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ECONOMIC EVALUATION OF TRAFFIC CONGESTION AT SIGNALISED INTERSECTION IN HYDERABAD METROPOLITAN CITY

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ABSTRACT

Intersections are usually considered as the critical points within the network and the evaluation of their performance, provides valuable information and useful in understanding about the network of the system. The capacity of signalized intersection is of more significant because such intersections often control the ability of the city streets to accommodate traffic. Traffic congestion causes negative impacts to transport sector and cause a massive increase in the transportation cost. Congestion cost evaluation helps wider aspects of the policy and planning and provides solutions to the traffic congestion problem. This study evaluates the traffic congestion cost at signalized intersections located in the area of Hyderabad city, Telangana state, India which prevail heterogeneous (Mixed) traffic conditions. Congestion cost estimations are done by considering the factors including traffic delay, traffic volume, passenger occupancy and value of travel time of different vehicle types. The annual congestion cost of traffic congestion at each approach of signalized intersections is quantified. The mode share of the present study reveals that private vehicles such as two-wheeler and car constitute an average share of 71% of total traffic and which has the maximum share of traffic compared to public vehicles. Therefore, this study executes a candid relief measure proposal as mode shift to public transport from private vehicles. The result shows that marginal change in the two-wheeler shift to public transport in Indian city reduce the congestion cost by 26% and thus can promote usage of public transport in the Hyderabad city to reduce congestion.

Keywords: *Congestion Cost, Mode Shift, Public Transport, Signalized Intersection*.

1. INTRODUCTION

Migration of people to urban centres due to economy growth in India has resulted in traffic problems in almost all the cities in our country. People who live in cities are expected to increase from 3500 million in the year 2010 to 6300 million in 2050. This two-fold increase will lead to many problems in all the major cities of the world and similar situation exists in India too. Hyderabad stands next to Gujarat and Maharashtra as 50% of the state population are living in cities. The major reason for traffic congestion in cities is the lesser use of public transportation and increase in usage of personal vehicles such as cars and two-wheelers.

1.1 SELECTION OF SIGNALIZED INTERSECTIONS

Some signalized intersections are selected as the study areas in Hyderabad city ***i.e., Q-city, Gudenmet X road, Laxmiguda X road, Patny X road and Opposite to Cyber towers***. In Hyderabad city, which is having more number of entities are signalized intersection in the urban road network. Hyderabad is the capital of the state of Telangana located at latitude of 17.3850° N and a longitude of 78.4867° E. It is the largest and one of the most populous cities in India.

Five signalized intersections, which are operating under heterogeneous traffic condition having a four-legged isolated type which permits left turn, operating as two-lane two-way in each direction. The signal is provided with fixed time operations, and continuous cycles irrespective of the actual traffic demand. The salient features of the signalized intersections are summarized in Table 1.

Table 1: Salient features of signalized intersections

Name of Intersection	Approach Name	Approach Width (m)	Green Time (Seconds)	Cycle Length
Intersection1	Approach1	11	98	120
	Approach2	7.4	101	120
	Approach3	3.8	56	120
	Approach4	3.7	70	120
Intersection2	Approach1	6	80	120
	Approach2	11.9	62	120
	Approach3	6.2	28	120
	Approach4	4.5	15	120
Intersection3	Approach1	10	70	120
	Approach2	9.2	70	120
	Approach3	6.7	27	120
	Approach4	3.7	27	120
Intersection4	Approach1	13.1	87	120
	Approach2	10.6	95	120
	Approach3	9.2	48	120
	Approach4	4.75	53	120
Intersection5	Approach1	9.8	63	120
	Approach2	8.9	35	120
	Approach3	5.2	85	120
	Approach4	9.3	28	120

2. LITERATURE REVIEW

2.1 TRAFFIC CONGESTION

According to the Institute of Transportation Engineers, traffic congestion is a situation where "there are more number of people trying to use a given transportation facility during a specific period of time than the facility can handle with what are considered to be acceptable levels of delay or inconvenience" (*"A Toolbox for Alleviating Traffic Congestion,"* 1989). Traffic congestion is a result of phenomenon called traffic waves. Traffic wave "occurs when cars slow down, and the slowing trend continues backward -- like a domino effect." The higher the demand for that specific road the bigger the traffic wave is (*"Traffic Causes,"* 2007).

2.2 WHAT CAUSES TRAFFIC CONGESTION

Factors contributing to traffic congestion can be divided in two groups: Traffic Disturbances and Network Overload (*"Traffic Causes,"* 2007). Traffic disturbances are temporary occurrences and only impact traffic as they happen. These include accidents, harsh weather conditions and road constructions. An accident can cause a road blockage or slow down traffic flow as drivers try to understand what is happening. Likewise, bad weather conditions can cause drivers to slow down as they worry for their safety. Also, road construction can cause reduction of lanes thereby forcing drivers to crowd the open lanes. Consequently, traffic congestion can be highly increased by these factors, but because of their randomness, not much can be done to prevent such incidents. Since Traffic Disturbances are temporary and unpredictable in nature, the focus of this paper will be Network Overloads. In Network Overload all the cases where the road congestion is caused either by decreased capacity of the road or increased demand for transportation. In other words, contributors to network overloads can be divided in supply factors and demand-increase factors. Starting with physical factors, the biggest contributors to this category are bottlenecks (*"Traffic Causes,"* 2007).

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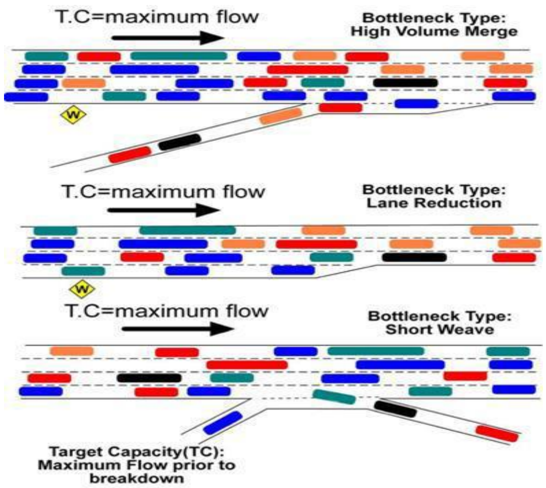


Figure 1: Bottleneck Types (*"Traffic Causes,"* 2007)

2.3 RESEARCH CONTRIBUTIONS

DeSerpa, A.C., (1971). [1] This study represents a theory of consumer behaviour, specifically designed to handle economic problems where in a time dimension is relevant. Over the past years there have been a no. of attempts to modify neoclassical consumer theory to deal with problems of this nature, but none of these works achieved the level of sophistication of the traditional approach, whereby testable properties of demand functions are deduced. More importantly, however, the restrictions on demand functions derived from neoclassical theory cannot be derived from existing theories of the time dimension in consumer choice. This is due not to any property intrinsic to the time dimension but to the fact that these theories are improperly specified. The essential features of the model presented in this paper are: (1) utility is a function not only of commodities but also of the time allocated to them; (2) the individual's decision is subject to two resource constraints, a money constraint and a time constraint; and (3) the decision to consume a specified amount of any commodity requires that some minimum amount of time be allocated to it, but the individual may spend more time in that activity if he so desires.

Decorla, P., Cohen, (1999). [2] This paper demonstrates how induced travel can be estimated for incorporation into the evaluation process for highway expansion projects, at a sketch planning level of analysis. The approach is useful especially in cases where four-step urban travel models are either unavailable or are unable to forecast the full induced demand effects. The methodology is applied to a hypothetical freeway expansion analysis. Our analysis suggests that the magnitude of travel induced by highway expansion increases significantly as a function of initial congestion levels prior to expansion. However, under even extreme cases of initial congestion and consequent forecasted induced travel, there is a positive impact with respect to congestion relief.

Weisbrod, G., Treyz, G., (2003). [3] Key findings are provided from NCHRP Study 2-21, which examined how urban traffic congestion imposes economic costs within metropolitan cities. Specifically, the study applied data from Chicago and Philadelphia to examine how various producers of economic goods and services are sensitive to congestion, through its impact on business costs, productivity, and output levels. The data analysis showed that sensitivity to traffic congestion varies by industry sector and is attributable to differences in each industry sector's mix of required inputs and hence its reliance on access to skilled labour, access to specialized inputs, and access to a large, transportation-based market area. Overall, this research illustrates how it is possible to estimate the economic implications of congestion, an approach that may be applied in the future for benefit–cost analysis of urban congestion-reduction strategies or for development of congestion pricing strategies. The analysis also shows how congestion-reduction strategies can induce additional traffic as a result of economic benefits.

3. METHODOLOGY

This dissertation work encompasses a methodological framework for the data collection, database preparation and data analysis to end up a unique traffic congestion cost at signalized intersection. The components used for the congestion cost estimation are traffic volume, traffic delay, passenger occupancy and value of travel time. In my dissertation work, I have collected the video-graphic data from the traffic commissionerate office Cyberabad. I have collected and analysed the data for the required parameters to end up with the unique congestion cost at signalized intersections. The reason why I selected these five intersections (i.e., Q – City, Gudenmet X road, Laxmiguda X road, Patny X road and Opposite to Cyber towers) was that they were having more traffic congestion because of heavy traffic volume and, traffic congestion was a common scenario in these five locations.

3.1 DATA COLLECTION AND ANALYSIS

In the present study also, the same has been adopted. The recorded video graphic data has been collected from the concerned Traffic Police Commissionerates where the intersections were located. Data collected on a typical day from 8:00 AM to 10:00 AM and 4:00 PM to 7:00 PM for traffic volume and converted to PCU by using IRC: SP 41(IRC: SP 41, 1994). Collected data was converted into digital form and database created for traffic volume. The following Figure 2 depicts the observed value of traffic in the signalized intersection.

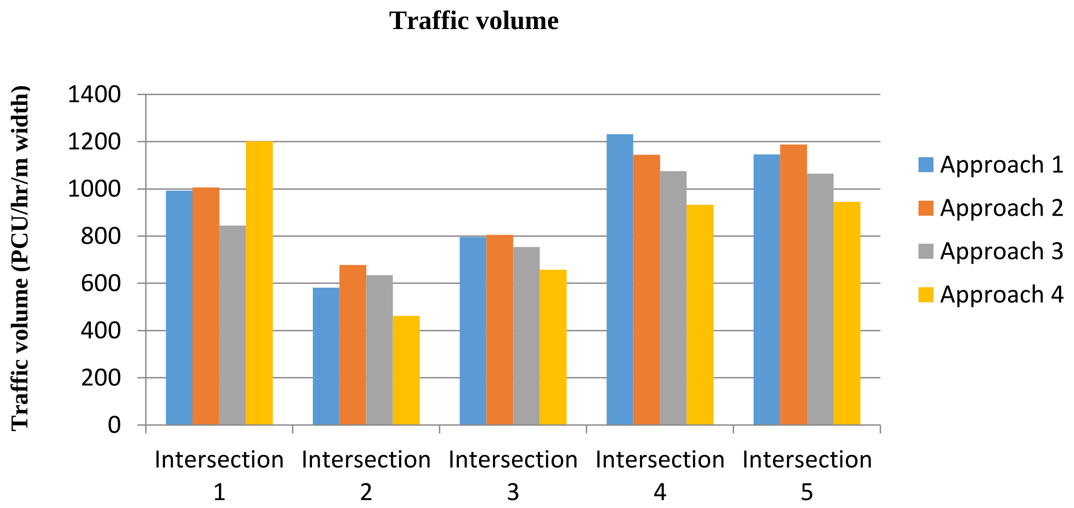


Figure 2: Traffic flow characteristics in the study intersections

Delay data collections were carried out by using the recorded video graphic data. And the delay data analysis is done in such a way that it can capture entry and exit vehicles in each approach along with the synchronization of time. Entry point and exit points were selected in such a way that it represents the queue arrival and discharges at each approaches. Travel time of the vehicles unaffected by signal is also measured separately when the signal was not on operating conditions and average delay was estimated. Figure 3 represents the range of observed delay values in each approach.

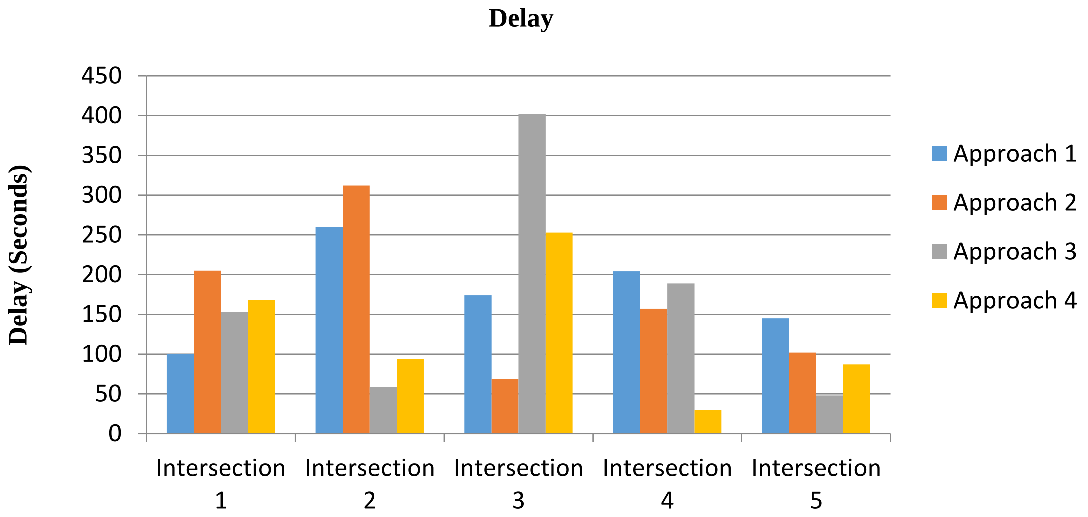


Figure 3: Observed delay in the study intersections

Passenger occupancy of the vehicle is done by manual observations. Passenger occupancy survey was conducted for different modes of vehicles which include car, two-wheeler, auto rickshaw and bus, at two roadway sections along the study intersections. For data collection, we personally note down the person occupied on it for different modes of vehicles from the recorded video graphic data. Data was collected on two study sites of every approach of all the intersections i.e., five on a normal day for different modes and their average values are considered as the passenger occupancy of the vehicle for delay cost estimation at signalized intersection. Passenger occupancy details for the study sites are given in Table 2.

Table 2: Passenger Occupancy for different modes

Road Name	Car	Two-wheeler	Auto rickshaw	Bus
Section 1	1.98	1.31	1.72	40.62
Section 2	2.12	1.47	2.00	44.36
Average Passenger Occupancy	**2.05**	**1.39**	**1.86**	**42.49**

The value of travel time was estimated from the secondary data which is collected from the National Transportation Planning and Research Centre (NATPAC). Data is segregated exclusively for this study and a total of 2000 respondents were gathered, who use this signalized intersection as a part of their travel. Preliminary analysis of data is required to get an insight into the socio-economic characteristics and trip characteristics of trip makers. Table 3 explains the summary statistics of socio-demographic and trip characteristics of respondents.

Table 3: Summary statistics of socio-demographic and trip characteristics of respondents

Variable	Component	Percentage
Gender	Male	75
	Female	25
Marital Status	Married	97
	Unmarried	3
Age distribution	<5	0
	5-14	0
	15-25	3
	26-60	75
	>60	22
Occupation	Government employee	28
	Private employee	36
	Business/self employed	19
	Retired	17
Education	Below SSLC	6
	ITI	13
	SSLC	16
	Plus two	39
	Diploma	17
	Degree	8
	Professional Degree	1
	Post Graduate	0
Personal Income	<=10000	13
	10000-20000	42
	20000-30000	37
	30000-50000	8
	50000-75000	0
	75000-100000	0
	>100000	0
Mode choice	Car	26
	Two-wheeler	42
	Auto rickshaw	11
	Bus	21

The concept of value of travel time (VOT) was introduced by Becker in 1965, with the concepts of the time allocation model (Becker, 1965). The time allocation model describes the consumer allocates his/her time and cost to several activities by maximizing his/her utility under time and budget constraints. DeSerpa (1971) estimated different values of time for different transportation modes and different components of a trip (DeSerpa, 1971). Beesley (1965) recognized the heterogeneity of the value of travel time for various travel segments including waiting time, walking time, and in-vehicle time (Beesley, 1965). Heckman (1974) shows that household size and other demographic factors are important in determining the value of travel time. The concept of value of travel time is based on classical micro-economic theory and can be defined as the marginal trade-off between travel time and travel cost (Small 2012). Value of travel time estimation is based on discrete choice modeling (Brownstone, 2000). The discrete choice model to estimate value of travel time is derived from random utility theory. Random utility theory works on the principle that consumers choose an alternative that brings highest utility from the finest set of available alternatives (McFadden, 1974). The value of travel time is calculated as the ratio of the parameters for travel time over the travel cost. The utility function of the alternative has the form given in below equation.

$$U_i = \beta_{tt}\, TT + \beta_{tc}\, TC + \varepsilon$$

Where β_{tt} and β_{tc} represent respective parameter of travel time and travel cost that are going to be estimated from the utility function and it is estimated by the maximum likelihood method. Hence, value of travel time for each alternative in each situation can be calculated from below Equation.

$$VOT = \frac{\beta_{tt}}{\beta_{tc}} \text{ X } 60 \text{ Rs. /hr}$$

The estimation of the value of travel time was done using Logit model. Since, the respondents have number of responses that influence their trip, multi nominal logit model (MNL) was formulated. The final model was developed based on several iterations, and Table 4 represents the parameter estimates of value of travel time.

Table 4: Value of Travel Time Model

Variable	Car		Bus		Auto Rickshaw		Two-wheeler	
	A	B	A	B	A	B	A	B
Travel time	-0.047	-6.572	-0.109	-9.541	-0.565	-8.28	-0.159	-6.278
Travel cost	-0.012	-4.401	-0.107	-8.289	0.226	-8.567	-0.053	-3.478
Gender	0.87	1.32	0.328	2.31	1.03	2.94	0.496	3.87
Age	0.162	2.65	0.008	3.12	0.73	2.994	-0.152	-5.63
Marital status	0.004	4.31	0.013	1.971	0.0059	1.45	0.012	1.63
Education	0.287	5.015	-0.186	-2.965	0.179	2.026	0.036	3.713
Employment	0.042	1.724	0.077	1.585	0.07	1.83	0.023	3.673
Personal income	0.301	3.017	-0.161	-1.941	-0.162	-1.99	0.105	1.92
VOT (Rs./hr)	**240**		**60**		**150**		**180**	
pseudo R^2	**0.25**							
Alkaline Information Criteria(AIC)	**1.48**							
Log-likelihood of estimated model	-2317.09							

Where, **A** = Coefficient, B = t-statistics

The negative sign of travel time and travel cost indicates that the utility decreases with an increase in travel time and travel cost. The t-statistic values indicated that the travel time and travel cost has significant impact on utilities at 95 % confidence interval. The Pseudo R^2 (ρ^2) values of the model lie between 0.2 and 0.4. This represents acceptable model fit. Alkaline information criteria (AIC) values of the model are low, which also indicates the best model. **From the model developed, value of travel time for car, bus, auto and two-wheeler are estimated as 240 Rs. /hr, 60 Rs. /hr, 150 Rs. /hr and 180 Rs. /hr** respectively and are used for delay cost estimation.

3.2 COST ESTIMATION

Since, the total cost evaluation is the summation of cost for different types of vehicles, cost calculated separately for each mode and aggregated for each approach. Estimation of delay cost at intersection 1 was estimated and presented in Table 5

Table 5: Detailed calculations of Delay Cost for Intersection 1

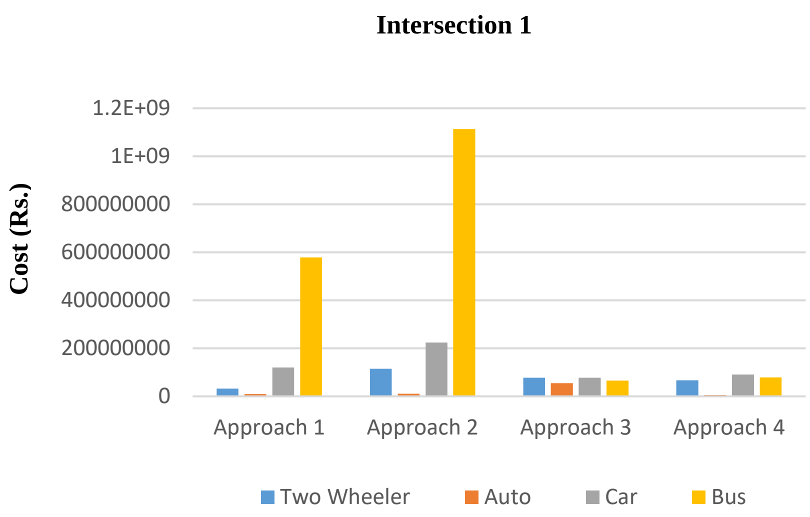
Intersection	Approach	Modes	VOT	Occupancy	Delay	Volume	Delay Cost (Per Day)	Annual delay cost (Rs.)
Intersection 1	1	Two-wheeler	180	1.39	100	520	86,736	3,16,58,640
		Auto	150	1.86		131	24,366	88,93,590
		Car	240	2.05		1003	3,28,984	12,00,79,160
		Bus	60	42.49		933	15,85,727	57,87,90,282
	2	Two-wheeler	180	1.39	205	920	3,145,85	11,48,23,452
		Auto	150	1.86		80	30,504	1,11,33,960
		Car	240	2.05		912	6,13,229	22,38,28,512
		Bus	60	42.49		875	30,48,658	1,11,27,59,988
	3	Two-wheeler	180	1.39	153	828	2,11,309	7,71,27,753
		Auto	150	1.86		532	1,51,397	5,52,59,744
		Car	240	2.05		421	2,11,275	7,71,15,244
		Bus	60	42.49		69	1,79,427	6,54,90,772
	4	Two-wheeler	180	1.39	168	657	1,84,107	6,71,99,116
		Auto	150	1.86		54	16,874	61,58,981
		Car	240	2.05		450	2,47,968	9,05,08,320
		Bus	60	42.49		76	2,17,005	7,92,06,799

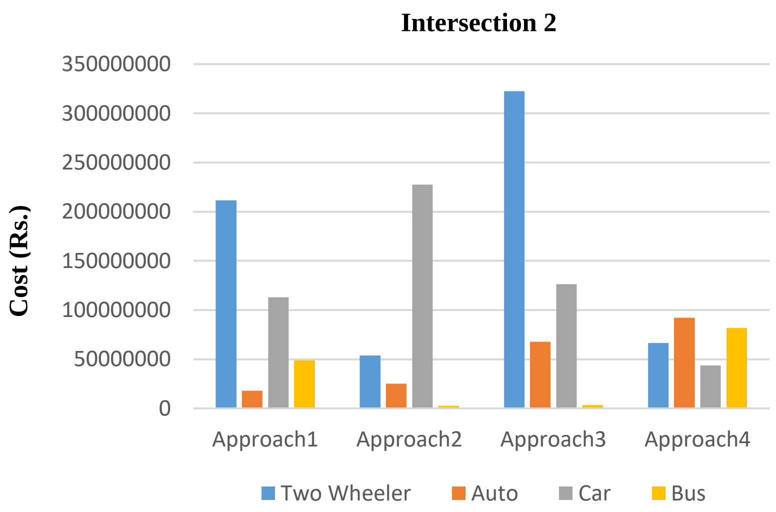
1. Passenger delay cost for two-wheeler at approach1 in Intersection1 = (100/3600)×520×1.39×180 = Rs. 3,614

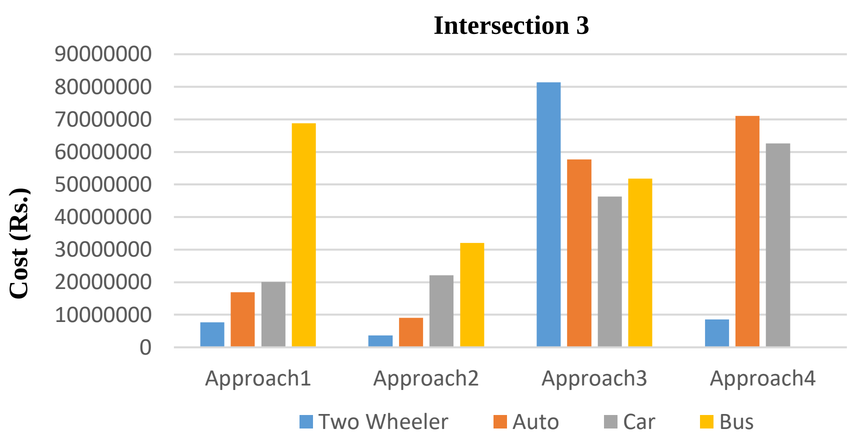
2. Passenger delay cost per day for two-wheeler at approach 1 in Intersection1:
=3614×24 = Rs. 86,736

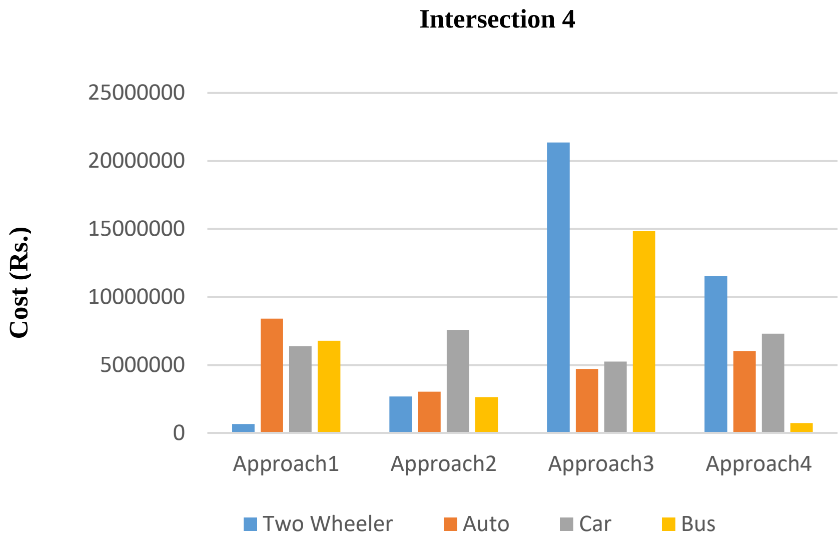
3. Passenger delay cost per year for two-wheeler at approach 1inIntersection1:
=86736×365 = Rs. 3,16,58,640

Therefore, 3 crore rupees are wasted in approach 1 due to congestion in the Intersection. Similarly, the annual delay cost is estimated in each intersection approach wise and it is depicted in below Figure 4.


Intersection 1
Cost (Rs.)
1.2E+09
1E+09
800000000
600000000
400000000
200000000
0
Approach 1
Approach 2
Approach 3
Approach 4
Two Wheeler
Auto
Car
Bus


Intersection 2
Cost (Rs.)
350000000
300000000
250000000
200000000
150000000
100000000
50000000
0
Approach1
Approach2
Approach3
Approach4
Two Wheeler
Auto
Car
Bus


Intersection 3
Cost (Rs.)
90000000
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
Approach1
Approach2
Approach3
Approach4
Two Wheeler
Auto
Car
Bus



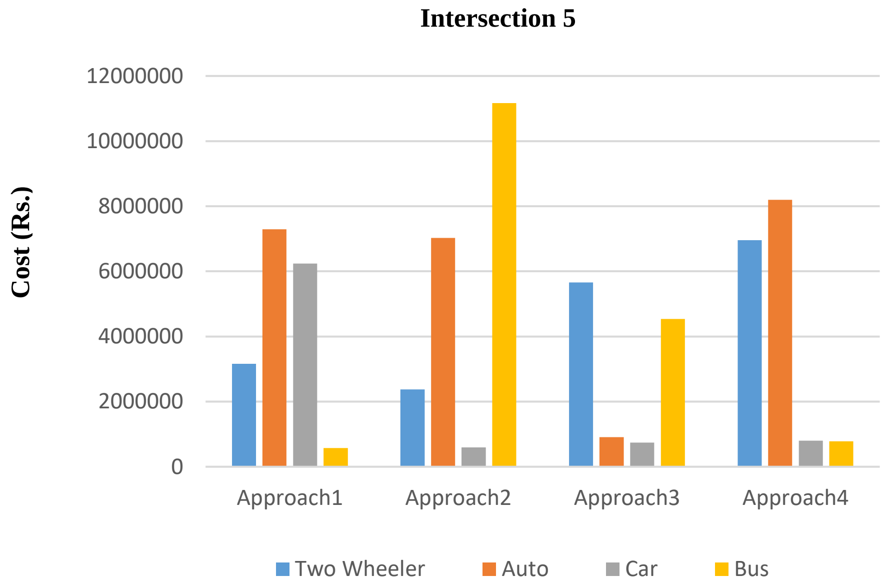


Figure 4: Observed delay cost in study intersections

From the above Figure 4, it was observed that there is a profound variation in the delay cost for different vehicle types in each approach.

3. RELIEF MEASURE

Traffic congestion is the impedance of vehicles impose on each other and can be caused generally as a result of more number of vehicles at same road at same time. Therefore, congestion on roads is increasing due to rapid growth of personalized vehicles. Preliminary analysis reveals that these areas accommodate more number of private vehicles. The traffic composition of different vehicles at intersections is presented in following Table 6.

Table 6: Traffic composition of vehicles in intersections

No.	Road name	TW (%)	Auto (%)	Car (%)	Bus (%)	LCV (%)	MCV (%)	HCV (%)	Cycle (%)
1	Intersection 1	50	17	27	3	1	1	0	1
2	Intersection 2	41	14	38	5	1	0	1	0
3	Intersection 3	38	19	38	2	1	1	0	1
4	Intersection 4	34	26	26	4	0	0	0	0
5	Intersection 5	52	28	12	6	0	0	1	1
	Average	**43**	**21**	**28**	**4**	**1**	**1**	**1**	**1**
	Maximum	**52**	**28**	**38**	**6**	**1**	**1**	**1**	**1**

TW : Two-wheeler
LCV : Light Commercial vehicle
MCV : Medium Commercial vehicle
HCV : Heavy Commercial vehicle

From the traffic composition of the different vehicles of the study intersections, it can be inferred that Two-wheeler (TW) constitute a maximum of 52%, to an average of 43% to the traffic composition. Two-wheeler (TW) has the highest composition of vehicle in the study stretches followed by car an average ranges of 28%. The average percentage of the auto rickshaw in the study stretches is 21% and the bus is 4%. The non-motorized vehicle like light commercial vehicle (LCV), medium commercial vehicle (MCV) and heavy commercial vehicle (HCV) constitute a maximum of 1% and cycles constitute a maximum of 1% to the entire traffic. This indicates that the presence of personal vehicles is high compared to the public and commercial vehicles in the study stretches. From the analysis, it is shown that the two-wheeler percentage is more and hence mode shift is fixed to shift a marginal unit from two-wheeler to bus.

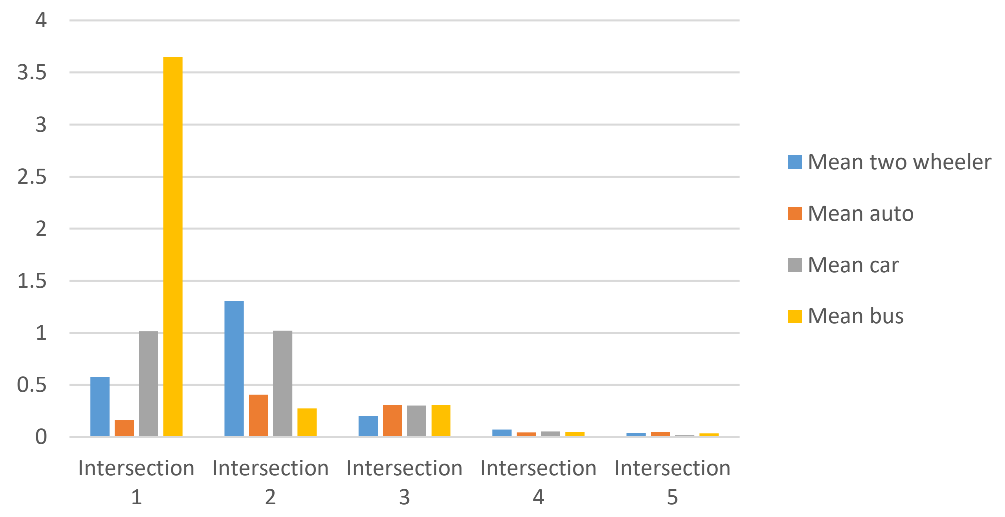


Figure 5: Observed Mode share of the study intersections

To do the mode shift from two-wheeler to bus, unit change reduction of the two-wheeler mode is shifted to bus. Furthermore, the total number of the vehicle that accommodated in the vehicle and changes in the vehicle volumes are calculated. From the derived number of vehicle, the cost associated with the new criteria is calculated and compared with normal conditions. The percentage reduction in the delay cost is observed and shown in following Table 7. A marginal reduction in the two-wheeler volume and mode shifting to public vehicles in these areas reduces the congestion cost as 26%.

Table 7: Summary of percentage reduction in the delay cost in signalized intersection in mode shift criteria

S.NO	Intersection	Approach	Decrease (%)	Overall Percentage Decrease (%)
1	Intersection 1	Approach 1	4.28	$25.8919 \approx 26$
		Approach 2	7.85	
		Approach 3	28	
		Approach 4	38.2	
2	Intersection 2	Approach 1	54.07	
		Approach 2	17.37	
		Approach 3	62.03	
		Approach 4	23.42	
3	Intersection 3	Approach 1	6.75	
		Approach 2	5.5	
		Approach 3	34.3	
		Approach 4	6	
4	Intersection 4	Approach 1	3	
		Approach 2	16.82	
		Approach 3	46.28	
		Approach 4	45.076	
5	Intersection 5	Approach 1	18.32	
		Approach 2	11.23	
		Approach 3	47.76	
		Approach 4	41.55	

Therefore, reducing the personalized vehicles reduces the delay cost. By shifting from two-wheeler to bus reduces the congestion cost indicating the reduction of congestion in the intersection which also allows the traffic flow in a smooth manner. Therefore, this study proposes a policy to encourage the usage of public transport by reducing the usage of two-wheeler in the Indian city especially in these five intersections of Hyderabad city.

4. CONCLUSIONS

The study estimated the traffic congestion cost at signalized intersection located in Hyderabad, an Indian city which prevails heterogeneous traffic condition. This study has taken into account both engineering and economic aspects while dealing with signalized intersection, and estimated passengers delay cost separately for each approach in the signalized intersection. Five 4-legged signalized intersections were considered and delay cost is estimated by considering its components such as traffic delay, passenger occupancy, traffic volume and value of travel time for different vehicle types. From the developed model, value of travel time for car, bus, auto and two-wheeler are estimated as 240 Rs. /hr, 60 Rs. /hr, 150 Rs. /hr and 180 Rs. /hr respectively and further used for delay cost estimation. Annual congestion delay cost for each vehicle type is estimated and aggregated for each approach and the delay cost is expressed in terms of Crore Rupees.

Traffic composition of the different vehicles of the study intersection reveals that the private vehicle, two-wheeler constitute a maximum of 52% to the entire traffic composition. Two-wheeler (TW) has the highest composition of vehicle in the study stretches followed by car an average ranges of 28%. The public vehicle, bus composition the average percentage of the public vehicle, bus constitute only is 4% to the entire traffic. Hence, these studies propose a candid congestion relief measure as a mode shift criteria from two-wheeler to bus. Delay cost is estimated after a marginal mode shift from two-wheeler to bus and compared with the normal condition. From this study, it is observed that congestion cost is reduced as 26 % from original after mode shift process. Therefore, mode shift from personalized vehicle to public vehicle reduces the congestion in the roadway and this study proposes as a policy measure to encourage the usage of public transport by reducing the usage of two-wheeler in Indian cities.

5. FUTURE SCOPE

This study proposes a demand side policy to the Indian city along with the congestion cost estimation at signalized Intersection. The scope of the study is limited to the urban four-legged signalized intersection with observed traffic flow and delay rate. Furthermore, this study has considered only the excess travel time for the congestion cost quantification and does not incorporate the indirect cost components such as wasted fuel and environmental factors. The present study can be further extended to analyze the various supply side and demand side strategies to the traffic congestion problem and thus can provide optimal solutions to the Indian cities. This study pointed out that promoting the usage of public vehicles by reducing the personalized vehicle, reduces the congestion cost to a great extent.

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