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ASSESSMENT OF TRAFFIC CONGESTION UNDER INDIAN ENVIRONMENT - A CASE STUDY

Satya Ranjan Samal ^{1,*}, Malaya Mohanty ¹, Moses Santhakumar Selvaraj ²

¹KIIT Deemed to be University, Bhubaneswar, India

²National Institute of Technology, Tiruchirappalli, India

*E-mail of corresponding author: satya.samalfce@kiit.ac.in

Resume

Traffic congestion is a major problem around the globe. The prime reason for congestion is unavailability of traffic infrastructure to meet the traffic demand. Road users are forced to face undesirable delay, which influences the economy, environment and health. The present study examines the congestion in the urban roads of Bhubaneswar, a smart city in India. Travel time for various categories of vehicles was estimated and congestion indices in terms of buffer index were evaluated. Multiple linear regression modeling has been used to evaluate the congestion parameters. The p-value for all the independent variables in the developed model is < 0.05 . Four elements, namely Strict traffic law implementation, Adequate parking facilities, Decentralization and Controlling the road side activities are required to improve the serviceability and mobility of urban road networks.

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1 Introduction

The development of any country, especially the country like India, is largely dependent on the transportation infrastructures. As the number of vehicles increased rapidly, the existing road infrastructure is not able to accommodate the present capacity, which leads to congested traffic environment [1]. In a developing country congestion has been the major setback for road users. Normally, congestion means that the present traffic demand is exceeding the existing roadway capacity. Congestion is not only affecting the travel time but it is also having an impact on human health, which leads to adverse traffic environment [2]. The traffic congestion results in stress of drivers, which leads to road crashes [3]. Growth of population as well as the number of vehicles and shifting of human resources from rural to urban networks, are the most contributing factors for the traffic congestion [4]. Unlike several major issues, such as indigence, starvation, poor education, etc. congestion is constantly suffered, day by day by millions of road users across the globe [5]. Faulty traffic infrastructures, insufficient human resources, limited roadway width and overtaking proneness of drivers fabricate extended congestion [6]. While the recurring congestion is based on saturated flow and behavioral traits, the non-recurring

congestion is based on construction, crashes or crisis with different causes, but having similar effects [7]. The socio-economic irregularities have been observed due to the covid-19 pandemic, which has affected the travel behavior on the road network [8]. Congestion impact can be associated to extra fuel consumption costs, additional transportation costs in terms of vehicle maintenance and operating costs, human health and environment associated problems [6]. Traffic congestion analysis can be done by using the parameters like level of service (LOS), lane-mile duration index and roadway congestion index [9]. Traffic congestion reduction strategies can be achieved by using congestion pricing techniques [10-13]. The utilization of suitable models, associated with road user behavior, can be effective for congestion reduction in terms of travel time, fuel consumption and emission [14].

Due to increase in human resources and number of vehicles, the existing transportation framework is not enough to tackle the present condition. In India, there is a little investigation put up with regard to congestion. Additionally, heterogeneous environments are making things difficult. This research is focused on the congestion indices to recognize the functional effectiveness of the roadway system and the practical congestion mitigation techniques are proposed.

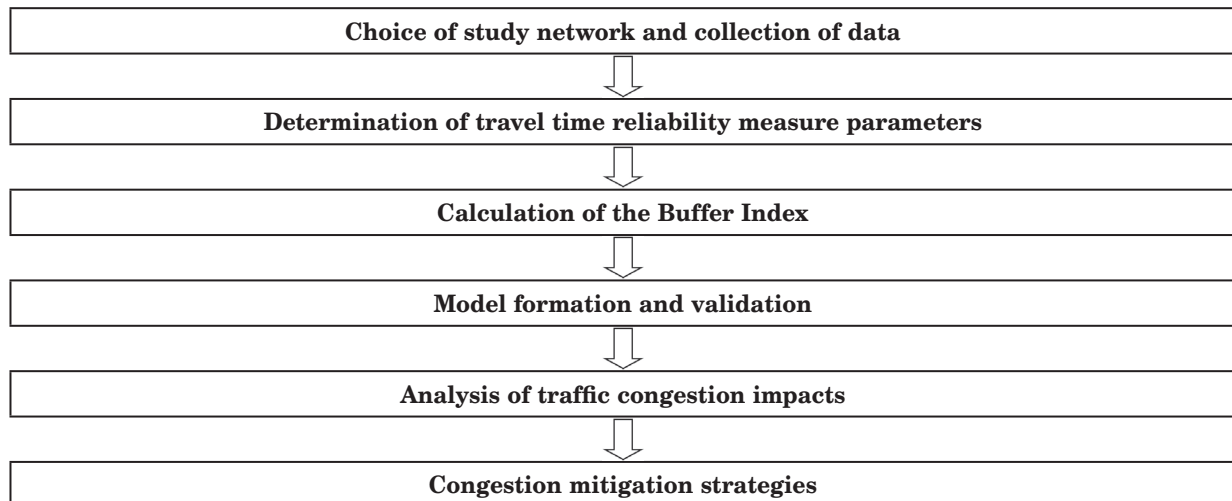


Figure 1 Methodology flowchart

2 Definition of traffic congestion

It would be essential to have a clarity regarding the way someone define the traffic congestion, before analyzing the elements associated with the congestion and its impact. Several definitions of congestion have been reported before. According to the Highway Capacity Manual (HCM, 2016) [15], congestion is measured using various parameters like mean trip speed, volume to capacity ratio, demand to capacity ratio etc. Along with the HCM (2016), other studies [1-10], related to congestion, reveal that road congestion can be defined based on three categories as follows:

- Based on demand and capacity,
- Based on travel time and
- Based on costs.

3 Study approach

The methodology is one of the most important aspects in any research for obtaining the desired results. The present study has adopted the following study approach, which is shown below in tabular format in Figure 1.

4 Data collection and analysis

The primary work for any study is the data collection. Majority of the research related to traffic start with the data collection, which gives an outline of the collected data followed by its analysis.

4.1 Travel time calculation and measures for travel time reliability

For determination of the buffer index, the

travel time plays an important parameter. The time taken from origin to destination was referred as the travel time. It can be calculated by using simple analytical approach or by computer software. In this research, information has been gathered by video graphic techniques and extracted manually with the help of Kinovea software, which plays the video at frame per second. The software can be used to capture, slow down, compare, annotate and measure motion in videos. The camera used for the study has a precision level of 25 frames per second. The travel time reliability measures play an important factor for the congestion analysis and has been calculated in this study.

4.2 Congestion indices

The congestion indices are the upgraded version of the V/C ratio. The V/C ratio is mainly focused on construction of the additional road infrastructure to meet the present traffic demand, whereas, the congestion indices are focused on the functional effectiveness based on mobility, serviceability and accessibility.

According to Lyman, and Bertini (2008) [16], the congestion indices are categorized as (a) Buffer Time Index, (b) Travel Time Index and (c) Planning Time Index whose general formulae and general descriptions are provided below.

$$\text{Buffer time Index} = (95^{\text{th}} \text{ percentile travel time} - \text{Mean travel time}) / \text{Mean travel time} \quad (1)$$

$$\text{Travel time Index} = \text{Mean Travel time} / \text{Off peak travel time} \quad (2)$$

$$\text{Planning time Index} = 95^{\text{th}} \text{ percentile travel time} / \text{Off peak travel time} \quad (3)$$

$$\begin{aligned}
 & \text{Buffer time Index} \\
 &= \frac{95^{\text{th}} \text{ percentile travel time} - \text{Mean Travel time}}{\text{Mean travel time}} \text{Travel time Index} \\
 &= \frac{\text{Mean Travel time}}{\text{Off peak travel time}} \text{Planning time Index} \\
 &= \frac{95^{\text{th}} \text{ percentile travel time}}{\text{Off peak travel time}}
 \end{aligned}$$

- **95th Percentile Travel Time** refers to the travel time where the passenger is behind the average time only one out of every twenty outings.
- **Buffer Time Index (BTI)** The supplementary time that passengers add to travel to make sure that they are on time. It is usually determined by subtracting the 95th percentile travel time from the mean travel time and then divided by the mean travel time.
- **Travel Time Index (TTI):** The mean time that is required to travel during the rush hours as compared to off peak hours is TTI. It is calculated by dividing the mean travel time with off peak travel time.
- **Planning Time Index (PTI):** The total time required to plan for an on-time arrival 95% of the time, calculated as the 95th percentile travel time divided by off peak travel time.

The researchers [16-20], though discussed about all congestion indices, but considered the buffer time index for the analysis. The BTI has been considered as congestion index in the current study. It can be identified that the buffer time index gives satisfactory result as compared to other two indices. This research was primarily concentrated on the buffer time index due to the heterogeneous traffic environment.

4.3 Choice of road network

The road network selection is the important and foremost step in the research. The requirement of research directly depends on the study area consideration. The urban road of the Bhubaneswar city is considered for the present study. Two locations were selected from the Bhubaneswar road network to analyze the congestion index whose attributes are given in Table 1. Road 1: Patia - Infocity road and road 2: Jaydevvihar -Nandankanan road (Figure 2). The locations were selected such that the traffic flow at those sites is not influenced by horizontal curvature, the presence of downstream or upstream intersection, bus stop, parked vehicles, pedestrian movements, or any kind of side friction.

Patia - Infocity road is a commercial road in Bhubaneswar city connecting Patia Junction and Infocity Junction. The road is a six-lane divided roadway with a footpath on either side of it and on-street parking on either side of the road along with the raised kerb on either side of the road.

Jaydevvihar - Nandankanan road is a main road in Bhubaneswar city connecting Jaydevvihar Junction and Barang Junction. The road is a six-lane divided roadway with a footpath on either side of it and on-street parking on either side of the road along with the raised kerb on either side of the road.

Two locations were taken for the present study. From 8 AM to 11 AM are considered as morning rush periods and from 2 PM to 3 PM are considered as morning off-peak hours. Video graphic survey was executed for the



Figure 2 Location of data collection (I) and (II) Patia- Infocity road; (III) and (IV) Jaydevvihar-Nandankanan road

Table 1 Roadway parameters used in the study

Roadway	Category	Lane attributes
Selected roadway 1	Arterial	6 lanes divided
Selected roadway 2	Arterial	6 lanes divided

Table 2 Buffer Time Index (%) of the selected roadway

Roadway	Movement	Buffer Time Index (%)
Selected Roadway1	Upward	26
	Downward	28
Selected Roadway2	Upward	36
	Downward	33

data collection in the selected roads. Considering the movements' direction, the buffer time index has been calculated as presented in Table 2. Although the other congestion indices were discussed by various researcher, in this research the buffer time index was taken as the congestion index due to the heterogeneous traffic environment and no lane discipline. The lesser the buffer time index, the better the serviceability of the roadway network.

5 Travel time modeling

The current research tried to establish a travel time model by considering the various elements associated with the traffic congestion. The main elements, which influence the travel time are speed of the vehicle and volume of traffic. The travel time model is considered for the congestion prediction. The observed value and the estimated value have to be compared and should be validated with minimum percentage error. The travel times were obtained for the peak hour of from 8.30 AM to 9.30 AM.

5.1 Model estimation

A regression model estimates the dependent variable

from one or additional independent variables, which affect the dependent variable. The study tried to develop a multiple linear regression model by considering the travel time as a dependent variable, speed and traffic volume as independent variables.

The obtained equation is as follows:

$$TT = 28.173 - (0.676 * A1) - (0.004 * A2) \quad (4)$$

$$= 28.173 - (0.676 * A1) - (0.004 * A2)$$

in which: TT = Mean travel time, s,

A1 = Speed of vehicle, m/s,

A2 = Traffic volume, PCU/h.

Model was evaluated considering the traffic volume and vehicle speed. The developed equation is valid for an operating speed greater than 5 m/s (18 km/h) and the traffic volume of more than 500 PCU/h. The p-value for all the regression coefficients has been provided in Table 3. It can be seen that the p-value for all the independent variables is less than 0.05, which indicates their significance at 5% level of significance. It shows that there is a significant difference between all the independent variables. Therefore, each independent variable has a significant effect on the outcome of dependent variable. Hence, it can be said that the regression is well fitted and the model developed is statistically correct.

Table 3 Statistical parameters of the regression analysis

(Constant)	Coefficients	P Value
	28.173	0.000
Speed	-00.676	0.000
Traffic Volume	-00.004	0.045

Table 4 Percentage of error in the process of validation

Timing	Observed travel time, s	Predicted travel time, s	Percentage error (%)	Average percentage error (%)
8.30 AM - 8.45 AM	18.29	18.04	1.36	3.5
8.45 AM - 9.00 AM	13.48	12.49	7.3	
9.00 AM - 9.15 AM	13.48	13.40	0.59	
9.15 AM - 9.30 AM	20.56	19.58	4.76	

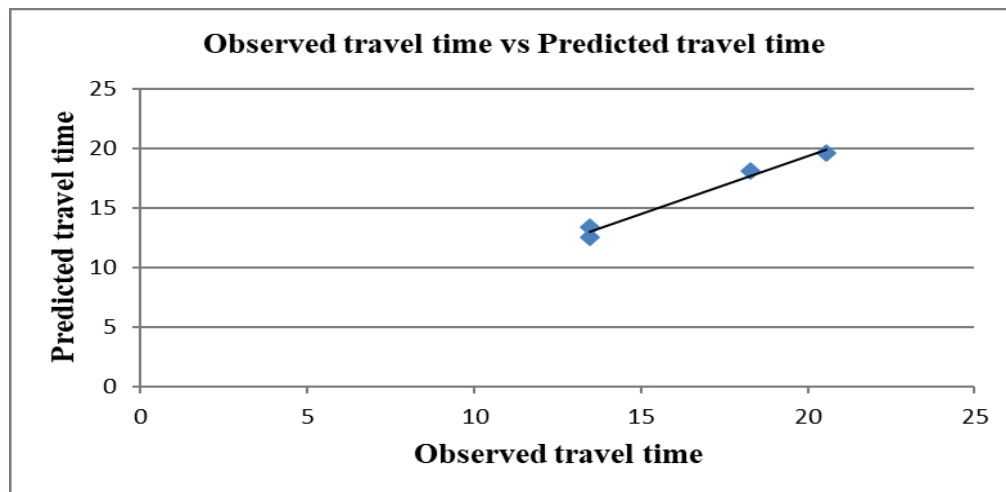


Figure 3 Variation of the observed travel time and predicted travel time

5.2 Model validation

Validation of the model is done by the comparison of the estimated value and observed value as shown in Table 4. The validation of model signifies its accountability to replicate in actual traffic scenario. Further, the variation of observed travel time with predicted travel time is presented in Figure 3. To validate the model, percentage errors, comparing observed travel time and predicted travel time, were evaluated. Model should be considered as fit if the difference of error percentage were within 10%.

To validate the proposed travel time model, the travel times computed by the model have been compared to those obtained from the field data. For the validation purpose, separated field data were collected from various locations of the six-lanes divided arterial road other than the location used for the model development. This ensures that the equation developed is not localized and can be utilized for the travel time estimation at various other locations. Table 4 shows the comparison of average travel time of all the categories of vehicles estimated from the proposed model and observed travel time as obtained from the field data. From Table 4, it can be observed that the values obtained from the proposed model are in close agreement with the observed field values. The average percentage error was found to be 3.5%. Therefore, it can be concluded that the proposed model is good enough to predict the travel time.

6 Traffic congestion impacts

Traffic congestion propagates significant difficulties to road users in Bhubaneswar city. Congested traffic extents lack of sureness in journey heading to tension and dangerous traffic environments. Due to traffic congestion people are suffering economically, physically and even mentally. The impact of traffic congestion on Bhubaneswar city may be viewed in various aspects including economy aspects, environment aspects and health aspects. For the present study the required data has been gathered from different sources, e.g. discussion, survey, field observation, personal communication and peer reviewed publications on the related affairs to identify the effect of traffic congestion on several elements.

6.1 Impact on economy

Due to the congestion, the road users were suffering in many ways. The majority suffering can be of spoiling time, increase in transportation price, increase in fuel expenditure, vehicle operating and maintenance costs. The study considered peak 1 hour for the delay cost survey for a section of 100m. The delay time has been observed by differentiating between the mean travel time for the off-peak period and rush/peak period. The details of the delay costs are presented in Tables 5

Table 5 Statistics for buses

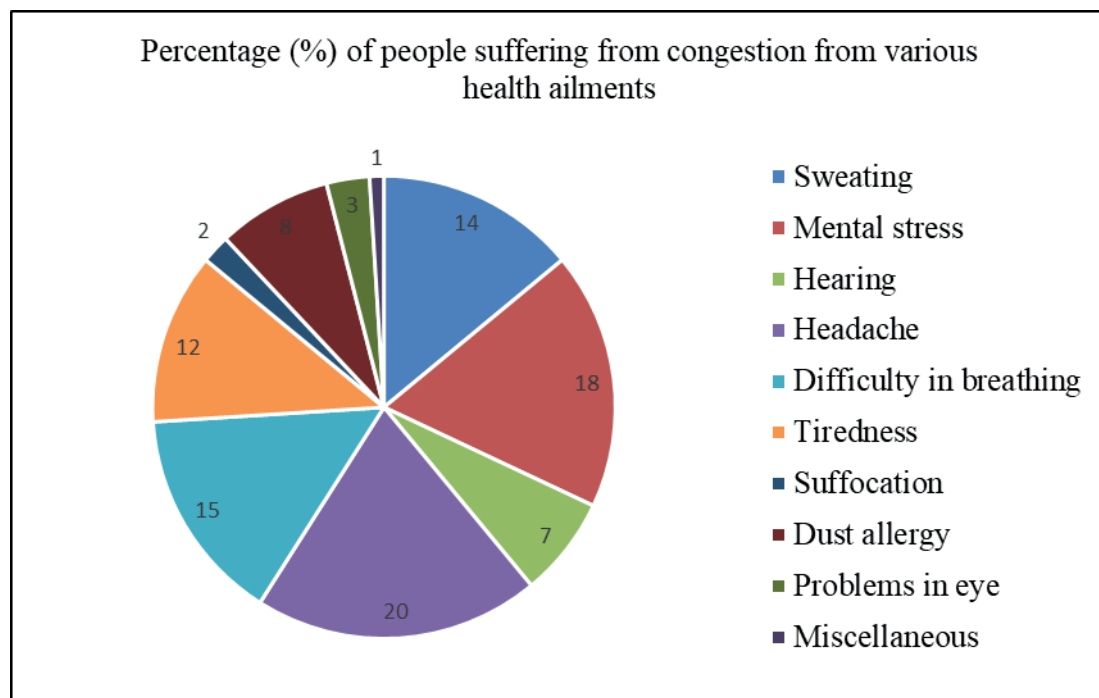
Roadway (1)	Buses (2)	Mean strength (Individuals/ Vehicle) (3)	Computed delay for 1 bus (Second/vehicle) (4)	Computed delay for 1 bus (Hour/vehicle) (5) = (4) / 3600	Costs of 1 h in Rupees (USD) (6)	Computed delay costs of buses for 1 h in Rupees (USD) (7) = (6) x (5) x (3) x (2)
Chosen Roadway 1	30	43	7	0.0019	39.5 (0.49)	97 (1.21)
Chosen Roadway 2	60	43	11	0.003	39.5 (0.49)	306 (1.21)
COMPUTED COSTS OF DELAY FOR BUSES FOR 1 HOUR IN RUPEES 403 (5.07 Euro and 5.05 Dollar)						

Table 6 Statistics for four wheelers

Roadway (1)	4-W (2)	Mean strength (Individuals/ Vehicle) (3)	Computed delay for 1 Four wheelers (Second/ vehicle) (4)	Computed delay for 1 4-W (Hour/vehicle) (5)	Costs of 1 h in Rupees (USD) (6)	Computed delay costs of four wheelers for 1 h in Rupees (USD) (7)
Chosen Roadway 1	154	4.8	8	0.002	62.5 (0.78)	93 (1.16)
Chosen Roadway 2	237	4.8	9	0.003	62.5 (0.78)	214 (2.68)
COMPUTED COSTS OF DELAY FOR FOUR WHEELERS FOR 1 HOUR IN RUPEES 307 (3.86 Euro and 3.84 Dollar)						

Table 7 Statistics for motorcycles

Roadway (1)	Motorcycles (2)	Mean strength (Individuals/ Vehicle) (3)	Computed delay for 1 motorcycle (Second/ vehicle) (4)	Computed delay for 1 motor cycle (h/vehicle) (5)	Costs of 1 h in Rupees (USD) (6)	Computed delay costs of motor cycles for 1 h in Rupees (USD) (7)
Chosen Roadway 1	700	1.5	7	0.002	32 (0.4)	68 (0.85)
Chosen Roadway 2	1140	1.5	8	0.002	32 (0.4)	110 (1.38)
COMPUTED COSTS OF DELAY FOR MOTORCYCLES FOR 1 HOUR IN RUPEES 178 (2.24 Euro and 2.23 Dollar)						

**Figure 4** Classified symptoms of congestion

through 7 for various categories of vehicles. The delay costs' survey has been conducted according to [21].

The delay costs for the buses, four wheelers and motorcycles are computed for the chosen roads by considering rush one hour in a 100m section based on Indian Roads Congress, Special Publication (IRC

SP) 30 (2010). The delay costs of buses was estimated as Rupees (Rs.) 403/hour. The delay costs for four wheelers were estimated as Rs (Rupees). 307/hour and for the motorcycles the costs were around Rs. 178/hour in a 100m section by only considering the rush hour. If the length of the road is more than the costs of the delay

Table 8 Categorizations of congestion reduction strategies

Elements	Response (%)	Ranking
Public awareness	3	Rank IV
Building flyovers	11	Rank II
Proper usage of public transport	7	Rank III
Execution of firm traffic laws	16	Rank I
Reshuffling of timings for government/private sectors	4	Rank IV
Removing Non-Motorized Vehicle	2	Rank IV
Decentralization	17	Rank I
Managing roadside activities	17	Rank I
Discourage to use private vehicles	1	Rank IV
Excessive parking costs	3	Rank IV
Improving pedestrian safety	2	Rank IV
Sufficient parking provision	17	Rank I

The ranking: < 5 % Rank IV; 6-10 % Rank III; 11- 15 % Rank II and > 15 % Rank I

will be more. During the congested period, the motorist must apply the brake and clutch frequently. Due to this, the fuel consumption increases and the serviceability and durability of the vehicle decreases. Thus, the Vehicle operating costs are directly proportional to congestion.

6.2 Impact on health

Due to congestion individuals have to occupy more hours on the roadway, which is straightway influencing the health of the inhabitants. The adverse effect on health due to congestion should not be ignored. The study has classified the symptoms in various manner, whose classification is shown in the pie chart form in Figure 4.

It can be observed that the general public are largely facing health issues associated with headache (20 %), mental stress (18 %), breathing issues (15 %) and sweating (14 %) due to traffic congestion. According to perception of road users, hearing (7%) and dust allergy (8%) are felt moderately during a traffic congestion. Issues like suffocation (2 %), Eye problem (3 %), etc. are rarely exhibited by the road users as an effect of congestion.

6.3 Impact on environment

Capacity of the roadway is up to full extent at the congested traffic. The extent of the congestion is directly proportional to the environmental pollution. The sound and air pollution are the important environmental pollutions caused by the congested traffic. The environment takes major part in the traffic congestion. The harmful gases like SO₂, CO, CO₂, and NO₂ are released from the vehicles during the congested traffic. From the study conducted by [22], it can be identified that 97% of scholars are disrupted due to honking, 86%

of the residents influenced by the noise pollution, 78 % undergo annoyance, 49 % bad temperament, 43 % of the public are facing difficulties in focusing and sleeping, 33 % of the inhabitants are struggling for hearing and 45 % of vehicle operators are blowing horn constantly in the congested traffic.

7 Proposed congestion reduction strategies

The present study was primarily concentrated on upgrading of the current traffic framework with minimum costs and efforts. Various elements have been considered as the congestion reduction strategies. The information was received from several prospects, such as common public, specialist, resource persons, educationists, engineers, roadside vendors etc. The categorization of congestion reduction strategies has been tabulated in Table 8.

Importance has not been considered for building the new infrastructures, as the present study was primarily concentrated on upgrading of the current traffic framework with minimum costs consideration. This study was aimed for the ranking approach, based on the feedback collected from the various sources. The lesser the rank, the higher the consideration needed for the elements, e.g. the elements categorized as Rank I, have to be executed instantly for the better outcomes. Majority of the inhabitants gave a strong recommendation mostly on the four elements that include Execution of firm traffic laws, Sufficient parking provision, Decentralization and Managing the road side activities. So, for the improvement in the serviceability and mobility of the urban road network these above-mentioned elements need to be implemented immediately. Because of the growth of motorcycle the number of non-motorized vehicles are become obsolete now a days. Other elements are also effective for the congestion reduction but for the instant results the

elements such as Execution of firm traffic laws, Sufficient parking provision, Decentralization and Managing the road side activities have to be taken seriously and proper execution need to be done at the earliest.

8 Conclusions and recommendations

The current research was focused on the congestion analysis and the negative impact of the traffic congestion. Necessary information was gathered from selected roads under Indian traffic environment and the congestion reduction strategies have been proposed. The level of congestion is varying depending upon the category of the vehicles and lane distribution. To evaluate the level of congestion and to identify the negative impact of the traffic congestion on various factors were analyzed. Congestion prediction under Indian environment is being complicated and cannot be totally eliminated due to the increase in numbers of the two wheelers and four wheelers, especially the passenger cars.

The buffer Index has been considered to analyze the congestion level on the selected road network. Due to the congested traffic, inhabitants are enforced to waste more hours on roadway. Therefore, the effect of the traffic congestion is negatively affecting the overall economy of the country. In addition, the environment and human health are being troubled because of the traffic congestion. Travel time model was demonstrated by considering various parameters influencing the travel time. The percentage error was observed below 10 %, so the general model is appropriate and it certifies the

analytical significance of the estimate model. Delay costs for various categories of vehicles are computed for the chosen roads by considering rush one hour in a 100m section based on IRC SP 30 (2010). The delay costs for buses were estimated as Rs. 403/hour. The delay costs for four wheelers were estimated as Rs. 307/per hour and for the motorcycle the costs were around Rs. 178/hour in a 100m section, by considering the rush hour only. If the length of the road were bigger, than the costs of the delay would be higher. During the congested period, the motorist must apply the brake and clutch frequently. Due to that, the fuel consumption increases and the serviceability and durability of a vehicle decreases. So, the vehicle operating costs are straightly related to congestion.

Majority of the inhabitants gave a strong recommendation mostly on the four elements that includes Strict traffic law implementation, Adequate parking facilities, Decentralization and Controlling the road side activities. So, for improvement in the serviceability and mobility of the urban road network, the above mentioned elements need to be implemented immediately. In developing countries, like India, heterogeneous traffic environment further complicated the situations. Due to the huge traffic congestion, the situation might sometimes be related to life and death and that cannot be compensated. Proper coordination between various organizations, starting from the research, planning, execution and practical implementation, has to be addressed with immediate effect to tackle the world's most debatable topic i.e. the traffic congestion.

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