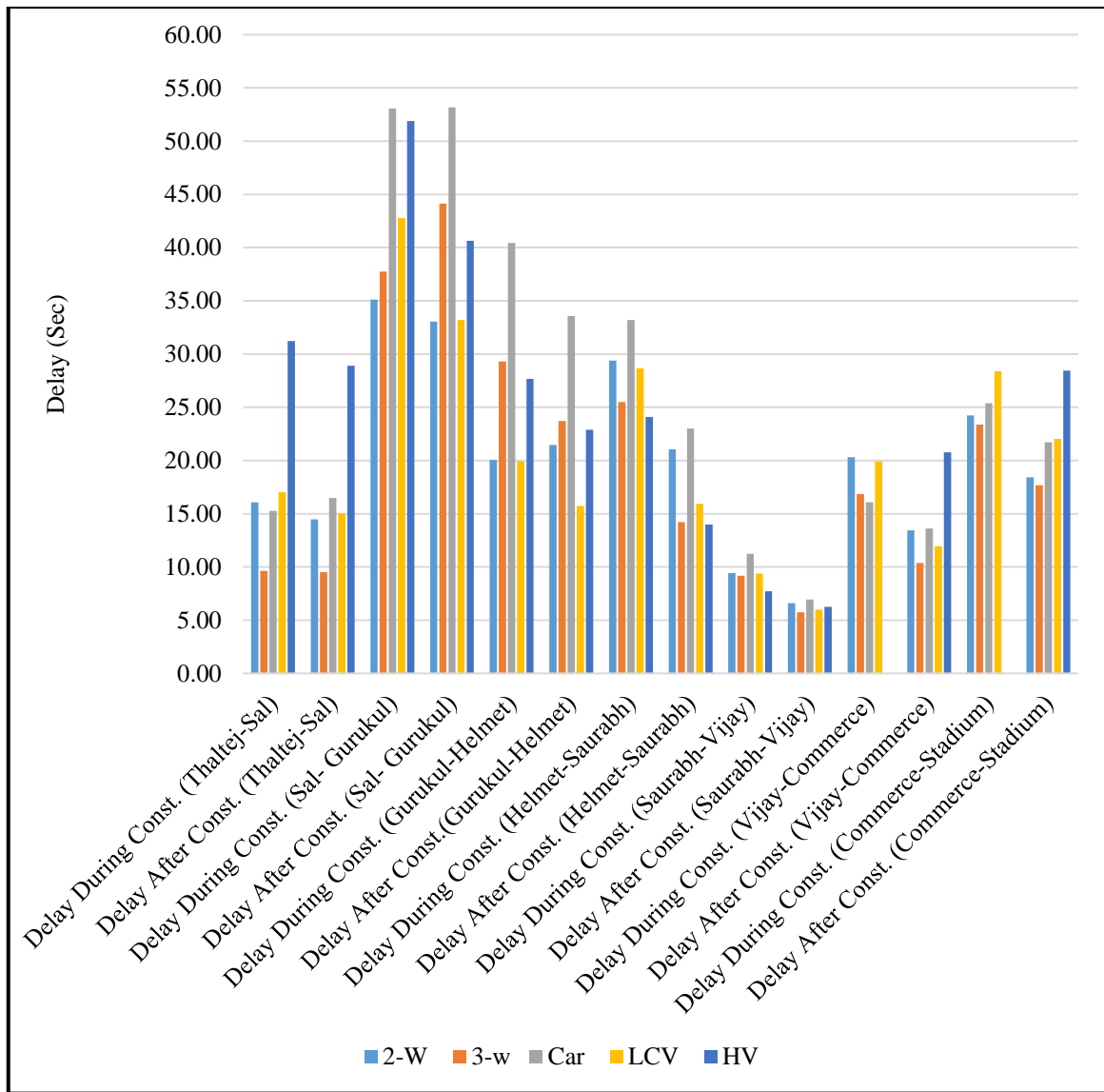


Figure 4.32 Vehicle wise delay comparison

From the figure 4.32, it is observed that there is a reduction in delay time after the construction stage. During Construction stage, the heavy vehicles' entry was prohibited on the links i.e., Vijay crossroad to Commerce crossroad and Commerce crossroad to Stadium crossroad. That's why the graph is not showing the presence of HV on these two links during the construction stage. From during and after construction study, it is observed that there is a reduction in delay. Table 4.8 shows the reduction in delay after the construction stage.

Table 4.8 % Reduction in delay after construction phase

Sr. No.	Name of link	% Reduction in delay for				
		TW	Auto	Car	LCV	HV
1	Thaltej crossroad to Sal crossroad	9.98	39.42	7.347	11.75	7.43
2	Sal crossroad to Gurukul crossroad	5.86	9.431	0.244	22.41	21.69
3	Gurukul crossroad to Helmet crossroad	6.52	19.01	16.95	21.08	17.26
4	Helmet crossroad to Saurabh crossroad	28.33	44.28	30.73	44.46	41.92
5	Saurabh crossroad to Vijay crossroad	30	37.5	38.15	36	19.05
6	Vijay crossroad to Commerce crossroad	33.84	38.36	15.19	40	--
7	Commerce crossroad to Stadium crossroad	24.02	24.39	14.38	22.40	--

From table 4.8, it is observed that there is a reduction in delay on all the links. Maximum reduction in delay is observed on the Helmet crossroad to Saurabh crossroad link having the reduction value 41.92%, while minimum reduction in delay is observed on the Thaltej crossroad to Sal crossroad link having the reduction value is 7.43%

4.7 Noise level analysis

In the study area, the noise level is measured for morning, noon and evening hours. The data such as available carriageway width and average building height is also measured. Location of noise data collection: Stadium crossroad to Thaltej crossroad, a 6.2 kilometre-long traffic corridor, has been chosen. The data have been collected at the mid-block of the section. A sound level meter was positioned at a height of 1.5 metres above the ground at the edge of the lane. Noise level has been recorded at every 3-minute interval along with the traffic data. Traffic data have been collected through videography survey method. The carriage way width and building height is measured for during and after construction stage. The surrounding building heights may affect the noise intensity. The building height is taken as the average height of all the buildings on the link. Figure 4.33 shows the location of the data collection. (source: <https://maps.google.com/>)

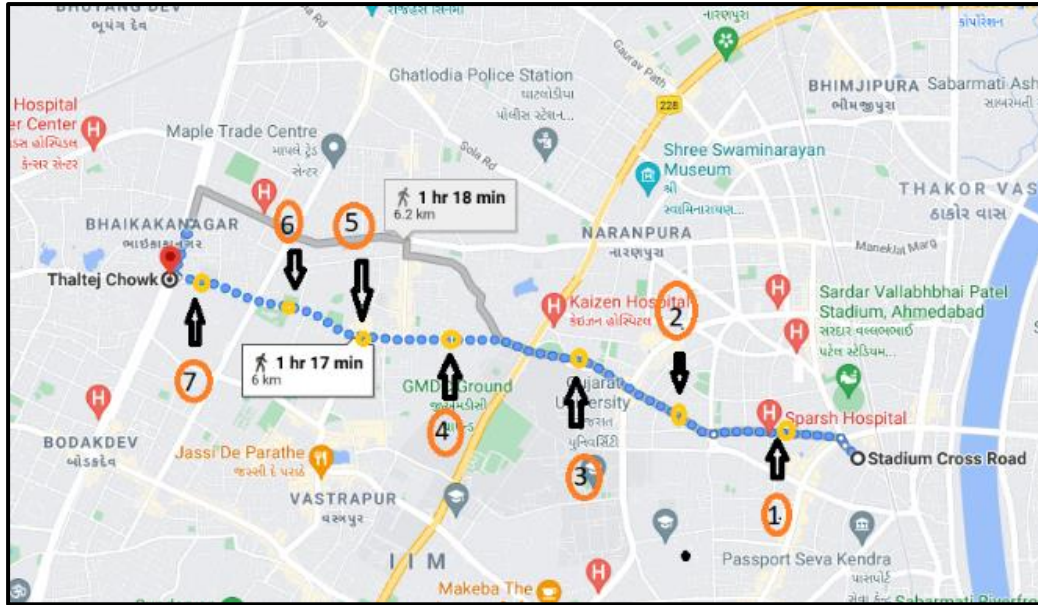


Figure 4.33 Location of data collection for noise level

The noise level is measured at the mid-block of the links to eliminate the noise effects of the intersection area. The road inventory survey was also carried out for and after construction stage. Table 4.10 shows the information about each link. Average building height of the link is taken. The project took 2 years for construction but there is no change in surrounding building height during and after construction stage.

Table 4.9 Study area links information for noise level data

Sr. No.	Name of link	Available carriageway width during construction (m)	Available carriageway width after construction (m)	Average Building height (m)
1	Stadium crossroad to Commerce crossroad	3.6	7.1	7.95
2	Commerce crossroad to Vijay crossroad	5.2	10	7.56
3	Vijay crossroad to Helmet crossroad	6.5	11.3	4.54
4	Helmet crossroad to Gurukul crossroad	4.4	12	12.83
5	Gurukul crossroad to Sunrise Park crossroad	9	11.5	7.53
6	Sunrise park crossroad to Sal crossroad	3.5	11.5	7.04
7	Sal crossroad to Thaltej crossroad	6	11.5	5.4

Noise descriptors

The sounds and disturbances perceived are typically not constant. A sound or noise's volume or sound pressure level changes with time in addition to its audible variations. The sound pressure level that is n percent of the time exceeded is known as the n-percent exceeded level, or L_n . L_{10} is the level exceeded for 10 % of time. 10% of the time, the sound or noise is louder than L_{10} . The sound pressure level is at or below L_{10} for the remainder of the time. These random or intermittent phenomena are likely responsible for the elevated sound pressure levels. L_{50} is the level exceeded for 50% of the time. According to statistics, it is the noise readings' middle value. It stands for the average of the varying noise levels. L_{90} is the level that is 90% of the time exceeded. The noise level is over this threshold 90% of the time. It is typically thought to be depicting the ambient or background noise level of an environment. L_{10} is greater than L_{50} , which is greater than L_{90} . L_{10} is described to traffic noise [117]. Figure 4.34 shows noise level in the study area during construction stage.

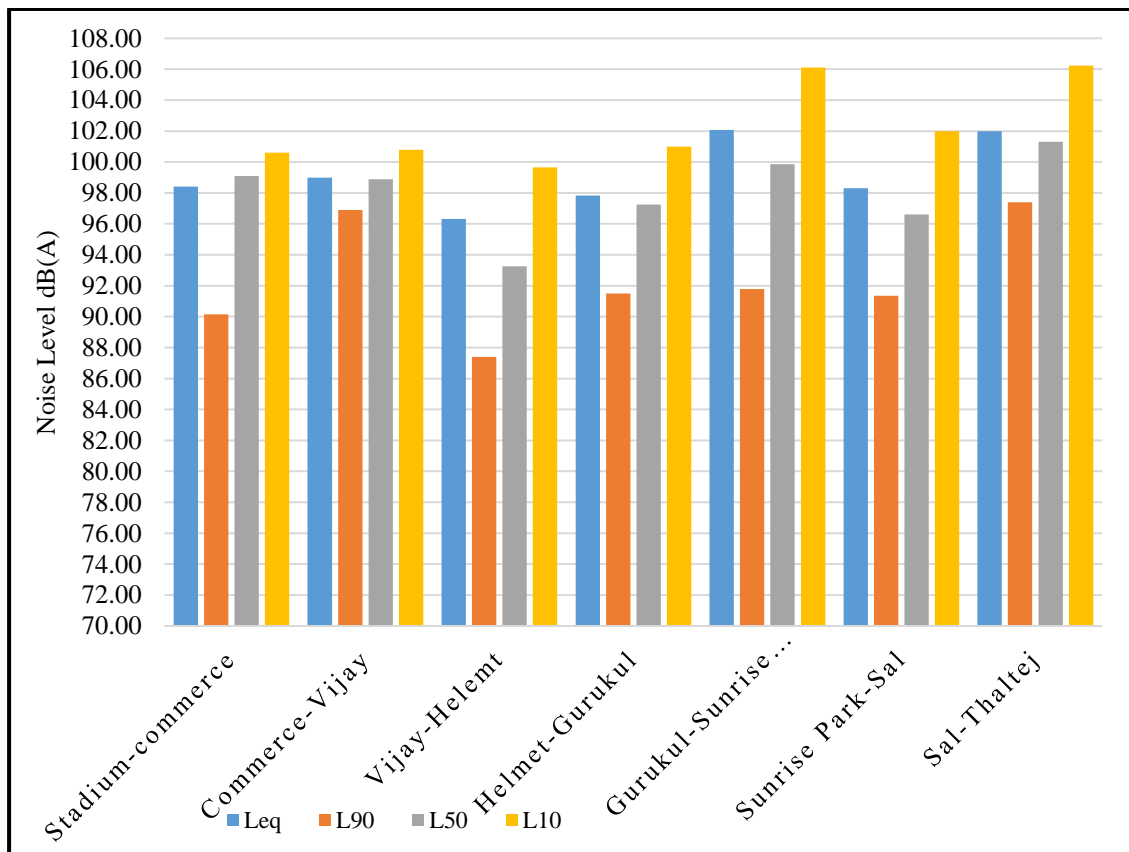


Figure 4.34 Noise level during construction stage

From the figure 4.34, maximum Leq is observed Gurukul to Sunrise park of 102.07 dB(A). Minimum Leq is observed at Vijay crossroad to Helmet crossroad of 96.31 dB(A). The observed noise level on all the links are higher than the standards of noise level in India. i.e., the limit of noise level in commercial area during day time is 65 dB(A). So, all the links are exposed to high noise level. Here is important to note that the major construction activity of metro rail was carried out during night time. So, the major cause of noise level in study area is traffic noise. These data have been collected after construction stage. These data have been presented in the figure 4.35.

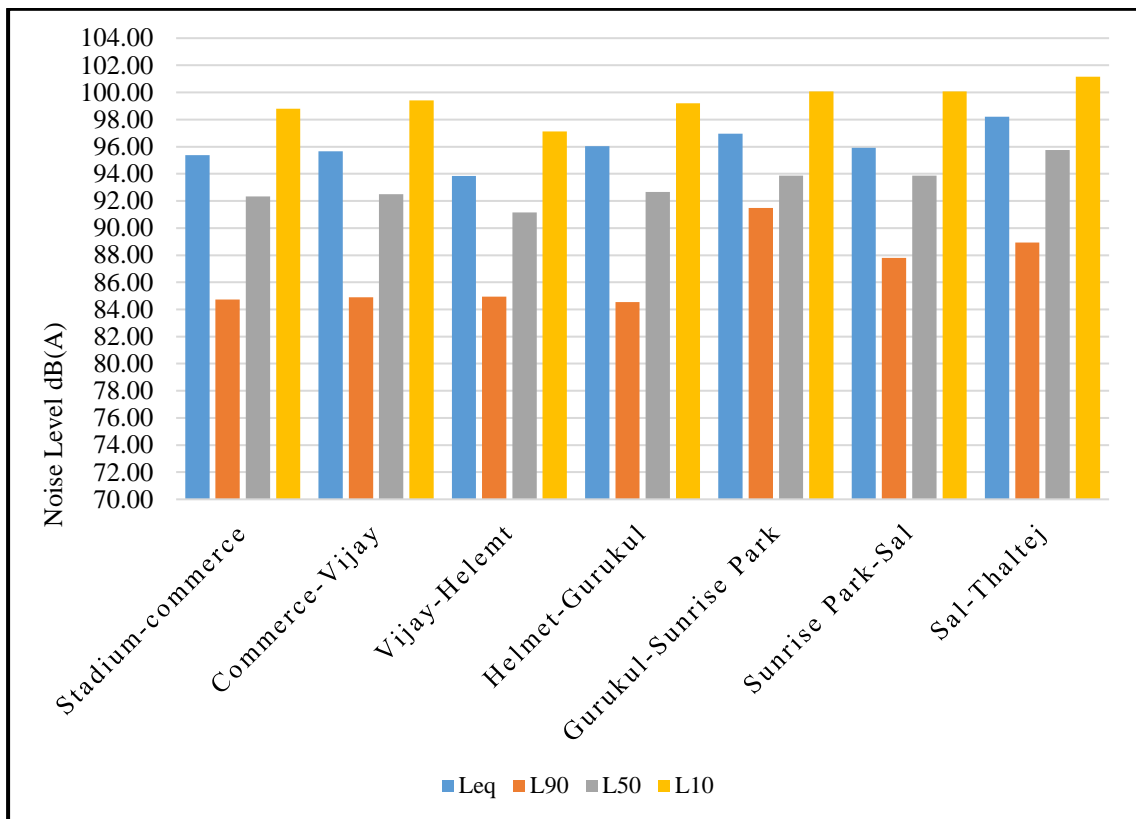


Figure 4.35 Noise level after construction stage

From the figure 4.35, maximum Leq is observed at Sal crossroad to Thaltej crossroad link having the value 98.22 dB(A). The major reason for increased noise level is unnecessary honking in the study area. Minimum Leq is observed at Stadium crossroad to Commerce crossroad having the value 95.38 dB(A). At the location Gurukul crossroad to Sunrise Park crossroad, value is highest as 90% of times the noise level is more than 91.48 dB(A). The link is surrounded by commercial centres. Overall, at all the locations the noise level is much higher than the standard value of 65 dB(A). Table 4.10 shows noise level reduction in the study area.

Table 4.10 % Reduction in noise level

Sr. No.	Name of link	Leq during construction stage dB(A)	Leq after construction stage dB(A)	% Reduction in noise level
1	Stadium crossroad to Commerce crossroad	98.41	95.38	3.080
2	Commerce crossroad to Vijay crossroad	99.00	95.67	3.362
3	Vijay crossroad to Helmet crossroad	96.31	93.84	2.565
4	Helmet crossroad to Gurukul crossroad	97.83	96.03	1.840
5	Gurukul crossroad to Sunrise Park crossroad	102.07	96.95	5.020
6	Sunrise Park crossroad to Sal crossroad	98.31	95.92	2.431
7	Sal crossroad to Thaltej crossroad	102.00	98.22	3.710

From the table 4.10, it is observed that there is a reduction in noise level. The maximum reduction in noise level is observed at the link of Gurukul crossroad to Sunrise Park crossroad and the minimum reduction in noise level is observed at Helmet crossroad to Gurukul crossroad link. Here, it is required to note that very less reduction in noise level is observed. This may be due to the study area is surrounded by commercial centres, shops, malls, temple and cinema. Furthermore, during the construction stage due to the congestion, unnecessary honking event may cause an increase in noise level. The construction activity did not affect the noise level while the survey. The major construction activities were carried out during the night time.

4.8 Summary

This chapter deals with the data collection and data analysis. The primary and secondary data are collected. The traffic data are collected through videography and noise level is measured with Sound pressure level meter. The data are represented through tables, bar charts, pie charts. Scatter plots are used to depict the speed-flow relationship. The whole process has been carried out for during construction stage and after construction stage. From the chapter, it is observed that, there is an increase in flow after construction stage, while reduction in delay and noise level after construction stage. The impacts of restricted area on flow, delay and noise level are also significant. The following chapter describes model development and validation.

Chapter- 5

Model Development and Model Validation

5.1 General

In this chapter, the prediction models are developed for flow, delay and noise in the study area for during and after construction using regression analysis. The developed models are validated using the Analysis of variance test and cross validation technique.

5.2 Prediction model for traffic flow during construction stage

In the study, regression analysis is used to develop the prediction models for flow, delay and noise level in the study area. Regression analysis helps in identifying and understanding the relationship between the dependent variable and one or more independent variables. By examining the relationship, regression analysis helps to determine how changes in the independent variables affects the dependent variable. Regression models are used to predict the value of the dependent variable based on the values of the independent variables. These models provide a mathematical equation that estimates the expected value of the dependent variable for given value independent variables. Here, it is important to note that the intercept of the model is considered as zero in case of flow and delay models. Because in absence of the considered independent variables, the dependent variable would be zero logically. It is sometimes referred to as regression through the origin, or RTO for short [118].

Various variables considered for the regression analysis are flow in PCU/hr, available one way carriageway width (ALW) in m, space mean speed (SMS) in kmph, and proportion of vehicle composition in traffic stream in percentage i.e., two wheeler (TW), car, auto rickshaw (Auto), light commercial vehicles (LCV) and heavy vehicles (HV). Table 5.1 shows Descriptive statistics of variables used in the development of model. Here, flow word is used in the context of traffic flow.

Table 5.1 Descriptive Statistics for flow analysis during construction stage

	Flow	TW	HV	LCV	Car	Auto	SMS	ALW
Mean	1474.60	64.96	0.80	1.56	18.24	14.43	26.81	6.96
Std. Error	27.92	0.40	0.04	0.06	0.33	0.19	0.26	0.08
Median	1351.00	64.06	0.58	1.43	18.75	14.29	26.95	7.00
Stad. Dev.	628.63	8.99	1.00	1.29	7.51	4.18	5.82	1.80
Variance	395176.98	80.85	1.01	1.67	56.45	17.46	33.91	3.25
Count	507	507	507	507	507	507	507	507

Here the composition of vehicles are in percentage. Table 5.2 shows the correlation matrix of the variables. Here, flow word is used in the context of traffic flow.

Table 5.2 Correlation matrix for flow during construction stage

	Flow	TW	HV	LCV	Car	Auto	SMS	ALW
Flow	1.000							
Tw	-0.317	1.000						
HV	0.034	-0.226	1.000					
LCV	0.090	-0.217	-0.015	1.000				
Car	0.355	-0.861	0.091	0.085	1.000			
Auto	0.008	-0.482	0.088	0.009	0.007	1.000		
SMS	-0.496	-0.203	0.249	0.070	0.151	0.085	1.000	
ALW	0.863	-0.482	0.015	0.084	0.564	-0.006	-0.298	1.000

From the table 5.2, it is observed that the independent variables i.e., TW (two wheeler in %), car, SMS (space mean speed in kmph) and ALW (available carriageway width in m) are showing good correlation with flow while heavy vehicles, light commercial vehicles and Auto are not showing good correlation with flow. $\text{Flow} = f(\text{TW, car, SMS, ALW})$. The regression analysis is carried out for the flow during construction stage. Table 5.3 shows the regression statistics.

Table 5.3 Regression statistics of flow model during construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.9530	0.9082	0.9047	478.36	365

From the table 5.3, it is observed that the R^2 value is coming out 0.9082. So, there is a good correlation among dependent variable and independent variables. Table 5.4 shows coefficient table for the flow during construction stage. The coefficients of independent

variable, their standard error, t-stat, p-value, upper and lower value for 95% confidence interval are mentioned in the table 5.4.

Table 5.4 Coefficient table of flow model during construction stage

Independent Variables	Coefficients	Std. Error	t-stat	p-value	95% confidence Interval	
					Lower Bound	Upper Bound
TW	20.1317	1.7020	11.8284	1.66E-27	16.78471	23.47879
Car	40.0706	4.7555	8.4261	8.6E-16	30.71868	49.42269
SMS	-52.1062	4.2808	-12.172	8.52E-29	-60.5245	-43.6878
ALW	135.5018	18.4751	7.3343	1.48E-12	99.16944	171.8342

From the table 5.4, it is observed that the major factors affecting flow are available carriage way width followed space mean speed (kmph), %car and % two-wheeler.

$$Flow = (20.13 * TW) + (40.07 * Car) - (52.10 * SMS) + (135.50 * ALW) \dots\dots\dots (5.1)$$

Here, the intercept is taken as zero. i.e., in absence of all independent variables, the dependent variable would be zero. The estimated standard deviation of the measurement error is the standard error of a coefficient estimate. Additionally, the standard error of the mean at X is the term used to describe the standard error of the projected height of the regression line for a particular value of X. The standard error for SMS is smaller as compared to rest of the variables. The ALW has larger standard error. So, this model is able to estimate the coefficient of TW, car and SMS with higher accuracy as compared to ALW. The t-value measures the ratio between the coefficient and its standard error. Here the t-value of independent variables are coming out more than t-critical. So, they can be considered as the affecting parameters on flow. For 95% of confidence interval, t-critical for two tailed test is 1.962 for degree of freedom (d.o.f) 365. If the p-value is less than or equal to the significance level, it can be concluded that there is a statistically significant association between the dependent and independent variable. Here, p-value is also coming out less than 0.05. So, all the considered independent variables are significant.

Analysis of the impacts of numerous independent factors on significant outcomes using regression modelling. But it is frequently unclear whether these models can be used for novel situations. A good fit of the model to the data used for modelling does not ensure subsequent models will also fit well. Therefore, it is essential to assess the model's performance for fresh data. Model validation refers to this investigation. The analysis of

the prediction error brought on by an overly optimistic estimation of the model parameters is the main component of model validation. The data set was used for both estimating the regression coefficients and assessing the model fit, which resulted in this prediction inaccuracy.

5.3 Model validation for traffic flow during construction stage

ANOVA (Analysis of variance) Test

It is a mathematical formula used in statistics to compare variances between mean (or average) values for several groups. It is used in a variety of situations to discover whether there are any differences between the means of various groups. ANOVA aids in comparing these group means to determine whether or not they are statistically distinct from one another. Table 5.5 shows ANOVA (Analysis of variance) test for flow during construction stage.

Table 5.5 ANOVA test for flow model during construction stage

	df	Sum of Square	Mean Square	F	Significance F
Regression	4	8.18E+08	2.04E+08	893.3087	2E-185
Residual	361	82609876	228836.2		
Total	365	9E+08			

From the regression analysis, the R^2 value is coming out 0.9082. The f critical for 95% confidence interval is 0.05. The ANOVA test shows good result as f significant is nearly zero i.e. f signi. = 0.000

Cross validation

It is required to check the model to determine whether the model's various properties (such as estimated regression coefficients) are consistent with the model fit to the original dataset. However, most of the time it is difficult to obtain new independent data to validate the model. An alternative is to partition the sample data into a training (or model-building) set, which can be used to develop the model, and a validation (or prediction) set, which is used to evaluate the predictive ability of the model. From the total data set 70%, data have been used for model development and 30% data have been used for validation. Therefore, scatter plot of observed flow vs predicted flow is plotted for the rest of 30% data set.

RMSE (Root mean square error)

The average discrepancy between the values predicted by a statistical model and the actual values is measured by the root mean square error (RMSE). It is the residuals' standard deviation in mathematics. The distance between the regression line and the data points is

represented by residuals. The degree of dispersion of these residuals is measured by RMSE, which demonstrates how closely the observed data is clustered around the anticipated values. Singh et al. state that RMSE and MAE values less than half the standard deviation of the measured data may be considered low and that either is appropriate for model evaluation. [119].

The RMSE-observations standard deviation ratio (RSR), a statistic for evaluating models, was developed by Singh et al. [119]. In order to ensure that the statistic produced and reported values may be used to a variety of constituents, RSR normalises RMSE using the observed standard deviation, combines the advantages of error index statistics and provides a scaling/normalization factor. For the resulting statistic and reported values to apply to varied constituents, RSR utilises the advantages of error index statistics and includes a scaling/normalization factor. RSR is given by equation 5.2

$$RSR = \frac{RMSE}{STDEV\ Obs} = \frac{\sqrt{\sum_{i=1}^n (Y_i^{obs} - y_i^{pred})^2}}{\sqrt{\sum_{i=1}^n (Y_i^{obs} - y_i^{mean})^2}} \dots\dots\dots (5.2)$$

RSR ranges from a big positive value to the ideal value of 0, which denotes zero residual variation or RMSE and hence faultless model simulation. The performance of the model simulation improves with decreasing RSR [120]. Scatter plot for observed vs Predicted flow during construction stage as shown in figure 5.1. This relationship is developed for the model validation in which 30% observed data are kept separate. To estimate the correctness of the developed model, predicted data (obtained from the developed model) are considered as independent (input) variables.

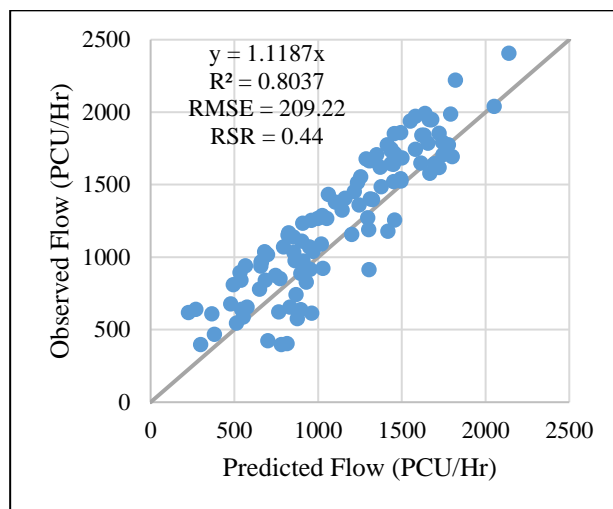


Figure 5.1 Observed vs predicted flow during construction stage

From the figure 5.1, it is observed that the R^2 value is coming out as 0.8037. Here, the RMSE is coming out high as the dependent variable is in multiple of thousands. The root mean square error is coming 209.22, which is less than the half of standard deviation of the observed data i.e. 474.7. RSR is coming out as 0.44, which is nearer to zero. The model performs well. It is found that model underestimates the values. It means the model predicts the values that are lower than actual. The values obtained from the predicted model should be multiplied by 1.1187 to estimate the observed values.

5.4 Prediction model for traffic flow after construction stage

The flow model is developed after construction stage. The independent variables are TW (two-wheeler in %), car in %, SMS (space mean speed in kmph), ALW (available carriageway width in m.), LCV (light commercial vehicle in %), Auto (auto rickshaw in %), HV (heavy vehicle in %). Table 5.6 shows the Descriptive statistics of the variables and the table 5.7 shows correlation matrix of variables.

Table 5.6 Descriptive statistics for flow after construction stage

	Flow	ALW	TW	Car	SMS	Auto	HV	LCV
Mean	1777.37	10.57	65.57	23.00	30.88	10.18	0.44	0.72
Standard Error	21.94	0.06	0.24	0.28	0.17	0.11	0.02	0.04
Mode	1600.00	11.50	66.67	25.00	38.50	11.11	0.00	0.00
Std, Deviation	588.43	1.67	6.55	7.42	4.64	3.02	0.65	0.97
Variance	346247.00	2.79	42.91	55.10	21.49	9.11	0.42	0.93
Count	719	719	719	719	719	719	719	719

Table 5.7 Correlation Matrix for flow analysis after construction stage

	Flow	SMS	TW	Auto	Car	LCV	HV	ALW
Flow	1.000							
SMS	0.111	1.000						
TW	-0.392	-0.053	1.000					
Auto	0.084	-0.025	-0.017	1.000				
Car	0.321	0.112	-0.886	-0.421	1.000			
LCV	-0.028	-0.226	0.095	0.239	-0.313	1.000		
HV	-0.031	-0.229	-0.182	-0.086	0.122	-0.055	1.000	
ALW	0.498	0.393	-0.702	-0.271	0.777	-0.368	0.189	1.000

From the table 5.7, it is observed that the independent variables i.e., TW (two wheeler), car and ALW (available carriageway width) are showing good correlation with flow while heavy vehicles, SMS, auto and light commercial vehicles are not showing good correlation with flow. Therefore, flow = f (ALW, TW, car). The regression analysis is carried out for flow after construction stage. Table 5.8 shows the regression statistics.

Table 5.8 Regression statistics of flow model after construction stage

Multiple R	R Square	Adjusted R Square	Std. Error	Observations
0.9636	0.9286	0.9263	495.19	503

From the table 5.8, it is observed that the R² values is coming out 0.9286. So there is good correlation among dependent variable and independent variables.

Table 5.9 shows coefficient table for flow after construction stage. The coefficients of independent variables, their standard error, t-stat, and p-value, upper and lower value for 95% confidence interval are mentioned in the table 5.9.

Table 5.9 Coefficient table of flow model after construction stage

Independent Variables	Coefficients	Std. Error	t-stat	p-value	95% confidence Interval	
					Lower Bound	Upper Bound
ALW	240.5954	20.00937	12.02413	1.98E-29	201.2825	279.9082
TW	-5.0683	1.657074	-3.05859	0.002343	-8.32399	-1.81262
Car	-18.4224	5.456885	-3.376	0.000793	-29.1437	-7.70118

From the table 5.9, based on coefficient value, it is observed that the major factors affecting flow are available carriage way width followed by car and TW. Therefore, Flow = f (ALW, TW, car)

The standard error for TW is smaller as compared to rest of the variables. The ALW has larger standard error. So, this model is able to estimate the coefficient of TW and car with higher accuracy as compared to ALW. The t-value measures the ratio between the coefficient and its standard error. Here the t value of independent variables are coming out more than t-critical. So, they can be considered as the affecting parameters on flow. For 95% of confidence interval, t-critical for two tailed test is 1.962 for d.o.f of 503. If the p-value is less than or equal to the significance level, it can be concluded that there is a statistically significant association between the dependent and independent variable. Here,

p-value is also coming out less than 0.05. So independent variables i.e., ALW, TW and car are significant. The intercept is taken as zero. In absence of independent variables, dependent variable will be zero.

$$Flow = (240.59*ALW) - (5.06*TW) - (18.42*Car) \dots\dots\dots (5.3)$$

5.5 Model validation for traffic flow after construction stage.

Model validation is carried out by two methods. ANOVA test and cross validation. Table 5.10 shows the ANOVA test for flow after construction stage.

Table 5.10 ANOVA test for flow model after construction stage

	df	Sum of Square	Mean Square	F	Significance F
Regression	3	1.59E+09	5.32E+08	2168.047	1E-285
Residual	500	1.23E+08	245213.7		
Total	503	1.72E+09			

From the regression analysis, the R² value is coming out 0.9286. The F critical for 95 % confidence interval is 0.05. The ANOVA test shows good result as f significant is nearly zero i.e. F signi. = 0.000

Cross validation

From the total data set 70% data have been used for model development and 30 % data have been used for validation. Figure 5.2 shows the scatter plot of observed vs predicted flow for the rest of 30 % data set.

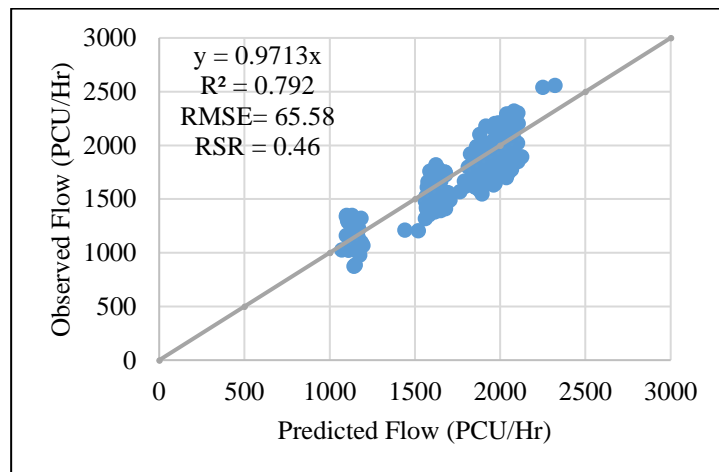


Figure 5.2 Observed vs predicted flow after construction stage

From the scatter plot of observed vs predicted flow for after construction stage, it is observed that the R² value is coming out as 0.792. The root mean square error is coming

out 165.58 which is less than the half of standard deviation of observed data. RSR is coming out as 0.46 which is nearer to zero. The model performs well. It is found that model overestimates the values. It means the model predicts the values that are higher than actual. The values obtained from the predicted model should be multiplied by 0.9713 to estimate the observed values.

5.6 Impact of construction work zone on flow

From the analysis, it is observed that there is an increase in flow after construction stage. To analyse the effect of construction work zone, the total restricted area is calculated based on work zone width and length, which is shown in table 5.11.

Table 5.11 Work zone area details for flow analysis

Sr. No.	Name of link	Width of work zone (m)	Length of work zone (m)	Restricted area (m ²)
1	Stadium crossroad to Commerce crossroad	3.6	700	2520
2	Commerce crossroad to Vijay crossroad	4.8	510	2448
3	Vijay crossroad to Saurabh crossroad	4.3	270	1161
4	Saurabh crossroad to Helmet crossroad	5.5	395	2172
5	Gurukul cross road to Sunrise Park cross road	2.5	420	1050
6	Sal crossroad to Thaltej crossroad	4	425	1700

Form the table 5.11, it is observed that the link of Stadium crossroad to Commerce crossroad has the largest restricted area. The difference in flow during construction stage and after construction stage is calculated for morning, noon and evening hours for each link. Figure 5.3 shows the scatterplot of restricted area vs difference in flow. The outlier points are not considered.

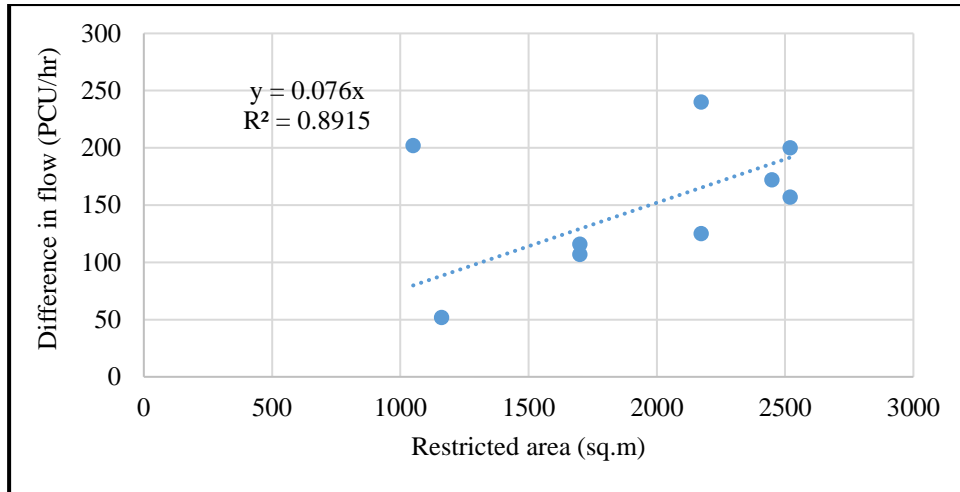


Figure 5.3 Restricted area vs difference in flow

From the figure 5.3, it is observed that there is an increase in difference in flow as the restricted area of work zone increases. It is clearly observed that there is a significant impact of work zone on the traffic flow.

5.7 Prediction model for delay during construction stage

The prediction model for delay is developed during construction stage. Various parameters such as length (in m), ALW (available carriageway width in m), flow (PCU/hr), speed (average speed in kmph) have been considered for model development. Table 5.12 Descriptive statistics of variables for delay analysis during construction stage. Table 5.13 shows correlation matrix for delay analysis during construction stage.

Table 5.12 Descriptive statistics for delay analysis during construction stage

	Delay	ALW	Length	Speed	Flow
Mean	14.83	5.22	367.18	27.28	1308.2
Std. error	0.48	0.05	9.85	0.72	18.20
Median	12.36	5.00	250.00	23.63	1226.5
Mode	17.03	6.00	1000.00	20.69	1419.0
Std. Dev.	12.69	1.47	262.80	19.21	485.71
Variance	160.9	2.15	69066.0	369.1	235914
Count	712	712	712	712	712

Table 5.13 Correlation matrix for delay analysis during construction stage

	Delay	ALW	Length	Speed	Flow
Delay	1.0000				
ALW	0.4013	1.0000			
Length	0.8446	0.4405	1.000		
Speed	-0.146	-0.226	-0.081	1.0000	
Flow	0.4967	0.4562	0.4092	0.3134	1.000

From the table 5.13, it is observed that the independent variables i.e., ALW (available carriageway width), length and flow are showing good correlation with delay. Speed is showing fair relation with delay, however it is an important factor logically. So, it is kept in the model development. It is observed that the Delay = f (ALW, length, flow, speed). Table 5.14 shows the regression statistics.

Table 5.14 Regression statistics of delay model during construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.95113	0.9046	0.9018	6.09	461

From the table 5.14, it is observed that the R² values is coming out 0.9046. So there is a good correlation among dependent variable and independent variables.

Table 5.15 shows coefficient table for delay during construction stage. Here, it is important to note that the intercept is kept zero because in absence of all independent variables, the dependent variable would be zero. The coefficients of independent variable, their standard error, and t-stat, and p-value, upper and lower value for 95% confidence interval are mentioned in table 5.15.

Table 5.15 Coefficient table of delay model during construction stage

Independent Variables	Coefficients	Std. Error	t-stat	p-value	95% Confidence Interval	
					Lower bound	Upper bound
ALW	-1.0270	0.1713	-5.9956	0.0000	-1.3636	-0.6904
length	0.0361	0.0013	28.2514	0.0000	0.0336	0.0386
Flow	0.0082	0.0008	10.3167	0.0000	0.0066	0.0098
Speed	-0.1379	0.0155	-8.8862	0.0000	-0.1684	-0.1074

From the table 5.15, based on coefficient value, it is observed that the major factors affecting delay are available carriage way width and speed followed by length and flow. The values of standard error for the variables are very small. So, this model is able to estimate the coefficient of independent variable with higher accuracy.

The t-value measures the ratio between the coefficient and its standard error. Here the t-value of independent variables are coming out more than t-critical value. So they can be considered as the affecting parameters on delay. For 95% of confidence interval, t-critical value for two tailed test is 1.962 for d.o.f of 461. If the p-value is less than or equal to the significance level, it can be concluded that there is a statistically significant association between the dependent and independent variable. Here, p-value is also coming out less than 0.05. So, independent variables i.e., ALW (m), length (m), flow (PCU/Hr) and speed (kmph) are significant. Delay = f (ALW, length, flow, speed)

$$Delay = (-1.020*ALW) + (0.0361*length) + (0.0082*Flow) - (0.1379*Speed)..... (5.4)$$

5.8 Model validation for delay during construction stage

Model validation is carried out by two methods i.e., ANOVA test and cross validation. Table 5.16 shows the ANOVA test for delay during construction stage.

Table 5.16 ANOVA test for delay model during construction stage

	df	SS	MS	F	Significance F
Regression	4	161057.1	40264.28	1084.018	2.5E-231
Residual	457	16974.61	37.14356		
Total	461	178031.7			

From the regression analysis, the R² value is coming out 0.9046. The f critical for 95 % confidence interval is 0.05. The ANOVA test shows good result as f significant is nearly zero i.e. f signi. = 0.000

Cross validation

From the total data set 70% data have been used for model development and 30 % data have been used for validation. Figure 5.4 shows the observed delay and predicted delay relationship.

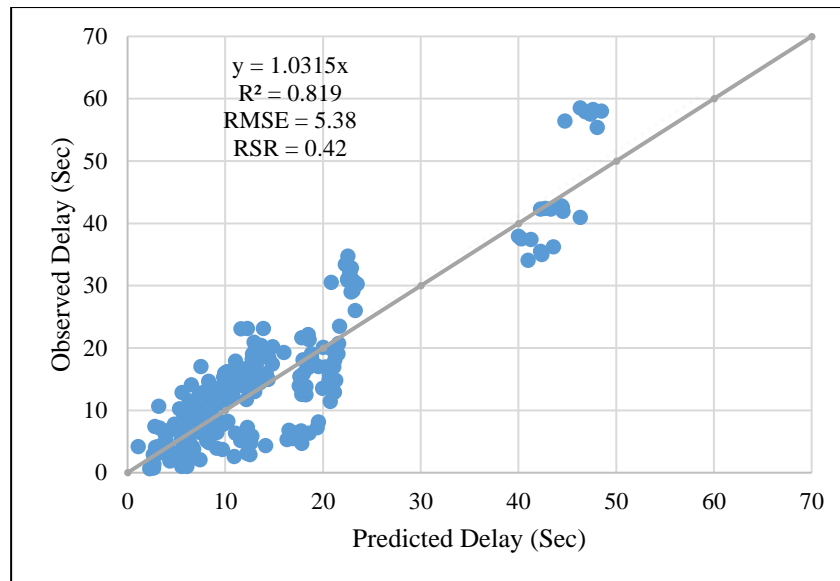


Figure 5.4 Observed vs Predicted delay during construction stage

From the scatter plot of observed vs predicted delay for during construction stage, it is observed that the R^2 value is coming out as 0.819. The root mean square error is coming out 5.38, which is less than the half of standard deviation of observed data. RSR is coming out as 0.42, which is nearer to zero. The model performs well. The model performs well. It is found that model underestimates the values. It means the model predicts the values that are lower than actual. The values obtained from the predicted model should be multiplied by 1.0305 to estimate the observed values.

5.9 Prediction model for delay after construction stage

The independent variables are ALW (available carriageway width in m), length, TW (two-wheeler), car, auto (auto rickshaw), LCV (light commercial vehicle), HV (heavy vehicle), flow, and speed. Table 5.17 shows the Pearson correlation between the variables.

Table 5.17 Descriptive statistics for delay analysis after construction stage

	Delay	ALW	Length	Flow	Speed
Mean	21.060	10.682	571.167	1351.106	31.700
Std. Error	0.536	0.072	10.338	21.946	0.222
Median	19.704	11.300	565.000	1470.600	30.708
Mode	24.407	11.500	565.000	1056.000	29.403
Std. Dev.	11.575	1.561	223.404	474.254	4.801
Count	467	467	467	467	467

Table 5.18 Correlation matrix for delay analysis after construction stage

	Delay	ALW	Length	Flow	Speed
Delay	1.0000				
ALW	0.0488	1.0000			
Length	0.8041	-0.2004	1.0000		
Flow	0.2213	0.7250	-0.0752	1.0000	
Speed	-0.6322	-0.1626	-0.3187	-0.2641	1.0000

From the table 5.18, it is observed that the independent variables i.e., length, speed and flow are showing good correlation with delay while available carriage way width is not showing good correlation with delay. The regression analysis is carried out for delay after construction stage. Table 5.19 shows the regression statistics.

Table 5.19 Regression statistics of delay model after construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.9785	0.9574	0.9537	4.9722	292

From the table 5.19, it is observed that the R^2 values is coming out 0.9574. The f critical for 95 % confidence interval is 0.05. There is good correlation among dependent variable and independent variables. Table 5.20 shows coefficient table for delay after construction stage. The coefficients of independent variables, their standard error, t-stat, p-value, upper and lower value for 95% confidence interval are mentioned in table 5.20.

Table 5.20 Coefficient table of delay model after construction stage

Independent Variables	Coefficients	Std. Error	t-stat	p-value	Lower 95%	Upper 95%
Length	0.0422	0.0011	36.7886	0.0000	0.0400	0.0445
Speed	-0.4132	0.0284	-14.5319	0.0000	-0.4692	-0.3572
Flow	0.0071	0.0005	13.0898	0.0000	0.0060	0.0082

From the table 5.20, based on coefficient value, it is observed that the major factors affecting delay are speed followed by Speed, followed by length and flow. The values of standard error for the variables are very small. So, this model is able to estimate the coefficient of independent variable with higher accuracy.

The t-value measures the ratio between the coefficient and its standard error. Here, the t-value of independent variables are coming out more than t-critical value. So they can be considered as the affecting parameters on delay. The p-value is also coming out less than 0.05. So, it can be concluded that there is a statistically significant association between the dependent and independent variables. Regression analysis for delay has been carried out for the after construction stage. Delay = f (Length, Speed, Flow)

$$Delay = (0.0422 * Length) - (0.4132 * Speed) + (0.0071 * Flow) \dots \dots \dots (5.5)$$

5.10 Model validation for delay after construction stage

Model validation is carried out by two methods i.e., ANOVA test and cross validation. Table 5.21 shows the ANOVA test for delay after construction stage.

Table 5.21 ANOVA test for delay model after construction stage

	df	SS	MS	F	Significance F
Regression	3	160592.1	53530.71	2165.279	3.5E-197
Residual	289	7144.751	24.72232		
Total	292	167736.9			

From the regression analysis, the R² value is coming out 0.9574. The F critical for 95% confidence interval is 0.05. The ANOVA test shows good result as f significant is nearly zero i.e. F signi. = 0.000

Cross validation

The model is developed for 70% data set and validated for rest of 30% data set. Figure 5.5 shows scatter plot of observed vs predicted delay.

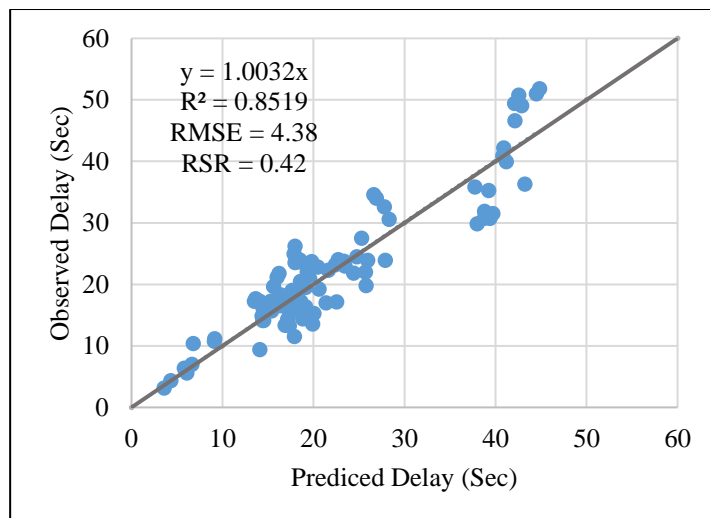


Figure 5.5 Observed vs predicted delay after construction stage

From the scatter plot of observed vs predicted delay for after construction stage, it is observed that the R^2 value is coming out as 0.8519. The root mean square error is coming out 4.38 which is less than the half of standard deviation of observed data. RSR is coming out as 0.42 which is nearer to zero. The model performs well. It is found that model underestimates the values. It means the model predicts the values that are lower than actual. The values obtained from the predicted model should be multiplied by 1.0032 to estimate the observed values.

5.11 Impact of construction work zone on delay

From the analysis it is observed that there is a reduction in delay after construction stage. To analyse the effect of construction work zone, the total restricted area is calculated based on work zone width and length, which is shown in table 5.22.

Table 5.22 Work zone area details for delay analysis

Sr. No.	Name of link	Width of work zone (m)	Length of work zone	Restricted area (m ²)
1	Thaltej crossroad to Sal crossroad	6.5	455	2957
2	Sal crossroad to Gurukul crossroad	6.0	1000	6000
3	Gurukul crossroad to Helmet crossroad	8.7 6.5	205 445	1783 2892
4	Helmet crossroad to Saurabh crossroad	6.3 3.6	250 230	1575 828
5	Saurabh crossroad to Vijay crossroad	6.3	215	1354
6	Vijay crossroad to Commerce crossroad	4 5.6	397 76	1588 716
7	Commerce crossroad to Stadium crossroad	3.69	700	2050

From the table 5.22, it is observed that there is significant variation in the width of links. The difference in delay during construction stage and after construction stage is calculated for morning, noon and evening delay for each link. Figure 5.6 shows the scatter plot of restricted area vs difference in delay.

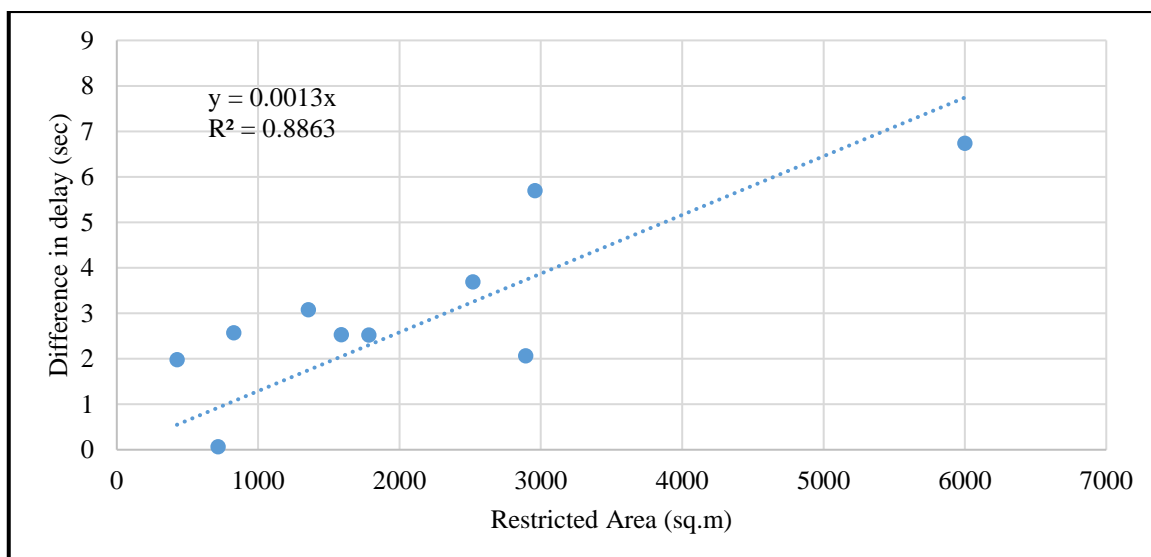


Figure 5.6 Restricted area vs difference in delay

From the figure 5.6, it is observed that there is an increase in difference in delay as the restricted area of work zone increases. It is clearly observed that there is a significant impact of work zone on the delay.

5.12 Prediction model for noise during construction stage

The prediction model for noise is developed during construction stage. Various parameters such as ALW (available carriage way width in m.), BH (building height in m.), Honk (honking event is defined as ‘In 3 min interval of time, how many times the honking occurs’, speed (in kmph), density (no of vehicles per km) and vehicle composition per three minute, i.e., TW (no. of two wheelers), auto (no. of auto rickshaws), LCV (no of light commercial vehicles), no. of cars, HV (no. of heavy vehicle) have been considered for model development. Table 5.23 shows descriptive statistics if the variables for noise level analysis during construction stage.

Table 5.23 Descriptive Statistics for noise analysis during construction stage

	Noise level	Honk	BH	SMS	ALW	Car	Auto	LCV	TW	HV
Mean	96.9	2.09	7.62	26.2	5.47	17.7	14.5	2.13	70.5	0.97
Std. Error	0.21	0.04	0.10	0.27	0.08	0.35	0.20	0.11	0.81	0.05
Median	97.6	2.00	7.53	27.6	5.20	16.0	14.0	1.00	74.0	1.00
Mode	99.1	2.00	7.95	27.6	3.60	16.0	17.0	1.00	75.0	0.00
Std. Dev.	4.95	1.03	2.43	6.52	1.81	8.41	4.75	2.66	19.2	1.10
Variance	24.4	1.06	5.93	42.4	3.29	70.7	22.5	7.07	368.	1.21
Count	567	567	567	567	567	567	567	567	567	567

To get the relation among the variables the correlation analysis is carried out. Table 5.24 shows the correlation matrix for noise level analysis during construction stage.

Table 5.24 Correlation matrix for noise level during construction stage

	Noise level	Honk	BH	SMS	ALW	Car	Auto	LCV	TW	HV
Noise level	1.000									
Honk	0.435	1.000								
BH	0.092	-0.01	1.000							
SMS	-0.07	-0.14	0.113	1.000						
ALW	0.068	0.134	-0.29	-0.20	1.000					
Car	0.566	0.234	-0.11	-0.13	0.236	1.000				
Auto	0.457	0.162	0.120	-0.10	-0.02	0.337	1.000			
LCV	0.424	0.296	-0.14	-0.31	0.303	0.493	0.230	1.000		
TW	0.699	0.248	0.247	0.091	-0.07	0.414	0.449	0.198	1.000	
HV	0.205	0.059	-0.06	0.202	0.057	0.326	0.203	-0.01	0.068	1.000

From the table 5.24, it is observed that the independent variables i.e., honk, car, auto, LCV and TW are showing good correlation with noise level while carriage way width, speed, heavy vehicles are not showing good correlation with noise.

Honk, car, auto, LCV and TW are considered for the regression analysis. The regression analysis is carried out for noise level during construction stage. The Table 5.25 shows the regression statistics.

Table 5.25 Regression statistics for noise level during construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.8209	0.6738	0.6696	2.8120	393

From the table 5.25, it is observed that the R^2 values is coming out 0.6738. So there is a good correlation among dependent variable and independent variables.

Table 5.26 shows coefficient table for noise level during construction stage. The coefficients of independent variables, their standard error, t-stat, p-value, upper and lower value for 95% confidence interval are mentioned in table 5.26.

Table 5.26 Coefficient table for noise level during construction stage

Independent Variables	Coefficients	Std. Error	t-stat	p-value	95% Confidence Interval	
					Lower 95%	Upper 95%
Intercept	82.160	0.626	131.288	0.000	80.929	83.390
TW	0.124	0.009	13.888	0.000	0.106	0.141
Car	0.125	0.021	5.921	0.000	0.084	0.167
Auto	0.107	0.035	3.010	0.003	0.037	0.176
Honk	0.915	0.150	6.099	0.000	0.620	1.210
LCV	0.263	0.063	4.171	0.000	0.139	0.387

Here, the intercept is not considered as zero. In absence of all the dependent variables, noise would not be zero. From the table 5.26, based on coefficient value, it is observed that the major factors affecting noise level are honking followed by LCV, car and TW.

The value of standard error for the variables are very small. Therefore, this model is able to estimate the coefficient of independent variable with higher accuracy. The t-value measures the ratio between the coefficient and its standard error. Here the t-value of independent variables are coming out more than t-critical. So they can be considered as the affecting parameters on delay. For the 95% of confidence interval, t-critical for two tailed test is 1.962 for d.o.f of 392. If the p-value is less than or equal to the significance level, it can be concluded that there is a statistically significant association between the dependent and independent variable. Here, p-value is also coming out less than 0.05.

So, independent variables are significant. Noise = f (Auto, Honk, car, LCV and TW)

$$\text{Noise level} = 82.160 + (0.124 * TW) + (0.125 * car) + (0.107 * Auto) + (0.915 * honk) + (0.265 * LCV) \dots \dots \dots (5.6)$$

5.13 Model validation for noise during construction stage

Model validation is carried out by two methods. ANOVA test and cross validation. Table 5.27 shows the ANOVA test for delay after construction stage.

Table 5.27 ANOVA test for noise level model during construction stage

	df	SS	MS	F	Significance F
Regression	5	6321.96	1264.39	159.9	8.1E-92
Residual	387	3060.16	7.9074		
Total	392	9382.12			

From the regression analysis, the R^2 value is coming out 0.6738. The f critical for 95 % confidence interval is 0.05. The ANOVA test shows good result as f significant is nearly zero i.e., f signi. = 0.000

Cross validation

The model is developed for 70% data set and validated for rest of 30% data set. Figure 5.7 shows the scatter plot of observed vs predicted delay relationship.

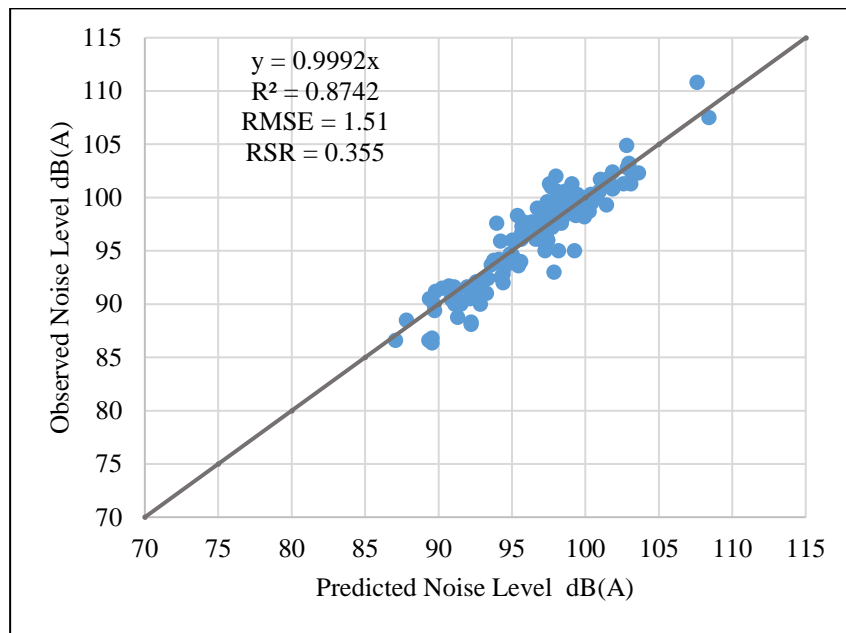


Figure 5.7 Observed vs predicted noise level during construction stage

From the scatter plot of observed vs predicted noise level during construction stage, it is observed that the R^2 value is coming out as 0.8742. The root mean square error is coming out 1.51 which is less than the half of standard deviation of observed data. RSR is coming out as 0.355 which is nearer to zero. The model performs well. It is found that model overestimates the values. It means the model predicts the values that are higher than actual. The values obtained from the predicted model should be multiplied by 0.9992 to estimate the observed values.

5.14 Prediction model for noise after construction stage

The prediction model for noise is developed after construction stage. Various parameters such as ALW (available carriage way width in m.), BH (building height in m), honk (honking event per 3 min), flow (no. of vehicles per hour), speed (in kmph), density (no of vehicles per km) and vehicle composition per 3 min time interval i.e., TW (no. of two wheelers), auto no. of (no. of auto rickshaws), LCV (no. of light commercial vehicles), no.

of car, HV (no. of heavy vehicle) have been considered for model development. Table 5.28 shows the descriptive statistics of variables for noise level after construction stage. Table 5.29 shows the Pearson correlation between the variables.

Table 5.28 Descriptive statistics for noise level analysis after construction stage

	Noise level	Honk	SMS	LW	BH	TW	Auto	Car	LCV	HV
Mean	93.33	1.45	30.90	10.69	7.59	89.32	14.44	32.49	0.98	0.17
Std. Error	0.23	0.03	0.14	0.05	0.08	0.76	0.19	0.38	0.04	0.01
Median	93.50	1.00	30.58	11.50	7.53	85.00	12.00	36.00	1.00	0.00
Mode	89.70	1.00	35.69	11.50	7.95	78.00	10.00	39.00	0.00	0.00
Std. Dev.	7.34	0.94	4.40	1.59	2.45	24.36	6.22	12.27	1.15	0.41
Variance	53.89	0.88	19.35	2.52	6.03	593.59	38.68	150.54	1.33	0.17
Count	1031	1031	1031	1031	1031	1031	1031	1031	1031	1031

Table 5.29 Correlation Matrix for noise analysis after construction stage

	Noise level	Honk	TW	Car	Auto	Speed	LW	BH	LCV	HV
Noise level	1.000									
Honk	0.627	1.000								
TW	0.573	0.307	1.000							
Car	0.434	0.154	0.452	1.000						
Auto	0.254	0.041	0.514	0.321	1.000					
Speed	-0.22	-0.18	-0.01	0.107	0.070	1.000				
LW	0.082	-0.08	0.272	0.592	0.212	0.381	1.000			
BH	-0.08	-0.02	-0.02	0.018	-0.06	-0.12	0.063	1.000		
LCV	-0.01	-0.03	0.164	0.099	0.261	-0.03	0.003	0.027	1.000	
HV	0.019	0.049	-0.005	0.031	-0.08	-0.04	0.013	0.006	0.054	1.000

From the table 5.29, it is observed that the independent variables i.e., honk, TW, and car are showing good correlation with noise level, whereas auto and speed have fair correlation with noise level. Building height, LCV, available carriageway width, heavy vehicles are not showing good correlation with noise level. But after analysing the p-value and t-value of variables i.e., Honk, car, TW and speed are considered for the regression analysis. The regression analysis is carried out for noise level after construction stage. The Table 5.30 shows the regression statistics.

Table 5.30 Regression statistics of noise level model after construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.8020	0.6432	0.6412	4.4583	737

From the table 5.30, it is observed that the R² values is coming out 0.6432. So there is fair correlation among dependent variable and independent variables.

Table 5.31 shows coefficient table for noise level after construction stage. The coefficients of independent variables, their standard error, t-stat, p-value, upper and lower value for 95% confidence interval are mentioned in table 5.30.

Table 5.31 Coefficient table of noise level model after construction stage

Independent Variables	Coefficients	Std. Error	t-stat	p-value	95% Confidence Interval	
					Lower 95%	Upper 95%
Intercept	84.6783	1.38333	61.21337	3.8E-290	81.96253	87.39407
Honk	3.48138	0.184554	18.86381	5.48E-65	3.119067	3.843702
TW	0.10295	0.007633	13.48822	3.42E-37	0.087966	0.117935
Car	0.14416	0.015335	9.401385	6.74E-20	0.114063	0.174274
SMS	-0.33791	0.040193	-8.4072	2.19E-16	-0.41682	-0.25901

From the table 5.31, based on coefficient value, it is observed that the major factors affecting noise level are honking event followed by speed car and TW. The value of standard error for the variables are very small. Therefore, this model is able to estimate the coefficient of independent variable with higher accuracy. t-stat value and p- value are also within the acceptance limit. So, it can be concluded that there is a statistically significant association between the dependent and independent variable. So, independent variables are significant. Noise = f (Honk, TW, Car, SMS)

$$\text{Noise level} = 84.6783 + (3.4813*\text{Honk}) + (0.10295*\text{TW}) + (0.14416*\text{Car}) - (0.33791*\text{SMS}) \dots\dots\dots (5.7)$$

5.15 Model validation for noise after construction stage

Model validation is carried out by two methods. ANOVA test and cross validation. Table 5.32 shows the ANOVA test for noise level after construction stage.

Table 5.32 ANOVA test for noise level model after construction stage

	df	SS	MS	F	Significance F
Regression	4	4	26225.3	6556.325	329.8504
Residual	716	732	14549.72	19.87666	
Total	720	736	40775.01		

The developed model is validated from ANOVA test, the R^2 is coming out as 0.6432 and significant f value is coming out as nearly zero. i.e., $F \text{ sig} = 0.00$. The F critical for 95 % confidence interval is 0.05

Cross validation: The model is developed for 70% data set and validated for rest of 30% data set. Figure 5.8 shows scatter plot of observed vs predicted delay after construction stage.

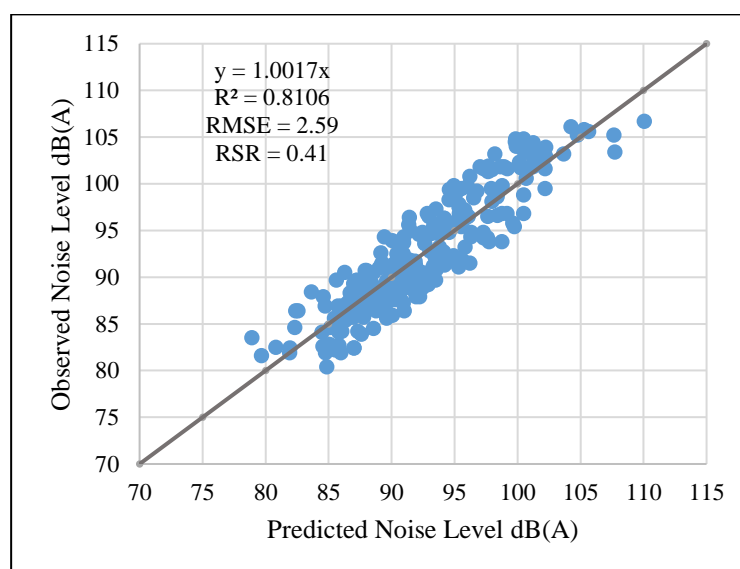


Figure 5.8 Observed vs predicted noise level after construction stage

From the scatter plot of observed vs predicted noise level after construction stage, it is observed that the R^2 value is coming out as 0.8106. The root mean square error is coming out 2.59 which is less than the half of standard deviation of observed data. RSR is coming out as 0.416 which is nearer to zero. The model performs well. It is found that model underestimates the values. It means the model predicts the values that are lower than actual. The values obtained from the predicted model should be multiplied by 1.0017 to estimate the observed values.

5.16 Impact of construction work zone on noise level

From the analysis, it is observed that there is a reduction in noise level after construction stage. To analyse the effect of construction work zone, the total restricted area is calculated based on work zone width and length which is shown in table 5.33.

Table 5.33 Work zone area details for noise level analysis

Sr. No.	Name of link	Width of work zone (m)	Length of work zone (m)	Restricted Area (m ²)
1	Stadium crossroad to Commerce crossroad	3.5	700	2450
2	Commerce crossroad to Vijay crossroad	4.8	250	1200
3	Vijay crossroad to Helmet crossroad	4.8	665	3192
4	Helmet crossroad to Gurukul crossroad	7.6	900	6840
5	Gurukul crossroad to Sunrise Park crossroad	2.5	420	1050
6	Sunrise Park crossroad to Sal crossroad	8	550	4400
7	Sal crossroad to Thaltej crossroad	5.5	425	2337

Form the table 5.33, it is observed that the link of Helmet crossroad to Gurukul crossroad has the largest restricted area.

Here, it is necessary to note that, the study shows lack of correlation between restricted area and difference of noise level for during and after construction stage.

Honking is indeed a hidden factor that can contribute to increased noise levels in urban areas, including construction work zones. Honking is often a response to traffic congestion or delays caused by construction work zones. When drivers become frustrated due to traffic disruptions, they may engage in aggressive driving behaviours, including excessive honking. Figure 5.9 shows the comparison of honking event or during and after construction stage.

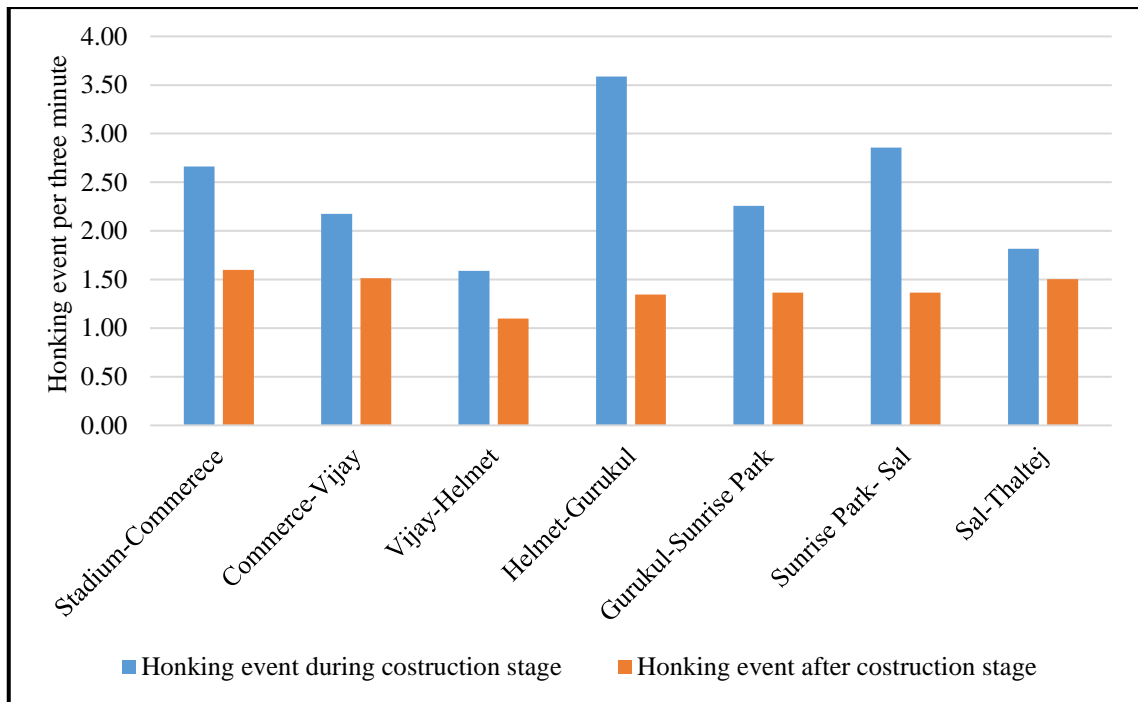


Figure 5.9 Comparison of honking event for during and after construction stage

From the figure 5.9, it is found that Helmet crossroad to Gurukul crossroad link has the highest difference in honking event. Sal crossroad to Thaltej crossroad link has the lowest difference in honking event.

In the regression model of noise level, the coefficient of variable of honking event is 6.4703 and 6.8659 for during construction stage and after construction stage respectively. Therefore, the average value of coefficient is 6.6681. The increase in 1 unit of honking event resulted in increase in noise level of 6.6681 dB(A).

Figure 5.10 shows the scatter plot of restricted area vs increase in noise level. In scatter plot, there are two vertical axes. The primary vertical axis shows the difference in honking event for during and after construction stage. The honking event is multiplied with the average coefficient of honking event to get the noise level. The secondary vertical axis shows the difference in noise level per unit honking event.

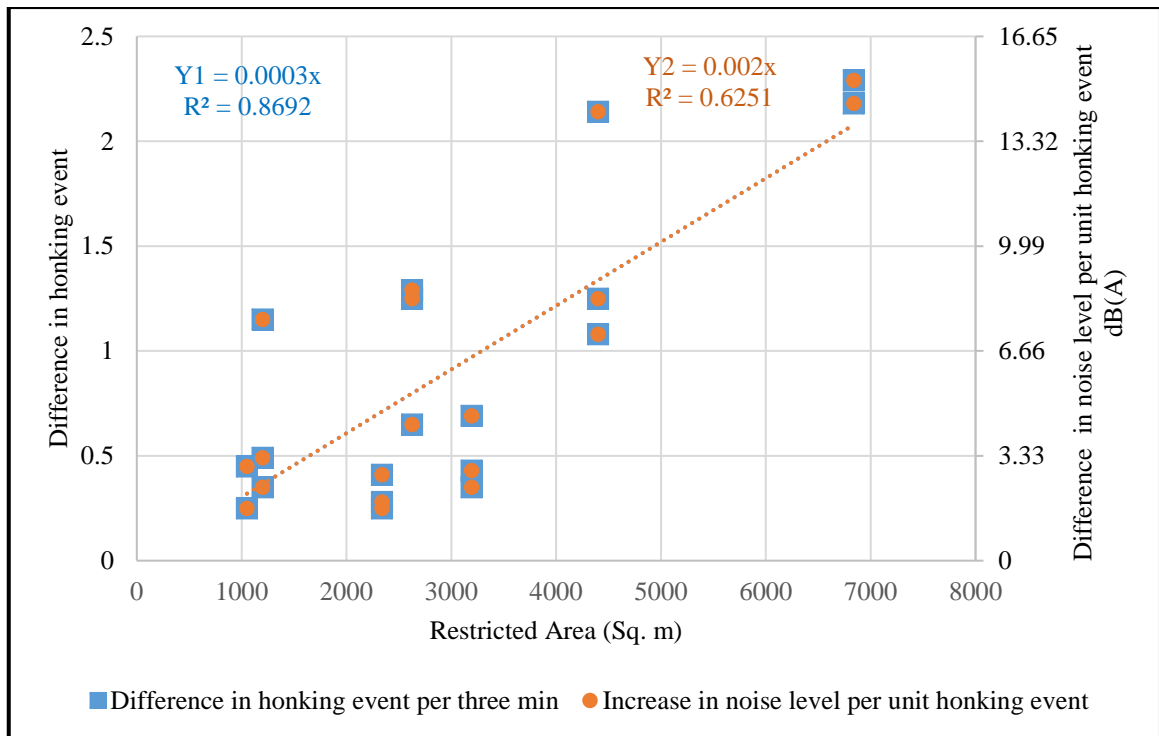


Figure 5.10 Restricted area vs difference in noise level

Figure 5.10 shows the scatter plot of restricted area vs increase in noise level per unit honking event. It is observed that there is an increase in difference in honking event as the restricted area increases. Y_1 indicates the difference in honking event and Y_2 indicates difference in noise level per unit honking event. From the graph, it is clearly observed that there is a significant impact of work zone on the honking event and ultimately affects the noise level.

5.17 Hypothesis testing

Hypothesis testing is a statistical tool used to determine whether or not the results of analysis are relevant. It involves establishing a null hypothesis and an alternate hypothesis. Both of these hypotheses are always mutually exclusive. If the null hypothesis is true, the alternative hypothesis is false, and vice versa. The null hypothesis is a concise mathematical statement that is used to indicate that there is no difference between two possibilities. In other words, there is no difference between certain characteristics of data. This hypothesis assumes that the outcomes of an experiment are based on chance alone. It is denoted as H_0 . The alternative hypothesis is an alternative to the null hypothesis. It is used to show that the observations of an experiment are due to some real effect. It indicates that there is a statistical significance between two possible outcomes and can be denoted as H_1 or H_a .

H_0 = Null hypothesis: There is no significant change (in flow, delay and noise level) after construction stage. i.e., after removal of work zone restriction.

H_a = Alternate hypothesis: There is significant change (in flow, delay and noise level) after construction stage i.e. after removal of work zone restriction. \bar{x}_1 and \bar{x}_2 are the means of samples from two populations for during and after construction stage respectively. S_1 and S_2 are the standard deviations samples (i.e., flow, delay and noise) for during and after construction stage respectively.

n_1 and n_2 are sample size for two sets (for during and after construction stage). $\bar{x}_1 - \bar{x}_2$ is difference of sample means. Standard deviation can be given by equation-5.8

$$\sigma_{(\bar{x}_1 - \bar{x}_2)} = \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} \dots\dots\dots(5.8)$$

The standard deviation at 95% of confidence interval can be given by

$$\sigma_{(\bar{x}_1 - \bar{x}_2)_{Z_c}} = \sigma_{(\bar{x}_1 - \bar{x}_2)} * 1.96 \dots\dots\dots(5.9)$$

If values obtained in equation 5.9 are less than the observed difference of mean (i.e., Observed > critical), then null hypotheses is rejected and alternate hypothesis is accepted [121]. The hypothesis testing is carried out for all the links. Tables 5.34 to 5.36 show the hypothesis test results on each link for flow, delay and noise level respectively.

Table 5.34 Hypothesis testing for flow

Statistical Parameters	Link-1	Link-2	Link-3	Link-4	Link-5	Link-6
\bar{x}_1 (PCU/hr)	574.28	1027.64	1262.1	1811.3	2510.48	1369.24
\bar{x}_2 (PCU/hr)	1208.21	1566.53	1627.1	1930.7	2851.7	1489.53
S_1 (PCU/hr)	162.644	156.804	220.22	180.78	301.773	239.59
S_2 (PCU/hr)	200.76	187.39	282.99	234.09	401.41	251.4
n_1	108	96	99	108	85	90
n_2	120	120	120	120	120	120
$\sigma_{(\bar{x}_1 - \bar{x}_2)}$ at 95% confidence interval (PCU/hr)	47.2359	45.9136	66.6754	54.007	96.3022	66.8845
Observed difference of mean (PCU/hr)	633.93	538.89	365	119.4	341.22	120.29
Decision: Observed value is greater that the critical value. Null hypothesis is rejected and alternate hypothesis is accepted						

From table 5.34, is observed that there is change in flow for all the links. And thus null hypothesis is rejected. Table 5.34 shows the hypothesis test result for delay analysis.

Table 5.35 Hypothesis testing for delay

Statistical Parameters	Link-1	Link-2	Link-3	Link-4	Link-5	Link-6	Link-7
\bar{x}_1 (Sec)	17.03	46.22	28.6	27.99	9.654	24.4	26.48
\bar{x}_2 (Sec)	5.75	41.55	23.76	20.36	6.644	15.34	22.64
S_1 (Sec)	3.5	8.638	6.73	5.286	2.91	3.623	7.353
S_2 (Sec)	1.35	9.488	6.29	3.623	3.23	6.492	6.7
n_1 (Sec)	65	66	65	64	65	66	66
n_2 (Sec)	65	66	66	65	66	65	66
σ ($\bar{x}_1 - \bar{x}_2$) at 95% confidence interval (Sec)	0.912	3.095	2.231	1.56	1.05	1.8	2.4
Observed difference of mean (Sec)	11.28	4.67	4.84	7.63	3.01	9.06	3.84
Decision: Observed value is greater than the critical value. Null hypothesis is rejected and alternate hypothesis is accepted							

From the table 5.35, it is observed that there is a change in delay for all the links. And thus the null hypothesis is rejected. Table 5.35 shows the hypothesis test result for noise analysis.

Table 5.36 Hypothesis testing for noise level

Statistical Parameters	Link-1	Link-2	Link-3	Link-4	Link-5	Link-6	Link-7
\bar{x}_1 dB(A)	98.03	98.19	93.84	96.28	102.07	96.46	101.3
\bar{x}_2 dB(A)	91.05	92.22	91.7	92.27	94.01	94.01	95.83
S_1 dB(A)	4.29	3.35	3.8	3.9	5.3	4.24	3.86
S_2 dB(A)	7.01	6.9	7.04	7.1	7.76	7.42	6.77
n_1	96	87	89	80	90	85	94
n_2	150	145	149	150	150	150	150
σ ($\bar{x}_1 - \bar{x}_2$) at 95% confidence	1.79	1.83	1.84	1.92	2.02	1.9	1.74
Observed difference of mean dB(A)	5.98	5.97	2.14	4.01	8.06	2.45	5.47
Decision: Observed value is greater than the critical value. Null hypothesis is rejected and alternate hypothesis is accepted.							

From the table 5.36, it is observed that there is a change in noise for all the links. And thus the null hypothesis is rejected. Table 5.36 shows the hypothesis test result for all three parameters i.e., flow, delay and noise level for all the links of the study area.

Table 5.37 Hypothesis testing for flow, delay and noise for all the links

Statistical Parameters	Flow	Delay	Noise
\bar{x}_1	1397.15 (PCU/hr)	21.059 (sec)	96.91 dB(A)
\bar{x}_2	1778.9 (PCU/hr)	14.83 (sec)	93.33 dB(A)
S_1	653.18 (PCU/hr)	11.56 (sec)	4.94 dB(A)
S_2	589.55 (PCU/hr)	12.67 (sec)	7.33 dB(A)
n_1	586	467	621
n_2	720	712	1044
$\sigma (\bar{x}_1 - \bar{x}_2)$ at 95% confidence interval	124.73 (PCU/hr)	1.4018 (sec)	0.183 dB(A)
Observed difference of mean	381.79 (PCU/hr)	6.22 (sec)	3.583 dB(A)
Decision: Observed value is greater than the critical value. Null hypothesis is rejected and alternate hypothesis is accepted.			

From the hypothesis testing, it is evident that the observed value is greater than the critical value. So null hypothesis (i.e. there is no significant change in flow, delay and noise level after construction stage) is rejected. Alternate hypothesis (i.e., there is significant change in flow, delay and noise level after construction stage) is accepted.

5.18 Summary

In this chapter, the prediction model development and validation using regression is carried out. The prediction model is developed for flow, delay and noise level for during and after construction stage of metro rail. The model parameters and their coefficients are also checked using t-stat value and p-value. The performance of the model is also checked using the statistical test ANOVA. Model performance parameters selected in the study are R^2 value, RMSE and RSR. Cross-validation techniques is also employed to evaluate the model's robustness. The hypothesis testing is also carried out. It shows that there is significant change in the impacts after construction stage.

Chapter- 6

Summary and Conclusion

6.1 General

The research work has been carried out on the busy streets of metro rail corridor. Data collection took 3 years to cover “during and after” impacts. In 2018 and 2019, during the construction stage, travel time, speed, flow and noise data had been collected. On the same locations, data had been collected in 2022, after the construction stage. (i.e., after removal of work zone restrictions).

6.2 Summary

- Work zone significantly affects traffic flow operations in urban roadway. Due to the construction of metro rail project, many disruptive situations arise, when the existing traffic lane is affected by construction work. Long-term work zone leads to many traffic problems like reduction in capacity, increase in delay and increase in noise level.
- First, the study area had been selected where the construction work zone effects are observed. Here, the study was carried to study the impact of construction work zone on traffic and noise level. So, the data were collected during the construction work zone and after the removal of restriction of work zone.
- Various parameters affecting traffic flow, delay and noise level were identified. Data were collected for morning, noon and evening peak hours of the day during and after construction stage. The relationships were established among the dependent variable and independent variables. Again the hypothesis testing was carried out to study the significant change in during and after construction stage.

6.3 Conclusion

This research work has explored various impacts of construction work zone of metro rail project in the selected study area. From in-depth analysis, the objectives of the thesis are achieved. The findings of the study are summarized below.

6.3.1 Traffic Flow analysis

(a) During construction stage

- From Stadium crossroad to Thaltej crossroad, the proportion of TW varies between 52

% and 78%, car varies between 7 % and 29% and auto varies from 13% to 15 %. Two wheeler is the dominant mode of transportation.

- From the observed data, the maximum flow rate is obtained on the link of Gurukul crossroad to Sunrise Park crossroad having the value of 3113 PCU/hr. The link is surrounded by many commercial and shopping centres. The minimum flow rate is observed at the link of Stadium crossroad to Commerce cross road having the value of 849 PCU/hr. The link is surrounded by residential type of land use. During the constitution stage the available carriageway width was just 3.5 m which restricted the use of large size vehicles.
- From the observed data, the maximum SMS is obtained on the link of Sal crossroad to Thaltej crossroad having the value of 34.63 kmph. Sal crossroad to Thaltej crossroad link is a connecting link to the Sarkhej-Gandhinagar highway. Sal crossroad to Thaltej crossroad link is comparatively less surrounded by commercial type of land use. The minimum speed is obtained on the link of Gurukul crossroad to Sunrise Park crossroad having the value of 19.63 kmph. The available carriageway width was 9.0 m during construction stage against 11.5 m of actual width. This link is surrounded by shopping mall, Swaminarayan Gurukul temple, Drive in Cinema and many shops which hindered the smooth flow of traffic and affected the speed.
- For the speed-flow relationship, the outer envelope is considered to get Q_{max} . From the speed-flow curve, the maximum value of Q_{max} as 3900 PCU/hr is obtained on the link of Gurukul crossroad to Sunrise Park crossroad. The minimum value of Q_{max} as 1015 PCU/hr is obtained on Stadium crossroad to Commerce crossroad. The speed at Q_{max} obtained on the Sal crossroad to Thaltej crossroad, which is highest, 33 kmph while speed at Q_{max} on Stadium crossroad to Commerce crossroad is found lowest, 16 kmph.
- From the developed model during construction stage, it is observed that the major factors affecting flow are TW, car, SMS, and ALW.

(b) After Construction stage

- After construction stage, it is observed that the dominant mode of transportation is two wheeler. From Stadium crossroad to Thaltej crossroad, the proportion of TW varies between 60% and 76%, car varies between 10% and 13% and auto varies between 9% and 13%.
- From the observed data, the maximum flow is obtained on the link of Gurukul

crossroad to Sunrise Park crossroad having the value of 3161 PCU/hr. As stated earlier this link is surrounded by commercial type of land use, the flow values is coming out maximum on this link. Same way, the minimum flow is observed at the link of Stadium crossroad to Commerce crossroad having the value of 1458 PCU/hr which is surrounded by residential type of land use. The available carriageway width was increased to 7.1 m. As compared to rest of the link, this link has the least carriage way width.

- From the observed data, the maximum SMS is obtained on the link of Sal crossroad to Thaltej crossroad having the value of 36.09 kmph. As stated earlier, Sal crossroad to Thaltej crossroad link is a connecting link to the Sarkhej-Gandhinagar highway. Sal crossroad to Thaltej crossroad link is comparatively less surrounded by commercial type of land use. The minimum speed is obtained on the link of Stadium crossroad to Commerce crossroad having the value of 27.51 kmph. The available carriageway width of the link was 7.1 m which was the minimum as compared to all the links of the study area.
- Form the Speed-flow curve, the maximum flow Q_{max} is obtained on the link of Gurukul crossroad to Sunrise Park crossroad of 4250 PCU/hr and minimum value of Q_{max} is obtained on the link of Stadium crossroad to commerce crossroad of 1700 PCU/hr. The speed at Q_{max} obtained on the Sal crossroad to Thaltej crossroad is found highest having value of 34 kmph while speed at Q_{max} on Stadium crossroad to Commerce crossroad is found lowest, 25 kmph.
- From the analysis, it is found that the increase in the flow is observed after construction stage due to the opening of lane which was previously closed during the construction stage. Maximum increased flow is observed on Stadium crossroad to Commerce Crossroad link and minimum increased flow is observed on Gurukul crossroad to Sunrise Park crossroad.
- From the developed model after construction stage, it is observed that the major factors affecting flow are TW, car and ALW.

To study the capacity and flow, various researchers have considered variables such as, speed, lane width, work zone type, work zone activity, proportion of heavy vehicles etc. From the literature review, it is observed that speed and proportion of heavy vehicles play an important role for estimating the capacity or flow specially in case of freeway work zone condition. In the present study the major factors affecting flow are speed, two wheeler and

car. In the literature, various techniques are used for estimating flow and capacity such as speed-flow relationship, regression analysis, simulation, ANN etc. In the present study, speed-flow relationship and regression analysis are used for analysing the impact of construction work zone on traffic flow.

6.3.2 Delay Analysis

(a) During Construction stage

- Percentage of 2W varies between 55% and 79.7%. Percentage of auto varies between 7.7% and 15.6%. Percentage of car varies between 7.3% and 32%. Other categories of vehicles are in small amount.
- Thaltej crossroad to Sal crossroad link has the highest speed of 26.07 kmph. The link had uniform carriageway width of 6.0 m. This link is a connected to the Gandhinagar-Sarkhej highway. This link is partially surrounded by open area. Helmet crossroad to Saurabh crossroad link has the lowest speed of 22.42 kmph. The main reason is that the Helmet intersection is major intersection connecting two major roads. This intersection has also BRTS corridor. Immediately after leaving the Helmet intersection, there was slow moving traffic due to the metro station construction work.
- The links have varying length. So, the delay per km has been calculated. Maximum delay is observed on Helmet crossroad to Saurabh crossroad link having delay as 58.68 sec/km/veh. The major reason for delay is heavy traffic flow leaving from the Helmet junction. The minimum delay is observed on Vijay crossroad to Commerce crossroad having delay as 31.53 sec/km/veh. The link is surrounded by residential area partially. Moreover, the slow moving vehicle proportion is low on this link.
- The relationship between speed and delay is negative exponential.
- Factors affecting delay during construction stage are length, ALW, flow and speed.

(b) After construction stage

- Percentage of 2W varies between 57.29% and 77.29%. Percentage of auto varies between 7.65% and 15.6%. Percentage of car varies between 10.42% and 33.45%. Other categories of vehicles are in small amount.
- Saurabh crossroad to Vijay crossroad link has the highest speed of 41.02 kmph. Gurukul crossroad to Helmet crossroad link has the lowest speed of 23.76 kmph. This link is surrounded by many hospitals, shops, malls and temple.

- The links have varying length. So, the delay per km has been calculated. Maximum delay is observed on Gurukul crossroad to Helmet crossroad link having delay as 55.51 sec/km/veh. The minimum delay is observed on Vijay crossroad to Commerce crossroad having delay as 11.30 sec/km/veh. The relationship between speed and delay is negative exponential.
- Factors affecting delay after construction stage are length, speed, flow.

To study the delay in work zone condition, various researchers have considered variables such as, speed, lane width, work zone type, work zone activity, proportion of heavy vehicles etc. From the literature review, it is observed that speed, type of lane closure and proportion of heavy vehicles play an important role for estimating delay. In the present study the major factors affecting delay are speed, length of work zone and flow. In the literature, various techniques are used for estimating delay such as regression analysis, simulation, ANN etc. In the present study, regression analysis is used for analysing the impact of construction work zone on delay.

6.3.3 Noise Level Analysis

The noise level analysis has been carried out for during and after the construction stage. Here, it is important to note that the major construction activities were carried out during night time. So the effect of construction activity on the noise level during day time is very less. Vehicular noise is the major source of noise on highly congested street in urban area.

(a) During construction stage

- Maximum Leq is observed at Gurukul crossroad to Sunrise Park crossroad link having the value of 102.07 dB(A) during construction. Minimum Leq is observed at Vijay crossroad to Helmet crossroad link having the value of 96.31 dB(A) during construction stage.
- L₁₀ is associated with traffic induced ambient environmental noise level. Maximum L₁₀ is observed at Sal crossroad to Thaltej crossroad link having the value of 106.24 dB(A) during construction stage. Minimum L₁₀ is observed at Vijay crossroad to Helmet crossroad link having the value of 99.65 dB(A).
- Major factors affecting noise level during construction are TW, car, Auto, honking and LCV.

(b) After construction stage

- Maximum Leq is observed at Sal to Thaltej crossroad link having the value of 98.22 dB(A) after construction stage. Minimum Leq is observed at Vijay to Helmet crossroad link having the value of 93.84 dB(A) during construction stage.
- Maximum L₁₀ is observed at Sal to Thaltej crossroad link having the value of 101.16 dB(A) after construction stage. Minimum L₁₀ is observed at Vijay to Helmet crossroad link having the value of 97.11 dB(A). Major factors affecting noise level after construction are honking, TW, SMS and car.

Honking is indeed a hidden factor that can contribute to increased noise levels in urban areas, including construction work zones. Honking is often a response to traffic congestion or delays caused by construction work zones. When drivers become frustrated due to traffic disruptions, they may engage in aggressive driving behaviours, including excessive honking. Here, it is concluded that the noise level in the study area before and after construction stage are higher than the standard noise limit in urban area which is 65 dB(A) in a commercial area during day time recommended by central pollution control board.

From the analysis, it is observed that there is a reduction in noise level after removal of restriction from the study area. Maximum reduction in noise level is observed at Gurukul crossroad to Sunrise Park crossroad link. Here, it is important to note that the noise levels during and after construction stage are very much higher than that of the standards provided by central pollution control board, India. Urban areas are characterized by high population density, with a larger number of people living in a confined space. This leads to increased human activities, such as traffic, construction, and commercial activities, resulting in higher noise levels. The study area is surrounded with commercial activities, including offices, markets, and entertainment venues.

The R² value of all the models are coming out good. For the validation of the model, R² value for observed vs predicted value and RSR are considered as model performance parameters. It is evident that available carriage way width is significant variable for the flow and delay. But for the noise level, the most significant variable is honking event.

The results have revealed several key findings. Firstly, the presence of metro rail construction work zones has a significant impact on traffic flow, leading to congestion and delays in affected areas. Additionally, the study highlights the impact on noise level. The construction work zone area i.e., restricted area has significant impacts on flow, delay and noise level.

6.4 Suggestions

Based on the findings of the thesis the following suggestions can be made to mitigate the negative effects of metro rail construction on urban road traffic and noise levels.

- Optimize signal timings and road capacity to improve traffic flow during construction phases.
- Utilize intelligent transportation systems and real-time traffic monitoring to promptly address congestion issues.
- Conduct thorough traffic impact assessments prior to construction to identify
- Implement noise control measures, such as erecting noise barriers or soundproofing structures near work zone.
- Enforce regulations on unnecessary honking event.
- Conduct regular noise monitoring and address any exceedances promptly.
- Provide timely and accurate information about construction timelines, traffic diversions, and noise mitigation efforts through various communication channels.

6.4.1 Recommendation

From the research, following points can be recommended for construction work zone area.

- Develop comprehensive traffic management plans in coordination with relevant authorities and stakeholders.
- Implement effective diversion routes and alternate transportation options to reduce congestion and minimize travel disruptions.
- Ensure clear signage and communication to inform drivers of construction-related changes and detours.

6.4.2 Application of study

The outcome of conducted research gives useful relationship among the various variables. It can be applied to estimate and quantify the impact of construction work zone area on road traffic flow, delay and noise level.

6.5 Contribution of the thesis

- During preparation of DPR (detailed project report) of any transportation infrastructure project, in the Cost-Benefit analysis of economic evaluation of transportation project, the cost component should be included for the negative impacts of construction work

zone on the existing traffic. The quantification of impacts can be utilized for Cost-Benefit analysis of the project. This research throws light on the negative effects of construction work zones, such as decreased traffic flow, increased delay and increased noise level. From the study, it can be concluded that per link per direction of traffic, (1) reduction in traffic flow can be estimated as about 76 PCU/hr per 1000 sq. m increase in restricted area, (2) increase in delay can be estimated as about 1.3 sec/veh per 1000 sq. m increase in restricted area and (3) increase in noise level can be estimated as 2.00 dB(A) per three min per 1000 sq. m increase in restricted area.

- Development is a critical issue that has received the majority of people's attention. It is widely assumed that development can have both positive and negative consequences. During the research, significant impacts were observed on traffic flow, delay and noise level in study area. Nowadays, everyone is concerned about the environment and its sustainability at both the micro and macro levels. The sustainable development goals adopted by United Nations (2015) has also considered city sustainability as one of the goals, which focuses on reducing per capita environmental/economic/health impact of cities and making green and public space more accessible to the society.

6.6 Limitations

The analysis was carried out using a particular case study or a small number of work zones, so it is possible that not all metro rail construction projects will benefit equally from the conclusions. The data such as pavement condition, diverted traffic and road gradient could not be covered in the analysis. The non-linear regression analysis and simulation could not be applied in the research work. Furthermore, while the study mainly examined the immediate effects of construction, more research is needed to determine the long-term effects on the traffic environment.

6.7 Future Scope

Future research on the effects of metro rail construction work zone on urban road traffic could go in a number of directions, according to the study's findings. These include long-term impact assessments, the integration of emerging technologies, policy and planning considerations, driver behaviour and safety, predictive modelling and simulation, environmental pollution, accidents, impact on network flow, and so on.

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List of Publications

- 1) T. Vyas and H. R. Varia, "Predicting traffic induced noise using artificial neural network and multiple linear regression approach," International Journal of Advanced Technology and Engineering Exploration, vol. 9, no. 92, pp. 1009-1027, 2022. ISSN(Print): 2394-5443 ISSN(Online) :2394-7454
[DOI:10.19101/IJATEE.2021.875512](https://doi.org/10.19101/IJATEE.2021.875512).
- 2) T. Vyas , S. Parmar and H. Varia, "Estimating Traffic Induced Noise in Urban Area: An Overview," Zeichen Journal, vol. 8, no. 03, pp. 487-495, 2022.
[DOI:15.10089.ZJ.2022.V8I03.285311.2746](https://doi.org/10.10089/ZJ.2022.V8I03.285311.2746)
- 3) T. Vyas and H. R. Varia, "A Review on Impact of Traffic Work zone on Capacity and Delay," Compliance Engineering Journal, vol. 11, no. 2, pp. 427-436, 2020. UGC-CARE Approved Group 'II' Journal. ISSN No.: 0898-3577.
[DOI: 16.10089.CEJ.2020.V11I1.285311.2944](https://doi.org/10.10089.CEJ.2020.V11I1.285311.2944)

Data Entry in MS Excel

Stadium to commerce																		
Time	t/w	car	auto	cycle	bus hv	LCV	vehicle/3veh/hr	PCU/3m	PCU/hr	%t/w	%bus	%cycle	%LCV	%car	%Auto	speed(m/	speed(km/	
3	31	3	4	0	1	2	41	820	26.6	532	75.60976	0	2.439024	4.878049	7.317073	9.756098	5.605381	20.17937
6	35	6	7	0	1	0	49	980	28.4	568	71.42857	0	2.040816	0	12.2449	14.28571	5.938242	21.37767
9	28	5	3	0	0	0	36	720	19	380	77.77778	0	0	0	13.88889	8.333333	5.112474	18.40491
12	30	5	11	0	0	0	46	920	30.9	618	65.21739	0	0	0	10.86957	23.91304	6.053269	21.79177
15	35	7	10	0	1	2	55	1100	40.4	808	63.63636	0	1.818182	3.636364	12.72727	18.18182	4.570384	16.45338
18	34	6	9	0	0	1	50	1000	33.9	678	68	0	0	2	12	18	8.77193	31.57895
21	27	5	8	0	0	0	40	800	25.65	513	67.5	0	0	0	12.5	20	6.25	22.5
24	32	3	5	0	2	0	42	840	21.9	438	76.19048	0	4.761905	0	7.142857	11.90476	6.459948	23.25581
27	27	2	6	0	2	0	37	740	20.55	411	72.97297	0	5.405405	0	5.405405	16.21622	6.188119	22.27723
30	46	5	6	0	2	1	60	1200	33.6	672	76.66667	0	3.333333	1.666667	8.333333	10	4.520796	16.27486
33	33	3	7	0	0	0	43	860	24.35	487	76.74419	0	0	0	6.976744	16.27907	6.203474	22.33251
36	41	6	2	0	2	1	52	1040	27.25	545	78.84615	0	3.846154	1.923077	11.53846	3.846154	9.191176	33.08824
39	33	1	5	0	1	0	40	800	19.9	398	82.5	0	2.5	0	2.5	12.5	8.741259	31.46853
42	38	1	4	0	0	0	43	860	19.9	398	88.37209	0	0	0	2.325581	9.302326	7.002801	25.21008
45	26	3	7	0	1	0	37	740	22.25	445	70.27027	0	2.702703	0	8.108108	18.91892	5.29661	19.0678
48	29	5	1	0	2	0	37	740	17.25	345	78.37838	0	5.405405	0	13.51351	2.702703	5.980861	21.53111
51	47	5	2	0	1	1	56	1120	28	560	83.92857	0	1.785714	1.785714	8.928571	3.571429	6.410256	23.07692
54	36	2	4	0	3	0	45	900	21.25	425	80	0	6.666667	0	4.444444	8.888889	8.650519	31.14187
57	34	3	2	0	2	0	41	820	18.4	368	82.92683	0	4.878049	0	7.317073	4.878049	6.793478	24.45652
60	37	7	5	0	1	0	50	1000	27.3	546	74	0	2	0	14	10	6.426735	23.13625
63	47	5	2	0	1	1	56	1120	28	560	83.92857	0	1.785714	1.785714	8.928571	3.571429	6.410256	23.07692
66	38	4	7	0	1	0	50	1000	27.45	549	76	0	2	0	8	14	8.223684	29.60526
69	16	4	4	0	1	0	25	500	15.55	311	64	0	4	0	16	16	6.648936	23.93617
72	24	4	10	0	1	1	40	800	30.15	603	60	0	2.5	2.5	10	25	5.827506	20.97902
75	45	3	11	0	0	0	59	1180	34.15	683	76.27119	0	0	0	5.084746	18.64407	6.203474	22.33251
78	29	5	10	0	1	2	47	940	36.3	726	61.70213	0	2.12766	4.255319	10.6383	21.2766	6.6313	23.87268
81	23	3	12	0	2	0	40	800	28.55	571	57.5	0	5	0	7.5	30	6.510417	23.4375
84	30	6	8	0	2	0	46	920	28.4	568	65.21739	0	4.347826	0	13.04348	17.3913	6.25	22.5
87	31	3	2	0	1	0	37	740	17	340	83.78378	0	2.702703	0	8.108108	5.405405	7.352941	26.47059
90	30	4	9	0	1	1	45	900	30.85	617	66.66667	0	2.222222	2.222222	8.888889	20	6.25	22.5
93	41	3	6	0	2	0	52	1040	26.45	529	78.84615	0	3.846154	0	5.769231	11.53846	5.681818	20.45455
96	34	5	2	0	1	2	44	880	26.85	537	77.27273	0	2.272727	4.545455	11.36364	4.545455	6.399862	23.0179
99	33	2	7	0	2	0	44	880	24.05	481	75	0	4.545455	0	4.545455	15.90909	6.082725	21.89781
102	32	3	9	0	1	0	45	900	27.15	543	71.11111	0	2.222222	0	6.666667	20	7.836991	28.21317

Data entry in MS Excel

MORNING PEAK HOUR												NOON HOUR												EVENING PEAK HOUR												
2W		3W		4W		BUS		LCV		HCV		2W		3W		4W		BUS		LCV		HCV		2W		3W		4W		BUS		LCV		HCV		
LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE	LISENCE PLATE			
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eg man	66	4528	80	342	71	1323	85	5403	62		85	6306	62	1993	92	7412	54	6039	82	8962	74	89	1029	58	4739	59	4955	56	4791	59	1012	62	8316	84		
eck bag	61	3233	81	7911	71	4471	90		65		86	3605	52	4963	85	9767	56	1035	86	7166	75	87	125	57	2269	64	438	55	1420	67	9731	59		82		
9171	72	9587	79	7577	70	4469	89		64		89	1715	56	3837	69	3493	58		87	133	70	86	6379	56	8384	55	3825	52	2882	51	2940	77		87		
2 girls	63	saunt	78	7575	74	425	85		68		90	952	50	6795	75	2855	59		83	8702	69	90	2022	59	2911	52	1004	50		56	9206	62		85		
5861	68	5362	77	6790	69	1044	91		70		87	2526	52	7166	98	2203	51		82	5809	75	85	4640	73	7942	71	8712	49	549	62	2917	73		87		
svenger	59	poster	66	6095	71	1872	92		71		86	6195	50	9462	77	3532	52		79	95	72	86	126	52	2482	51	5461	57	1025	61		68		86		
	56	9121	60	3880	75		90		66	AVG.TRV	86.429	6916	59	7543	82	247	54		79	75	avg.trav	86.857	madam	55		55	6062	60		68		66		88		
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	57		67		68		89		68		68	3507	68		74		58							5668	59		56	7304	58		66		62			
	56		66		64		85		66		66	8303	49		80		59							3389	61		61	9390	56		63		61			
	55		65		67		90		62		62	3844	50		79		45							3289	62		61	5700	61		62		65			
	68		61		69		88		66		66	4744	55		68		44							5354	68		63	2250	62	AVG.TRV	63.769	65.962				
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	62		58		66							42		78		46										53		52		55						
	62		59		61							48		79		51										52		54		52						

	A	B	C	D	E	F	G	H	I	J	K	L	M
Thaltej-Sal													
				ALW	Length	2W	3W	CAR	LCV	HV	Flow	delay	speed
1	thal-sal	M	3	11.50	455.00	61.50	9.00	28.50	1.00	0.00	1584.60	21.35	26.31
2	thal-sal	M	6	11.50	455.00	62.14	8.74	29.13	0.00	0.00	1560.00	23.67	25.34
3	thal-sal	M	9	11.50	455.00	64.43	8.76	26.80	0.00	0.00	1434.60	14.31	29.58
4	thal-sal	M	12	11.50	455.00	59.52	12.86	27.62	0.00	0.00	1674.60	15.34	29.19
5	thal-sal	M	15	11.50	455.00	58.04	12.05	29.91	0.00	0.00	1803.60	15.24	28.89
6	thal-sal	M	18	11.50	455.00	61.19	11.44	26.37	0.00	1.00	1661.40	16.36	28.69
7	thal-sal	M	21	11.50	455.00	59.47	11.58	28.95	0.00	0.00	1504.20	19.85	27.15
8	thal-sal	M	24	11.50	455.00	56.73	9.62	33.65	0.00	0.00	1671.60	14.37	29.61
9	thal-sal	M	27	11.50	455.00	62.14	9.71	28.16	0.00	0.00	1569.60	19.46	27.14
10	thal-sal	M	30	11.50	455.00	59.67	8.29	30.39	1.66	0.00	1488.00	19.51	27.60
11	thal-sal	M	33	11.50	455.00	60.11	6.91	32.98	0.00	0.00	1437.00	17.39	28.01
12	thal-sal	M	36	11.50	455.00	60.23	7.60	30.99	1.17	0.00	1368.60	23.50	25.54
13	thal-sal	M	39	11.50	455.00	57.44	9.23	32.31	1.03	0.00	1610.40	19.14	27.57
14	thal-sal	M	42	11.50	455.00	55.94	10.89	32.18	0.00	0.99	1746.60	21.28	26.25
15	thal-sal	M	45	11.50	455.00	60.47	7.91	31.63	0.00	0.00	1647.60	18.12	27.86
16	thal-sal	M	48	11.50	455.00	48.33	10.00	40.00	1.67	0.00	1654.20	17.09	28.16
17	thal-sal	M	51	11.50	455.00	58.71	8.96	32.34	0.00	0.00	1578.00	20.22	26.81
18	thal-sal	M	54	11.50	455.00	57.21	8.96	33.83	0.00	0.00	1601.40	19.44	27.58
19	thal-sal	M	57	11.50	455.00	52.63	11.96	34.45	0.00	0.96	1868.40	15.99	28.94
20	thal-sal	M	60	11.50	455.00	56.65	11.33	32.02	0.00	0.00	1649.40	15.01	29.10
21	thal-sal	M	63	11.50	455.00	55.98	11.00	32.06	0.96	0.00	1763.40	14.10	29.68
22	thal-sal	M	66	11.50	455.00	57.97	9.66	32.37	0.00	0.00	1644.00	16.32	29.01
23	thal-sal	M	69	11.50	455.00	63.78	12.60	23.62	0.00	0.00	969.00	20.88	26.64
24	thal-sal	M	72	11.50	455.00	63.71	7.26	28.23	0.00	0.81	964.20	17.20	27.91
25	thal-sal	M	75	11.50	455.00	70.24	19.64	19.64	0.00	0.00	1177.20	16.41	29.10
26	thal-sal	M	78	11.50	455.00	68.63	19.61	19.61	0.00	0.00	1103.40	19.60	27.60
27	thal-sal	M	81	11.50	455.00	70.59	17.65	17.65	0.00	0.00	1200.00	17.56	28.54
28	thal-sal	M	84	11.50	455.00	70.63	16.88	16.88	0.00	0.00	1134.60	21.74	26.67
29	thal-sal	M	87	11.50	455.00	66.67	22.84	22.84	0.00	0.00	1183.20	15.68	29.47
30	thal-sal	M	90	11.50	455.00	57.69	29.23	29.23	0.00	0.00	1056.60	14.84	29.90
31	thal-sal	M	93	11.50	455.00	65.33	23.33	23.33	0.00	0.00	1117.20	21.14	26.92
32	thal-sal	M	96	11.50	455.00	71.52	15.82	15.82	0.00	1.27	1199.40	9.39	32.91
33	thal-sal	M	99	11.50	455.00	68.21	18.54	18.54	0.00	0.00	1104.60	14.08	30.30
34	thal-sal	M	102	11.50	455.00	60.00	22.76	22.76	1.38	0.00	1229.40	16.10	29.31
35	thal-sal	M	105	11.50	455.00	67.26	22.02	22.02	0.00	0.00	1221.00	18.61	28.08
36	thal-sal	M	108	11.50	455.00	70.66	19.16	19.16	0.00	0.00	1165.20	16.81	28.90
37	thal-sal	M	111	11.50	455.00	76.22	16.46	16.46	0.00	0.00	1050.60	17.90	28.38
38	thal-sal	M	114	11.50	455.00	62.18	25.64	25.64	1.28	0.00	1254.60	14.51	30.07
39	thal-sal	M	117	11.50	455.00	66.47	20.23	20.23	0.00	0.00	1289.40	9.39	32.91
40	thal-sal	M	120	11.50	455.00	65.87	19.76	19.76	1.20	1.20	1398.00	18.96	27.89
41	thal-sal	N	3	11.50	455.00	65.19	20.99	20.99	0.00	0.00	1371.60	14.35	30.16
42	thal-sal	N	6	11.50	455.00	71.43	14.29	14.29	0.00	0.00	1145.40	17.66	28.49
43	thal-sal	N	9	11.50	455.00	59.47	13.16	27.37	0.00	0.00	1518.60	15.23	28.93
44	thal-sal	N	12	11.50	455.00	64.65	11.62	22.73	0.00	1.01	1586.40	19.32	27.01
45	thal-sal	N	15	11.50	455.00	63.38	18.88	24.88	0.04	0.00	1671.60	15.13	28.88

Data Entry in MS Excel

Stadium to Commerce (Morning)

Time	Noise Level	Honking	T/W	Car	HV	Auto	LCV	SMS	Flow
09:03	104.1	3	68	12	0	14	2	25.90	1251
09:06	98.7	1	69	15	0	12	0	27.81	1119
09:09	101.9	2	59	11	0	14	0	22.88	1046
09:12	85.5	1	68	9	0	16	1	23.41	1193
09:15	98.6	2	69	11	1	11	1	25.55	1195
09:18	93.7	1	72	8	0	13	0	24.01	1035
09:21	89.6	1	58	10	0	11	1	26.37	982
09:24	100.8	3	62	9	0	11	1	23.90	1004
09:27	97.6	2	70	15	0	11	1	24.85	1180
09:30	89.7	1	68	7	0	15	0	23.07	1043
09:33	99.6	3	64	13	1	14	2	29.02	1338
09:36	91.5	1	62	8	0	12	0	25.54	972
09:39	96.7	2	72	11	0	12	1	23.43	1142
09:42	94.4	1	57	9	0	13	0	23.39	950
09:45	101.7	3	65	14	0	16	1	26.13	1251
09:48	96.7	2	62	11	0	17	1	21.25	1205
09:51	89.8	1	63	10	0	12	1	21.63	1052
09:54	95.7	2	72	10	0	12	0	23.64	1054
09:57	94.8	1	64	12	0	14	1	24.17	1162
10:00	94.5	2	66	8	1	11	2	23.35	1175
10:03	86.6	1	68	11	0	10	1	20.70	1058
10:06	90.8	2	71	9	0	12	1	26.89	1081
10:09	105.8	4	61	9	0	10	3	25.06	1091
10:12	94.6	1	70	10	0	11	0	27.66	998
10:15	98.6	2	67	10	0	11	0	27.55	977
10:18	86.8	1	63	12	1	15	0	26.88	1203
10:21	92.7	2	58	11	0	9	1	22.92	960
10:24	85.3	1	64	8	0	13	1	23.07	1047
10:27	93.7	2	61	12	0	15	2	24.12	1230
10:30	100.4	3	68	7	0	14	0	25.38	1015
10:33	95.6	1	59	13	0	13	0	24.16	1044
10:36	88.7	1	65	10	0	16	1	26.11	1171
10:39	94.6	1	71	9	1	12	0	28.87	1115
10:42	87.9	1	67	11	0	11	0	27.71	997