



Impact Analysis of Metro Rail Construction Work Zone on Traffic Flow

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Abstract : Cities play a vital role in generating economic growth and prosperity. In India, 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 delay in the surrounding areas. The study focused on evaluating traffic patterns, including traffic volume, speed, travel time, and delay during and after the construction work zone. The prediction models for flow and delay are developed. For the developed models, two validation techniques i.e., cross validation and statistical validation are applied. The findings of the study revealed that the presence of a metro rail construction work zone resulted in noticeable disruptions to traffic flow during construction stage. The observed reduction in flow varies from 1 % to 11% on the majority links of the study area. The common factors affecting flow during and after construction stages are available lane width, space mean speed, proportion of car and proportion of two-wheeler.

Index Terms –traffic flow, work zone, regression, cross validation.

I. INTRODUCTION

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, with some metro projects 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 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.

During the execution of these projects, many times lane closure, partial lane closure are 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. A work zone is a stretch or area of a road where some construction, maintenance, or utility work is being done. The aim of this study is to understand and to analyze the impacts on traffic flow, due to presence of construction work zone on urban streets.

II. STUDY AREA AND DATA COLLECTION

2.1 Study Area

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 kilometers, of which approximately 6.5 kilometers are underground, and the remainder are elevated sections. With 2 corridors and 32 stations, the project will connect four corners of Ahmedabad. Figure 3.6 shows East-West Corridor. For traffic flow parameter analysis, Stadium crossroad to Thaltej crossroad approach was considered.



To study the Traffic flow parameters, Stadium to Thaltej crossroad has been divided in to 6 links. During construction stage of metro rail project, the lane width of the roads were partially closed. Tab. 1 shows the category of road, available lane width (ALW) and work zone width (WWZ) during construction stage. Here the link of Stadium crossroad to Commerce crossroad is 4 lane divided two-way sub arterial road, while rest of the links are 6 lane divided arterial road. 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.

Sr. No	Link Name	Type of Street	ALW during construction (m)	WWZ during construction (m)
1	Stadium crossroad to Commerce crossroad	Sub Arterial	3.5	3.6
2	Commerce crossroad to Vijay crossroad	Arterial	5.2	4.8
3	Vijay crossroad to Saurabh crossroad	Arterial	7	4.3
4	Saurabh crossroad to Helmet crossroad	Arterial	6.5	5.5.
5	Gurukul crossroad to Sunrise Park	Arterial	9	2.5
6	Sal crossroad to Thaltej crossroad	Arterial	7.5	4.0

3.1 Vehicle Composition during Construction Stage

Figure 2 displays six 3D pie charts showing the vehicle composition (mode share) for different origin-destination pairs. The charts are arranged in a 2x3 grid. The modes are: %TW (blue), %Auto (red), %Car (green), %LCV (purple), and %HV (cyan).

Origin-Destination Pair	%TW	%Auto	%Car	%LCV	%HV
Stadium-Commerce	77%	14%	8%	0%	1%
Commerce-Vijay	68%	15%	14%	1%	2%
Vijay-Saurabh	64%	15%	18%	1%	2%
Saurabh-Helmet	61%	15%	21%	1%	2%
Gurukul-Sunrise Park	66%	13%	19%	1%	1%
Sal-Thaltej	54%	14%	29%	1%	2%

Fig. 2 - Vehicle composition in the study area during construction stage (From Stadium to Sal crossroad)

Fig. 2 shows the vehicle composition of all the links during construction stage. From the figure; it is observed that for all the links two-wheelers have major proportion. From the videography, the flow data were extracted. The flow data have been collected for morning, noon, and evening peak hours.

*In the study, heavy vehicle (HV) word is used. In this category, number of buses, 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.

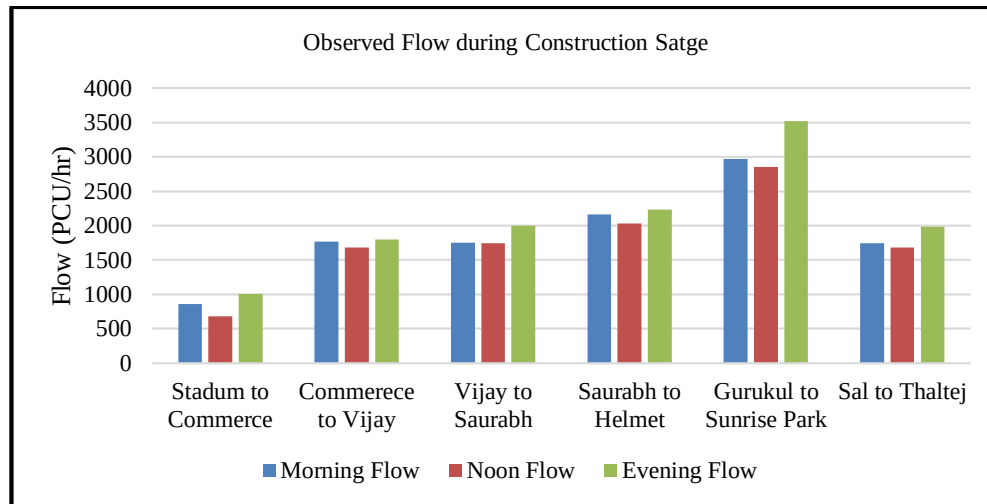


Fig. 3 - Observed flow during construction stage

From the Fig. 3, maximum flow is observed on the link on Gurukul to Sunrise Park. Stadium to commerce link has the minimum flow. The flow and speed are closely related with each other. The speed data is extracted from videography. The space mean speed on each link is determined. Fig. 4 shows the observed space mean speed (SMS) on each link.

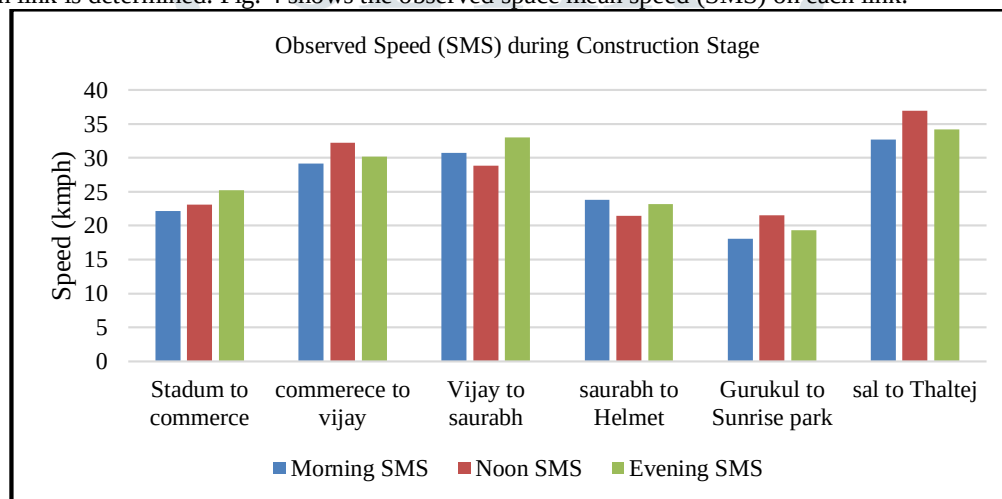


Fig. 4 - Observed speed during construction stage

From Fig. 4, maximum speed of 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.

3.2 Speed – Flow Relationship (During Construction)

The speed flow relationship has been developed by considering the outer envelope curve and thus maximum flow is obtained from the graph (Fig. 5 to Fig. 10).

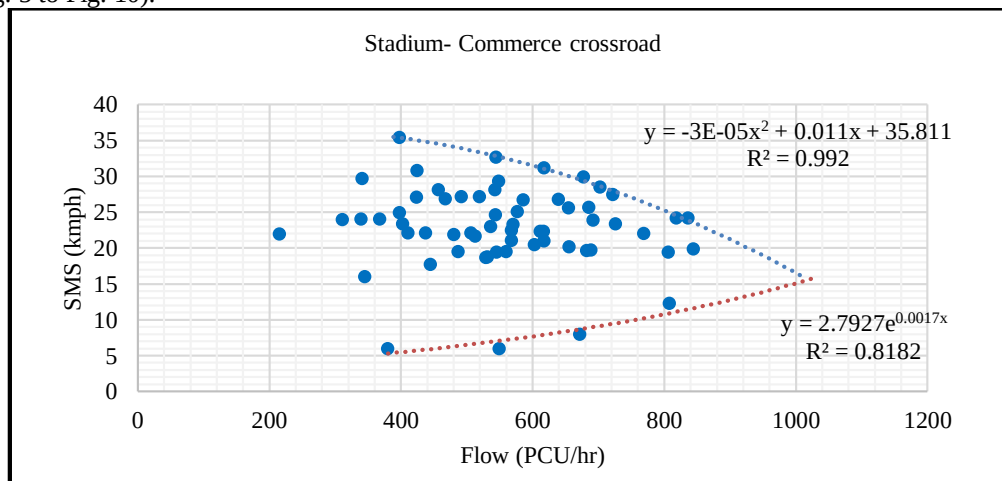


Fig. 5 - Speed-flow relationship during construction stage (Stadium to Commerce crossroad)

From the Fig. 5, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.992, while lower curve is following exponential relationship having R2 value as 0.8182. There is a reduction in speed as the flow increases. After that, the reduction in flow and speed is observed which is showing forced flow condition of traffic.

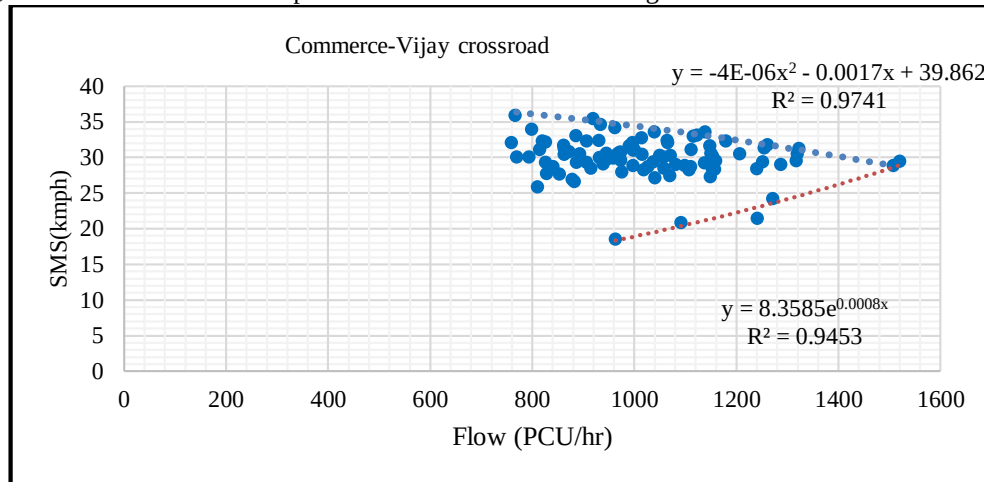


Fig. 6 - Speed-flow relationship during construction stage (Commerce to Vijay crossroad)

From the Fig. 6, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.9741, while lower curve is following exponential relationship having R2 value as 0.9453. There is a reduction in speed as the flow increases. After that, the reduction in flow and speed is observed which is showing forced flow condition of traffic. Speed-flow relation is developed for Vijay to Saurabh crossroad during construction stage, which is shown in Fig. 7.

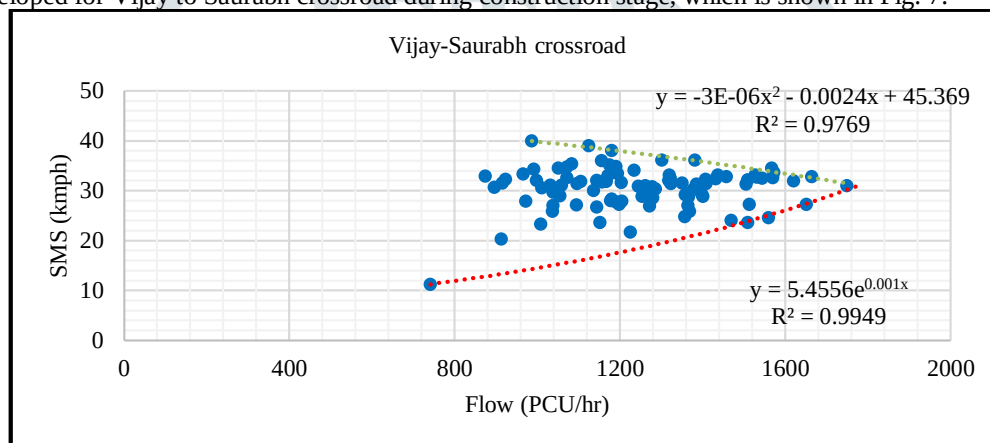


Fig. 7 - Speed-flow relationship during construction stage (Vijay to Saurabh crossroad)

From the Fig. 7, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.9769, while lower curve is following exponential relationship having R2 value as 0.9949. Speed-flow relation is developed for Saurabh to Helmet crossroad during construction stage, which is shown in Fig. 8.

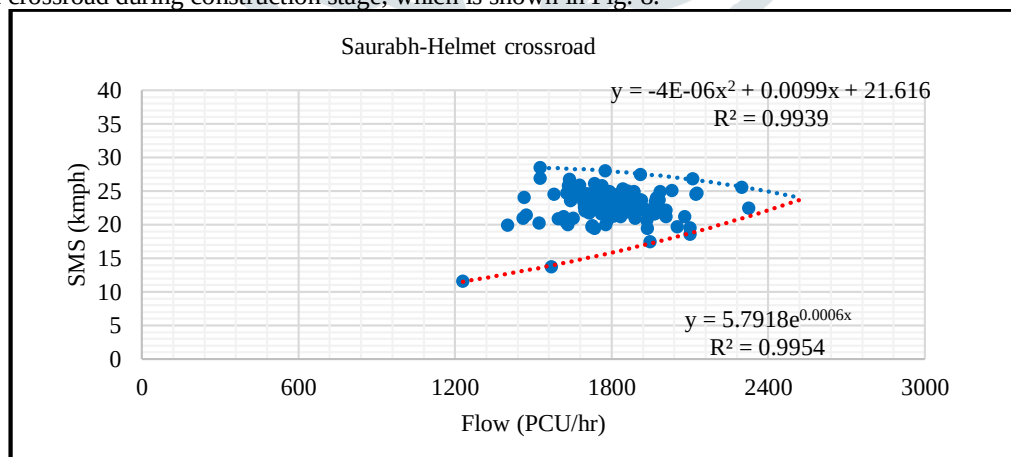


Fig. 8 - Speed-flow relationship during construction stage (Saurabh to Helmet crossroad)

From the Fig. 8, 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 Fig. 9.

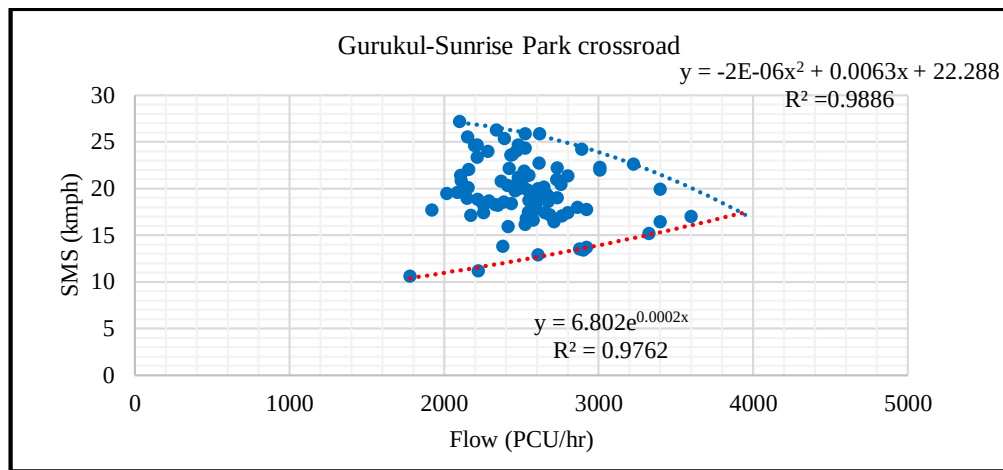


Fig. 9 - Speed-flow relationship during construction stage (Helmet to Sunrise Park crossroad)

From the Fig. 9, 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 Fig. 10.

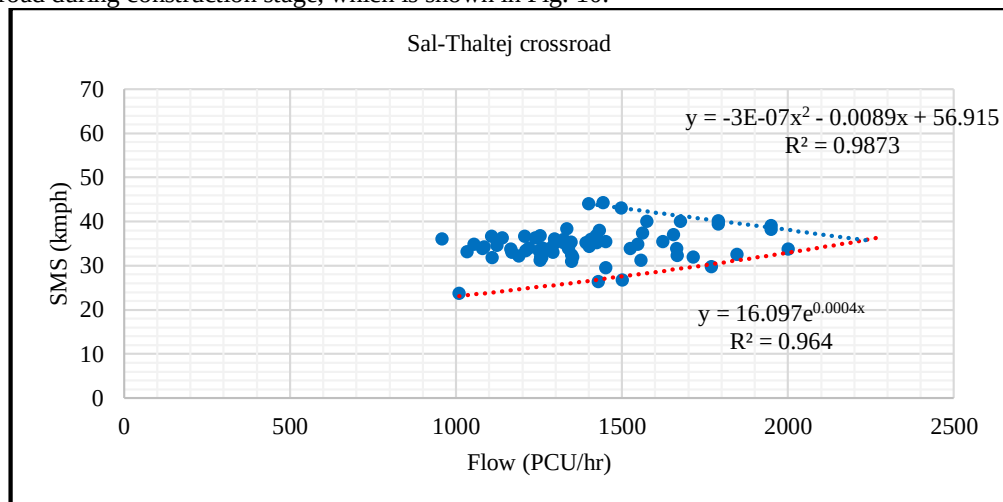


Fig. 10 - Speed-flow relationship during construction stage (Sal to Thaltej crossroad)

From the Fig. 10, 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.

Form the speed flow relationship of each link, the maximum flow (Q_{max}) is obtained, and the corresponding speed is obtained from the graph. Tab. 2 shows the summary of speed flow relationship of each link.

Tab. 2- Speed-Flow relationship summary during construction stage

Link	Speed- Flow Relationship (During construction stage)	R ²	Q _{max} (PCU/hr)	Speed@ Q _{max} (kmph)
1. Stadium to Commerce	$v = -3E-05x^2 + 0.011x + 35.811$	0.992	1015	16
	$y = 2.7927e^{0.0017x}$	0.8182		
2. Commerce to Vijay	$v = -4E-06x^2 - 0.0017x + 39.862$	0.9741	1520	29
	$y = 8.3585e^{0.0008x}$	0.9453		
3. Vijay to Saurabh	$v = -3E-06x^2 - 0.0024x + 45.369$	0.9769	1760	30
	$y = 5.4556e^{0.001x}$	0.9949		
4. Saurabh to Helmet	$v = -4E-06x^2 + 0.0099x + 21.616$	0.9939	2550	24
	$y = 5.7918e^{0.0006x}$	0.9954		
5. Gurukul to Sunrise Park	$v = -2E-06x^2 + 0.0063x + 22.288$	0.9886	3900	18
	$y = 6.802e^{0.0002x}$	0.9762		
6. Sal to Thaltej	$v = -3E-07x^2 - 0.0089x + 56.915$	0.9873	2200	33
	$y = 16.097e^{0.0004x}$	0.964		

From the Tab. 2, it is observed that the maximum Q_{max} value is for link No.5, i.e., Gurukul to Sunrise Park. The minimum Q_{max} is observed at Stadium to Commerce crossroad link. Maximum speed at Q_{max} is observed at Sal to Thaltej crossroad and the minimum speed at Q_{max} is observed at Stadium to Commerce crossroad link.

3.3 Traffic Flow Analysis after Construction Stage

The traffic data have been collected after constructions stage. Fig. 11 shows the traffic composition at the links after construction stage.

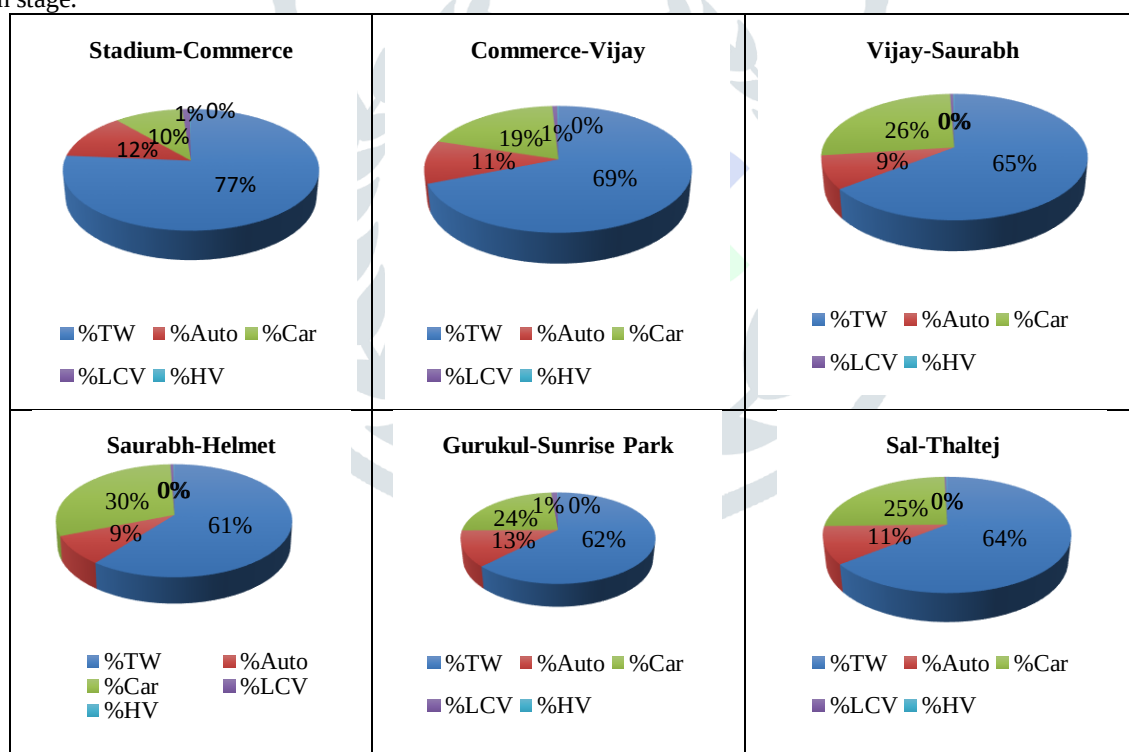


Fig. 11 - Vehicle composition in the study area after construction stage (From Stadium to Sal crossroad)

From Fig. 11, it is observed that the two-wheeler has the highest share in the traffic composition at all the links followed by car and auto rickshaw. Rest of the mode has less share in traffic composition. The speed and flow data have been collected on all the links. Fig. 12 shows the observed traffic flow for morning, noon, and evening hours.

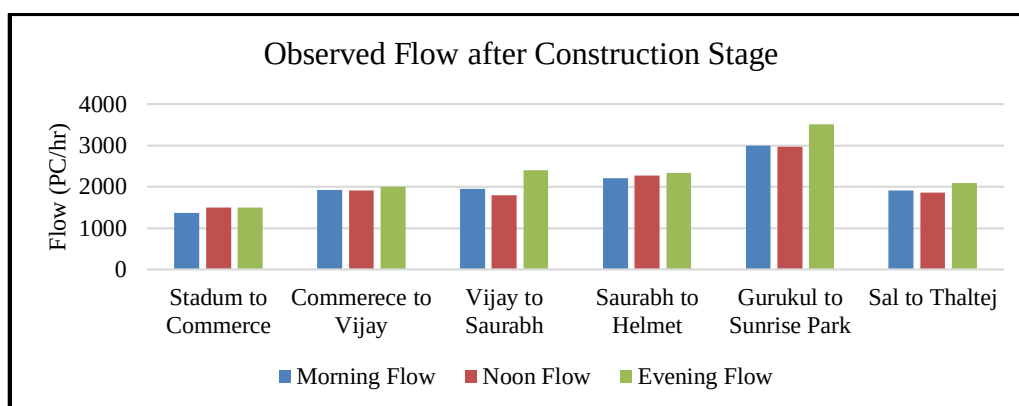


Fig. 12 - Observed flow after construction stage

From the Fig. 12, 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 is calculated from the spot speed data. The space mean speed on each link for morning, noon and evening hours are presented in Fig. 13.

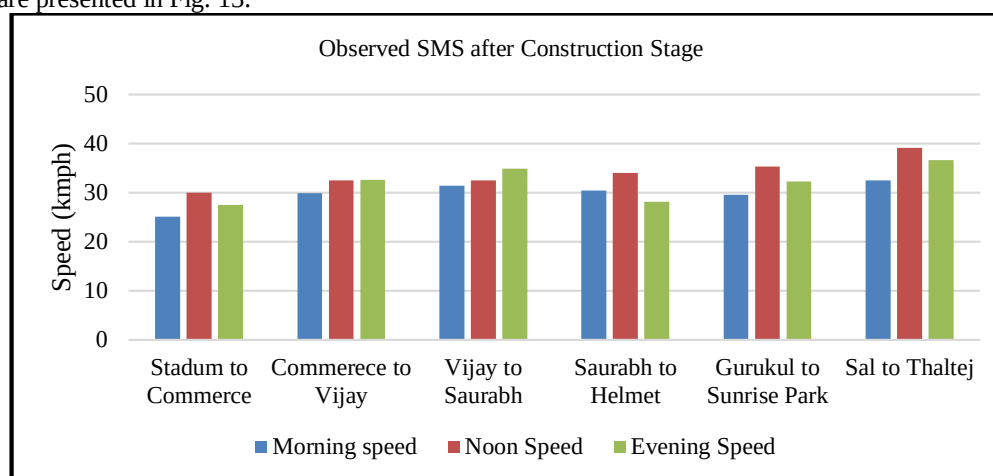


Fig. 13 - Observed speed after construction stage

From the Fig. 13, it is observed that the Sal to Thaltej crossroad link has the maximum speed for morning, noon, and evening time. The minimum speed is observed on the link of Stadium to Commerce crossroad. The observed average maximum speed is 36.09 kmph on the link of Sal to Thaltej crossroad and the observed average minimum speed is 27.51 kmph on the link of stadium to Commerce crossroad.

3.4 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.

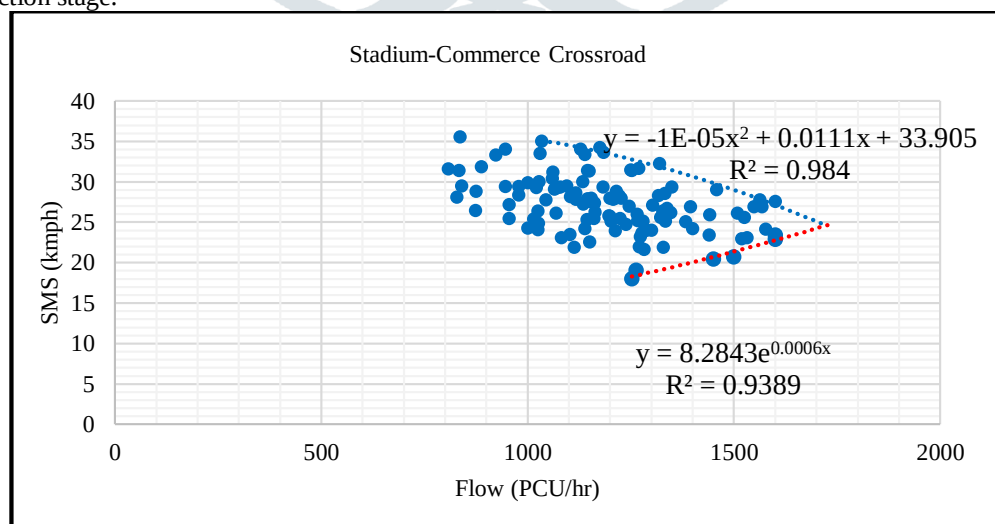


Fig. 14 - Speed flow relationship after construction stage (Stadium to Commerce crossroad)

From the Fig. 14, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.984, while lower curve is following exponential relationship having R2 value as 0.9389. Fig. 15 shows speed flow relationship for the link of Commerce crossroad to Vijay crossroad after construction stage.

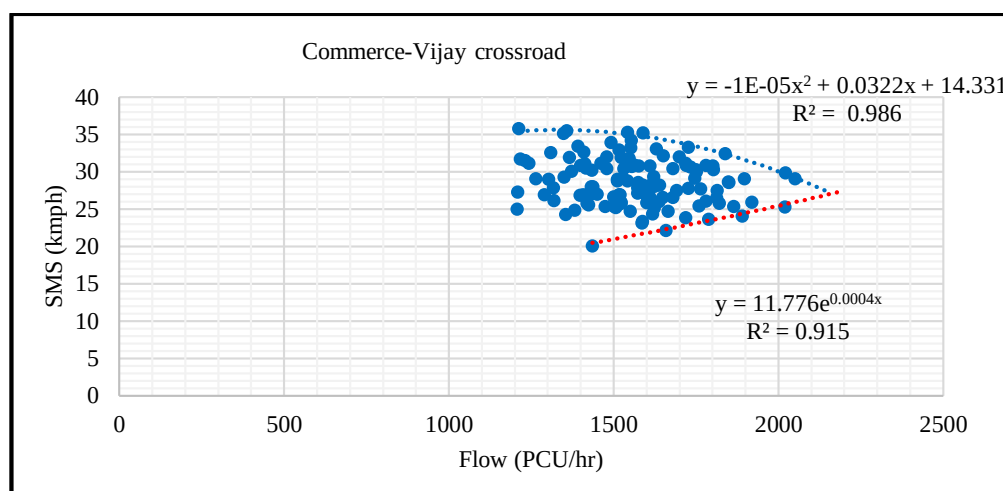


Fig. 15 - Speed flow relationship after construction stage (Commerce to Vijay crossroad)

From the Fig. 15, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.986, while lower curve is following exponential relationship having R2 value as 0.915. Fig. 16 shows speed flow relationship for the link of Vijay crossroad to Saurabh crossroad after construction stage.

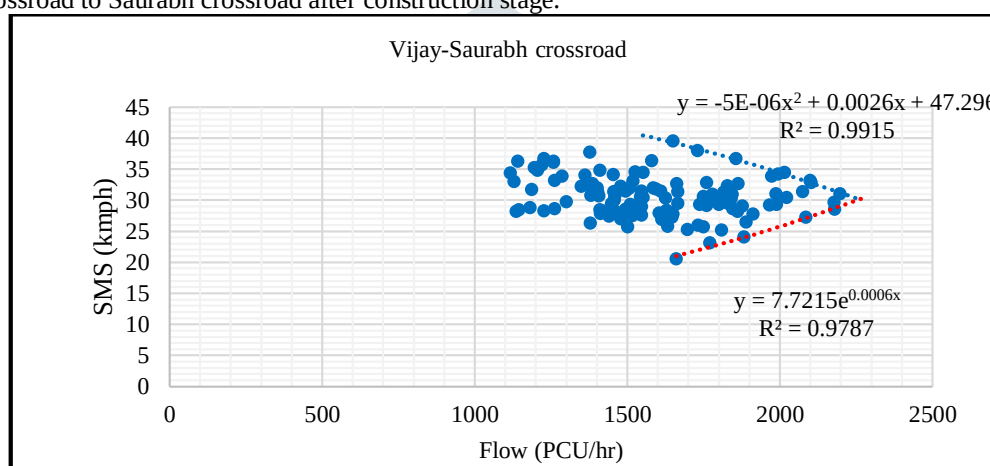


Fig. 16 - Speed flow relationship after construction stage (Vijay to Saurabh crossroad)

From the Fig. 16, 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. Fig. 17 shows speed flow relationship for the link of Saurabh crossroad to Helmet crossroad after construction stage.

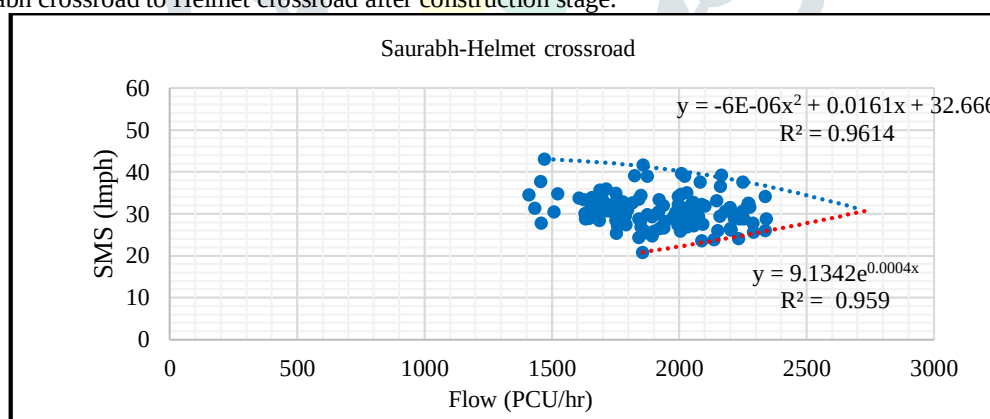


Fig. 17 - Speed flow relationship after construction stage (Saurabh to Helmet crossroad)

From the Fig. 17, 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. Fig. 18 shows speed flow relationship for the link of Gurukul crossroad to Sunrise Park crossroad after construction stage.

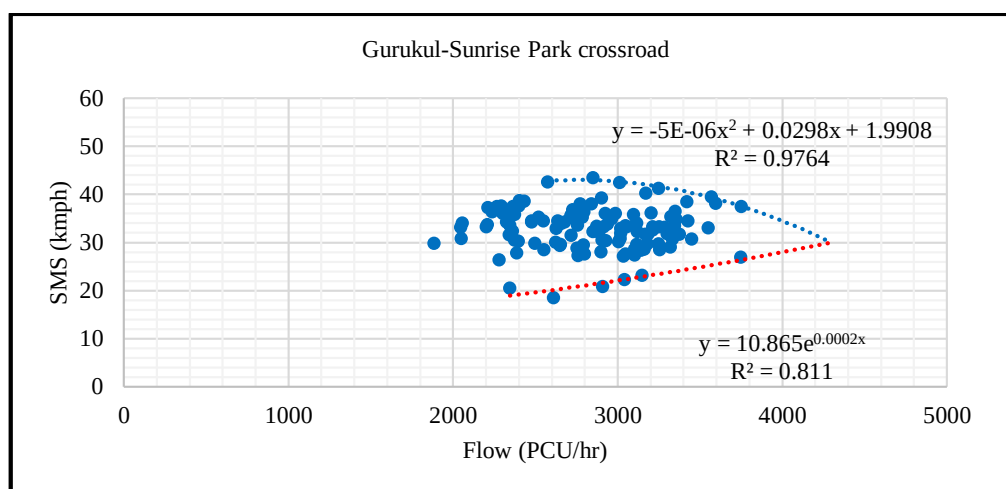


Fig. 18 - Speed flow relationship after construction stage (Gurukul to Sunrise Park crossroad)

From the Fig. 18, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.9764, while lower curve is following exponential relationship having R2 value as 0.811. Fig. 19 shows speed flow relationship for the link of Sal crossroad to Thaltej crossroad after construction stage.

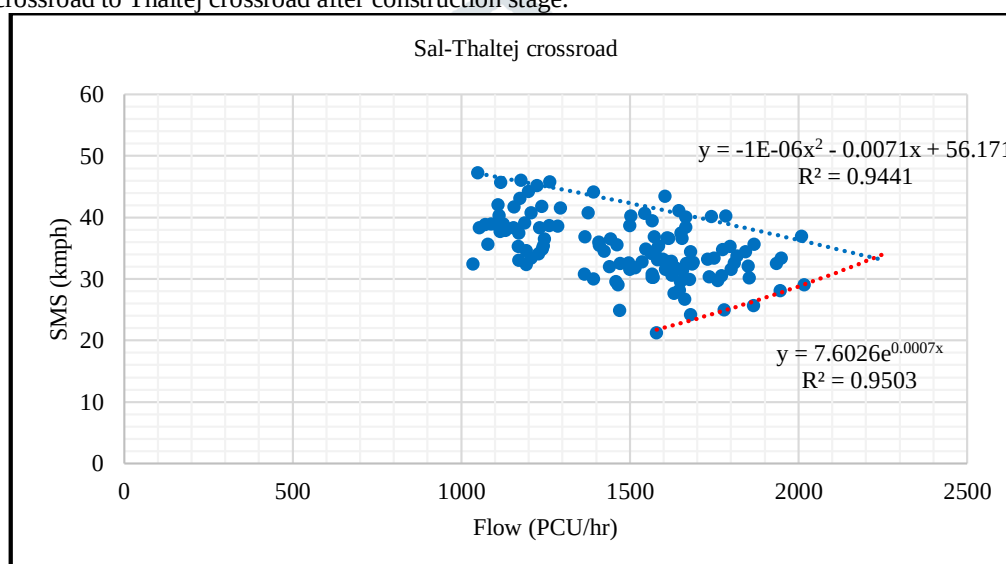


Fig. 19 - Speed flow relationship after construction stage (Sal to Tahltej crossroad)

From the Fig. 19, it is observed that the upper envelope curve is following 2nd order polynomial relation having R2 value as 0.9441, while lower curve is following exponential relationship having R2 value as 0.9503. Form the speed flow relationship of each link, the maximum flow (Qmax) is obtained and the corresponding speed is obtained from the graph. Tab. 3 shows the summary of speed flow relationship of each link after construction stage.

Tab. 3- 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 Tab. 3, 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 Qmax value is for link no.5, i.e., Gurukul to Sunrise Park. The minimum Qmax is observed at Stadium to Commerce crossroad link. Maximum speed at Qmax is observed at Sal to Thaltej crossroad and the minimum speed at Qmax is observed at Stadium to Commerce crossroad link.

The collected data are compared to study the effects of during construction stage and after construction stage in the study area. Fig. 20 shows the comparison of flow for during and after construction stage.

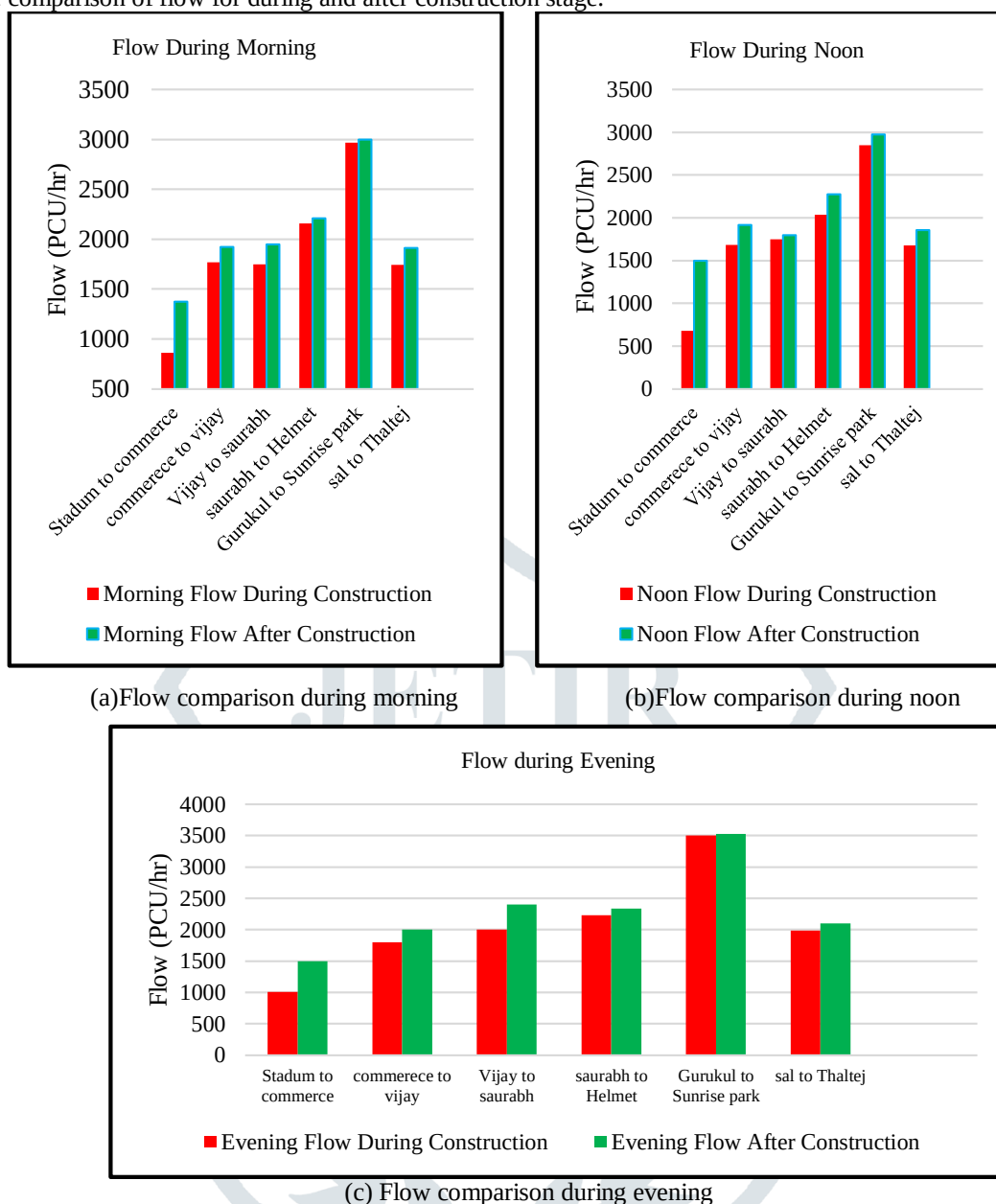


Fig. 20 – flow comparison

From the Fig. 20, it is observed that there is an increase in flow after construction stage, which is summarized in the Tab. 4. Tab. 4 - % 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 Tab. 4, it is observed that there is significant increase in the flow on the link Stadium to Commerce and Commerce to Vijay crossroad. The major reasons for increase in the flow is that there was a significant reduction in the lane width during the construction stage. The heavy vehicles and buses were not allowed on these links during the construction stage. It is observed that other links i.e., Saurabh to Helmet, Gurukul to Sunrise Park and Sal to Thaltej have also increase in the flow after construction stage.

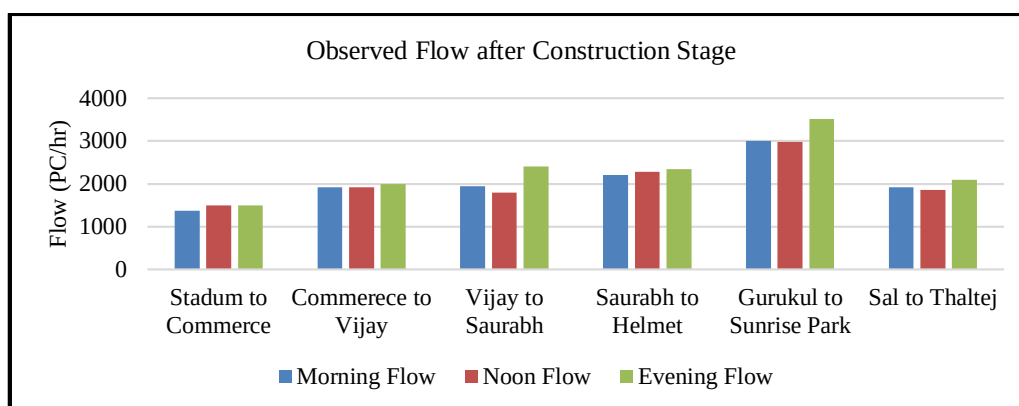


Fig. 12 - Observed flow after construction stage

From the Fig. 12, 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 is calculated from the spot speed data. The space mean speed on each link for morning, noon and evening hours are presented in Fig. 13.

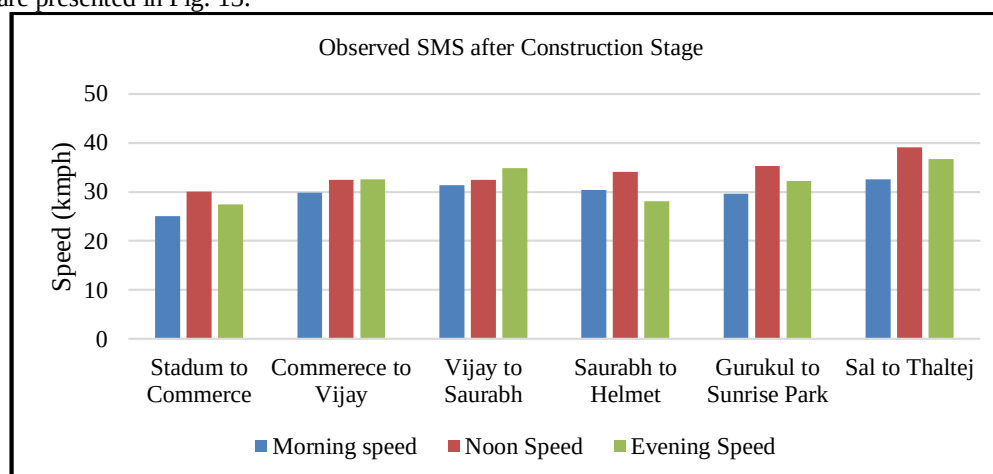


Fig. 13 - Observed speed after construction stage

From the Fig. 13, it is observed that the Sal to Thaltej crossroad link has the maximum speed for morning, noon, and evening time. The minimum speed is observed on the link of Stadium to Commerce crossroad. The observed average maximum speed is 36.09 kmph on the link of Sal to Thaltej crossroad and the observed average minimum speed is 27.51 kmph on the link of stadium to Commerce crossroad.

IV. MODEL DEVELOPMENT

4.1 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 impact 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 values independent variables.

The strength of the linear link between two variables is gauged by the Pearson product-moment correlation coefficient. It is also known as the correlation coefficient or Pearson's correlation. Here, flow word is used in the context of traffic flow.

Tab. 5- Pearson correlation for flow during construction stage

Independent Variables	Pearson correlation
Two-Wheeler (TW)	0.317***
Heavy vehicle (HV)	0.0343*
Light Commercial Vehicle (LCV)	0.0907**
Car	0.3554***
Auto Rickshaw (auto)	0.0913**
Space mean speed (SMS)	-0.496***
Available lane width (ALW)	0.862***

(**Correlation is significant at 0.05 level, *** Correlation is significant at 0.01 level)

From the Tab. 5, it is observed that the independent variables i.e., TW (two wheeler), car, SMS (space mean speed), ALW (available lane width), LCV (light commercial vehicle) and auto are showing good correlation with flow while heavy vehicles are not showing good correlation with flow as per Pearson correlation. Flow = f (TW, car, SMS, ALW, LCV, auto). The regression analysis is carried out for flow during construction stage. Table 5-2 shows the regression statistics.

Tab. 6 - Regression statistics of flow model during construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.9550	0.9121	0.9081	469.5490	365

From the Tab. 6, it is observed that the R² values is coming out 0.9121. So, there is good correlation among dependent variable and independent variables. Table 5.3 shows coefficient table for flow during construction stage. The coefficients of independent variable, their standard error, t-stat, p-value, upper and lower value for 95% confidence interval is mentioned in the table 5.3.

Tab. 7 - 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	19.430	1.688	11.507	2.6744E-26	16.109	22.750
Car	39.148	4.673	8.376	1.2478E-15	29.957	48.340
SMS	-57.544	4.429	-12.991	6.7584E-32	-66.25	-48.833
ALW	116.858	18.773	6.224	1.3467E-09	79.939	153.778
LCV	43.139	18.478	2.334	0.02011813	6.799	79.479
Auto	18.024	5.741	3.139	0.00183358	6.733	29.315

From the Tab. 7, it is observed that the major factors affecting flow are available lane width followed by light commercial vehicle and car.

$$\text{Flow} = (19.43 \times \text{TW}) + (39.14 \times \text{Car}) - (57.54 \times \text{SMS}) + (116.85 \times \text{ALW}) + (43.13 \times \text{LCV}) + (18.02 \times \text{Auto}) \dots \dots \dots (5.1)$$

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 TW is smaller as compared to rest of the variables. The ALW and LCV has larger standard error. So, this model is able to estimate the coefficient of TW, car, SMS and auto with higher accuracy as compared to ALW and LCV. 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. t-critical for two tailed test is 1.962 for the 95% of confidence interval for degree of freedom (d.o.f) 359. 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. 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.

4.2 Model Validation for Traffic Flow during Construction Stage

Model validation is carried out by two methods. ANOVA test and cross validation.

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 they are statistically distinct from one another. Tab. 8 shows ANOVA (Analysis of variance) test for flow during construction stage.

Tab. 8 - ANOVA test for flow model during construction stage

	df	Sum of Square	Mean Square	F	Significance F
Regression	6	821144446.92	136857407.82	620.74	8.4E-186
Residual	359	79150968.08	220476.23		
Total	365	900295415.00			

From the regression analysis, the R² value is coming out 0.9128. The ANOVA test shows good result as f significant is nearly zero i.e. f signi. = 0.000

4.3 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.

4.4 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. (2004) 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.

Singh J. et al. (2004) developed the **RMSE-observations standard deviation ratio (RSR)**, a statistic for evaluating models. In order to ensure that the statistic produced and reported values may be used to a variety of constituents, RSR normalizes RMSE using the observed standard deviation, combines the advantages of error index statistics and provides a scaling/normalization factor. In order for the resulting statistic and reported values to apply to varied constituents, RSR utilizes the advantages of error index statistics and includes a scaling/normalization factor. RSR is given by equation 5.2

$$RSR = \frac{RMSE}{STDEV\ Obs} = \frac{\sqrt{\sum_{i=1}^n (y_{iobs} - y_{ipred})^2}}{\sqrt{\sum_{i=1}^n (y_{iobs} - y_{imean})^2}} \dots \dots \dots (5.2)$$

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. Scatter plot for observed vs Predicted flow during construction stage as shown in fig. 21.

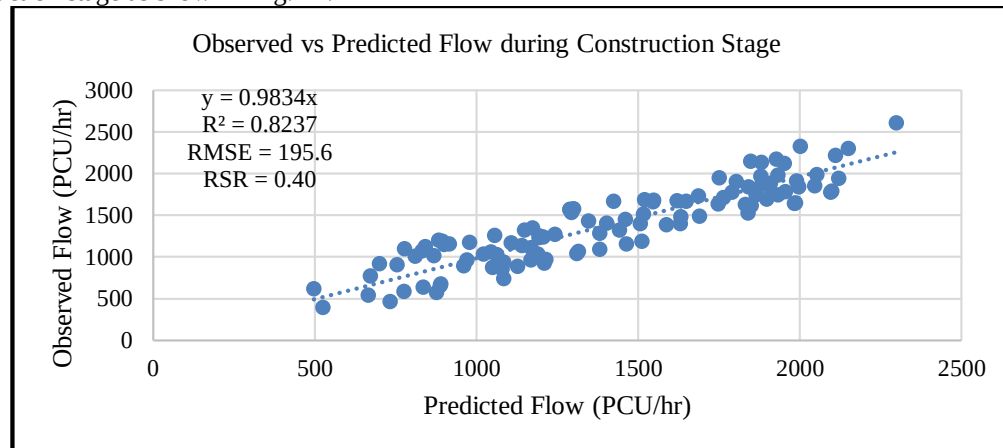


Fig. 21 - Observed vs predicted flow during construction stage

From the figure 5.1, it is observed that the R2 value is coming out as 0.8237. The root mean square error is coming out 195.6, which is less than the half of standard deviation of observed data i.e. 486.5. RSR is coming out as 0.40, which is nearer to zero. The model performs well.

4.5 Prediction Model for Traffic Flow after Construction Stage

The flow model is developed after construction stage. The independent variables are TW (two-wheeler), car, SMS (space mean speed), ALW (available lane width), LCV (light commercial vehicle), auto (auto rickshaw), HV (heavy vehicle). Tab. 9 shows the Pearson correlation between the variables.

Tab. 9 - Pearson correlation for flow after construction stage

Dependent Variables	Pearson correlation
Space mean speed (SMS)	0.111**
Two Wheeler (TW)	-0.392***
Auto Rickshaw (Auto)	0.084*
Car	0.321***
Light Commercial Vehicle (LCV)	-0.028*
Heavy vehicle (HV)	-0.031*
Available lane width (ALW)	0.498***

(*Not significant, **Correlation is significant at 0.05 level, *** Correlation is significant at 0.01 level)

From the Tab. 9, it is observed that the independent variables i.e., SMS (space mean speed), TW (two-wheeler), car and ALW (available lane width) are showing good correlation with flow while heavy vehicles, auto and light commercial vehicles are not showing good correlation with flow as per Pearson correlation. Therefore, flow = f (ALW, TW, car, SMS). The regression analysis is carried out for flow after construction stage. Tab. 10 shows the regression statistics.

Tab. 10 - Regression statistics of flow model after construction stage

Multiple R	R Square	Adjusted R Square	Standard Error	Observations
0.9637	0.9288	0.9272	500.5917	719

From the Tab. 10, it is observed that the R2 values is coming out 0.9288. So, there is good correlation among dependent variable and independent variables. Table 5.7 shows coefficient table for flow after construction stage. The coefficients of independent variables, their standard error, t-stat, p-value, upper and lower value for 95% confidence interval is mentioned in the Tab. 11.

Tab. 11 - 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	277.9028	19.9599	13.9229	3.64E-39	238.7156	317.09
TW	-2.4693	1.0730	-2.3012	0.015410	-5.8675	0.9287
Car	-22.2580	4.6245	-4.8130	1.81E-06	-31.3372	-13.1788
SMS	-15.8285	4.6950	-3.3713	0.000788	-25.0461	-6.6108

From the Tab. 11, based on coefficient value, it is observed that the major factors affecting flow are available lane width followed by car, SMS and TW. Therefore, $\text{Flow} = f(\text{ALW}, \text{TW}, \text{car}, \text{SMS})$

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, 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. t-critical for two tailed test is 1.962 for the 95% of confidence interval for d.o.f 715. 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. p-value is also coming out less than 0.05. So independent variables i.e., ALW, car and SMS are significant.

$$\text{Flow} = (277.90 \cdot \text{ALW}) - (2.46 \cdot \text{TW}) - (22.25 \cdot \text{Car}) - (15.82 \cdot \text{SMS}) \dots\dots\dots(5.3)$$

4.6 Model validation for traffic flow after construction stage.

Model validation is carried out by two methods. ANOVA test and cross validation. Tab.12 shows the ANOVA test for flow after construction stage.

Tab. 12 - ANOVA test for flow model after construction stage

	df	Sum of Square	Mean Square	F	Significance F
Regression	4	2.34E+09	5.85E+08	2335.251	0
Residual	715	1.79E+08	250592		
Total	719	2.52E+09			

From the regression analysis, the R² value is coming out 0.9288. The ANOVA test shows good result as f significant is nearly zero i.e. f signi. = 0.000

4.7 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.

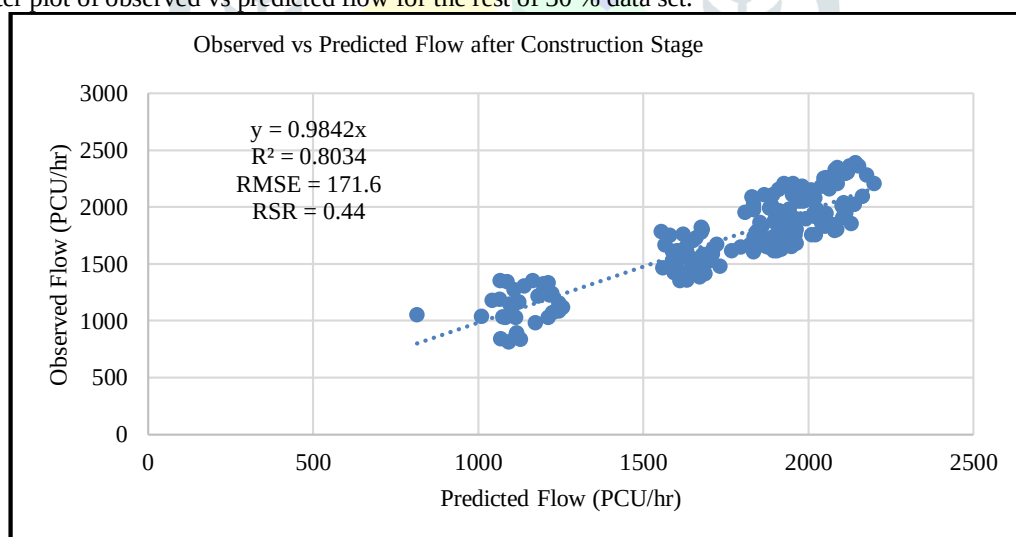


Fig. 22 - Observed vs predicted flow after construction stage

From the scatter plot of observed vs predicted flow for after construction stage, it is observed that the R² value is coming out as 0.8034. The root mean square error is coming out 171.6 which is less than the half of standard deviation of observed data. RSR is coming out as 0.44 which is nearer to zero. The model performs well.

V. 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 5.9.

Tab. 13 - Work zone area details for flow analysis

Link name	Width of work zone (m)	Length of work zone (m)	Restricted area (m ²)
Stadium crossroad to Commerce crossroad	3.6	700	2520
Commerce crossroad to Vijay crossroad	4.8	510	2448
Vijay crossroad to Saurabh crossroad	4.3	270	1161
Saurabh crossroad to Helmet crossroad	5.5	395	2172
Gurukul crossroad to Sunrise Park crossroad	2.5	420	1050
Sal crossroad to Thaltej crossroad	4	425	1700

Form the table 5.9, it is observed that the link of Stadium cross road 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.

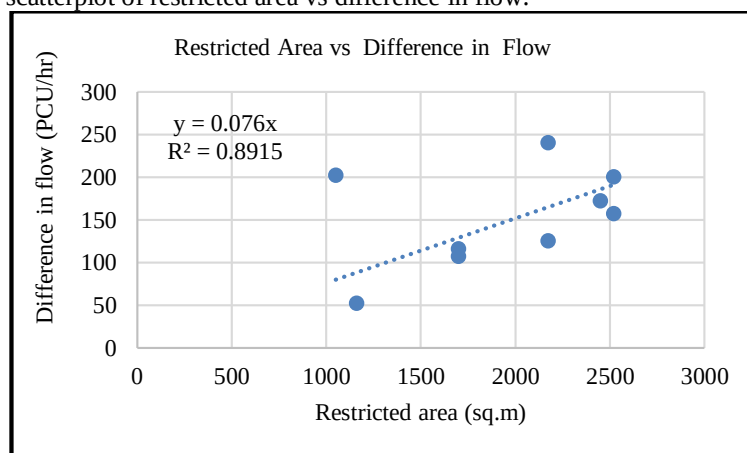


Fig. 23 -Restricted area vs difference in flow

VI. CONCLUSION AND DISCUSSION

a) Traffic Flow analysis during construction stage

- From Stadium to Thaltej crossroad, the proportion of TW varies from 52 % to 78%, car varies from 7 % to 29% and auto varies from 13% to 15 %.
- From the observed data, the maximum flow is obtained on the link of Gurukul to Sunrise Park having the value of 3113 PCU/hr. The minimum flow is observed at the link of Stadium to Commerce cross road having the value of 849 PCU/hr.
- From the observed data, the maximum SMS is obtained on the link of Sal to Thaltej having the value of 34.63 kmph. The minimum speed is obtained on the link of Gurukul to Sunrise Park having the value of 19.63 kmph.
- For the speed-flow relationship, the outer envelope is considered to get Qmax .
- From the speed-flow curve, the maximum value of Qmax as 3900 PCU/hr is obtained on the link of Gurukul-Sunrise Park. The minimum value of Qmax as 1015 PCU/hr is obtained on Stadium to Commerce crossroad.
- The speed at Qmax obtained on the Sal to Thaltej crossroad, which is highest, 33 kmph while speed at Qmax on Stadium-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, ALW, LCV & auto.

b) After Construction stage

- From Stadium to Thaltej crossroad, the proportion of TW varies from 60% to 76%, car varies from 10% to 13% and auto varies from 9% to 13%.
- From the observed data, the maximum flow is obtained on the link of Gurukul to Sunrise Park having the value of 3161 PCU/hr. The minimum flow is observed at the link of Stadium to Commerce crossroad having the value of 1458 PCU/hr.
- From the observed data, the maximum SMS is obtained on the link of Sal to Thaltej having the value of 36.09 kmph. The minimum speed is obtained on the link of Commerce to Stadium having the value of 27.51 kmph.
- Form the Speed-flow curve, the maximum flow Qmax is obtained on the link of Gurukul to Sunrise Park of 4250 PCU/hr and minimum value of Qmax is obtained on the link of Stadium to commerce crossroad of 1700 PCU/hr.
- The speed at Qmax obtained on the Sal to Thaltej crossroad is founf highest having value of 34 kmph while speed at Qmax on Stadium-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 to Commerce Crossroad link and Minimum increased flow is observed on Gurukul to Sunrise Park crossroad.

- From the developed model after construction stage, it is observed that the major factors affecting flow are TW, car, SMS and ALW. After construction effect of LCV and Auto are not significant. Table-6.1 shows the summary of traffic flow analysis.

Tab. 14 Summary of flow analysis

	During Construction		After Construction	
Based on observed data				
	Link	Value	Link	Value
Max Flow	Gurukul-Sunrise	3113 PCU/hr	Gurukul-Sunrise	3161 PCU/hr
Min Flow	Stadium-Commerce	849 PCU/hr	Stadium-Commerce	1458 PCU/hr
Max SMS	Sal-Thaltej	34.63 kmph	Sal-Thaltej	36.09 kmph
Min SMS	Saurabh-Helmet	22 kmph	Stadium-Commerce	27.51 kmph
Based on speed-flow curve analysis				
Max Flow	Gurukul-Sunrise	3900 PCU/hr	Gurukul-Sunrise	4250 PCU/hr
Min Flow	Stadium-Commerce	1015 PCU/hr	Stadium-Commerce	1700 PCU/hr
Max Speed @ Q _{max}	Sal-Thaltej	33 kmph	Sal-Thaltej	34 kmph
Min Speed @ Q _{max}	Stadium-Commerce	16 kmph	Stadium-Commerce	25 kmph
Main factors affecting flow based on regression analysis				
factors	ALW, SMS, Car, TW, LCV, Auto		SMS, ALW, Car, TW	

Tab. 15 – Summary of flow model

Dependent variable	Model	Accuracy check for developed model (70 % data set)		Accuracy check for model validation (30% data set)			Affecting parameters
		R^2	F Signi.	Observed vs Predicted relation	R^2	RSR	
Flow during construction stage	$Flow = (19.43*TW) + (39.14*Car) - (57.54*SMS) + (116.85*ALW) + (43.13*LCV) + (18.02*Auto)$	0.9121	0.000	$y = 0.9834x$	0.8237	0.40	TW, car, SMS, ALW, LCV, auto
Flow after construction stage	$Flow = (277.90*ALW) - (2.46*TW) - (22.25*Car) - (15.82*SMS)$	0.9228	0.000	$y = 0.9842x$	0.8034	0.44	ALW, TW, car, SMS

The R^2 value of all the models are coming out good. For the validation of the model, R^2 value for observed vs predicted value and RSR are considered as model performance parameters. From the Tab. 15, it can be concluded that the developed model performs well. It is evident that available lane width is significant variable for the flow estimation during and after the construction of metro rail project

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