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Economic Evaluation of Traffic Congestion at Intersection: Case study from an Indian City

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Abstract

Traffic congestion cause negative impacts to transport sector and cause a massive increase in the transportation cost. Congestion cost evaluation helps wider aspects in the policy and planning and thus by providing potential solution to the traffic congestion problem. This study evaluates the traffic congestion cost at signalized intersections located in the state of Kerala, India which prevail heterogeneous traffic conditions. Congestion cost estimations are done by considering the factors including delay, traffic volume, passenger occupancy, and value of travel time of different vehicle types. Annual congestion cost of traffic congestion at each approaches of signalized intersections are quantified. The mode share of the present study reveals that the private vehicle such as two wheeler and car constitute an average share of 75% of total traffic and which has the maximum share of traffic compared to public vehicles. Therefore, this study considers a candid relief measure proposal as mode shift to public transport from private vehicle. The result shows that marginal change in the two wheeler shift to public transport in Indian city reduce the congestion cost by 38% and thus can promote usage of public transport in the Indian cities to reduce congestion.

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Keywords: Congestion Cost; Signalized Intersection; Heterogeneous Traffic; Mode Shift; Public Transport.

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1. Introduction

Traffic congestion has a direct effect on our quality of life since most people suffer from the daily inconvenience of excessive delay, air pollution and health problem. The growth of traffic congestion in the roadway accumulates over the past few years and has become a major concern for engineers, planners and policy makers in the metropolitan cities around the world. It includes considerable costs for the community and great deal of effort is devoted in every large city to reduce the negative impact of this phenomenon. Traffic congestion is defined as the traffic delay of vehicles and that relates to the travel time difference between the existing roadway and its actual condition and it also occurs when supply side of the road networks are saturated and can longer take additional vehicle(Lomax et al., 1997). Various policy measures including supply side and demand side strategies have to be implemented based on the gravity of the problem around the locality(Basso et al., 2011),(Aftabuzzaman et al., 2011),(Decorla-Souza and Cohen, 1999),(Decorla-Souza and Cohen, 1999). For an appropriate policy measure proposal, it is very essential to quantify the traffic congestion in the monetary value.

Intersection is an important node in the road network and where many activities take place as different direction divergence of traffic, pedestrian activities and signal operation. The concern about growing delay in the signalised intersection is due to an increase in trend in the vehicular traffic volume, in adequate geometric standard on the roadway facilities communicating the impact of extra travel time over the money. The delay causes while waiting time of road users to ease the queue thus by missing important activities and also late arrival in the destination. Hence, delay is reflected as the economic losses for road users. Delay cost, referred as the predominant cost of transportation system and explored as the key element in the economic evaluation of traffic congestion. (Weisbrod et al., 2003), (Goodwin, 2004),(Kockelman, 2004), (Kockelman, 2004),(R Arnott, 2007),(Jenelius et al., 2011). Researchers quantified the congestion cost incorporating operational, traffic flow and passengers characteristics. Delay, number of vehicles, passenger occupancy, and value of travel time of different vehicles are the factors contributing the traffic congestion cost (Hansen, 2001),(Hansen, 2001),(Goodwin, 2004). As predominant indication, this study uses the delay as the key component to quantify the congestion cost at signalized intersection.

Delay, the performance measure that is used for the operational evaluation of the intersection and is estimated as the extra time consumed by the vehicles in traversing the intersection. Depending on the topography, traffic operation in the intersection is made through straight, right and left movements. At signalized intersection, traffic flow movement is controlled by providing a red-amber-green signal at each approach. The mode of vehicle, operational and geometric features of each approach may vary from one another and that cause variations in the delay cost. Hence, delay cost has to be estimated separately for each approach. Additionally, delay cost at signalised intersection is the cumulative effect of delay cost at each approach. The generalized form of congestion cost at signalised intersection is expressed in the equation 1.

$$d_{intersection} = \sum_{i=1}^{n} \sum_{m=1}^{k} delay_{i,m} \, v_{i,m} \, vot_{i,m} \, o \qquad (1)$$

Where delay is the delay of the vehicle, v is the traffic volume, o is the occupancy, vot is the value of travel time, i is the different approaches and m is the vehicle type for an intersection.

Signalized intersection in India has undergone severe delay due to the predominant reasons and sometimes need a separate solution and while an exclusive mitigation of delay in the intersection may smoothen the entire network traffic flow. Hence, this study focuses on the economic evaluation of traffic congestion at signalized intersection as separate entities. Considering these facts, sites are selected for the congestion cost estimation at signalized Intersection.

2. Study area

The study area selected as Thiruvananthapuram which is having more number of entities are signalized intersection in the urban road network .Thiruvananthapuram is the capital of the state of Kerala located at latitude of 8°30'24" N and a longitude of 76°57'24" E. It is the largest and the most populous city in Kerala. Seven signalized intersection, which is operating under heterogeneous traffic condition having 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 actual traffic demand. The salient features of the signalised intersection are summarized in Table 1.

Table 1: Salient features of Signalised Intersection

Name of Intersection	Approach Name	Approach Width(m)	Green time(Seconds)	Cycle Length
Intersection1	Approach1	11.8	45	120
	Approach2	9.1	62	120
	Approach3	5.2	22	120
	Approach4	17.1	22	120
Intersection2	Approch1	11.9	71	120
	Approach2	7.3	59	120
	Approach3	3.3	21	120
	Approach4	3.5	14	120
Intersection3	Approch1	5.8	80	120
	Approach2	11.6	72	120
	Approach3	5.8	19	120
	Approach4	3.5	10	120
Intersection4	Approch1	9.4	70	120
	Approach2	8.5	70	120
	Approach3	6.4	27	120
	Approach4	3.7	27	120
Intersection5	Approch2	10.1	100	150
	Approach1	13.5	110	150
	Approach3	8.1	30	150
	Approach4	3.75	70	150
Intersection6	Approch1	9.1	63	120
	Approach2	9.3	35	120
	Approach3	4.8	85	120
	Approach4	9.5	18	120
Intersection7	Approch1	6.4	105	120
	Approach2	6.3	105	120
	Approach3	3.8	10	120
	Approach4	5.2	18	120

3. Data Collection and Analysis

This study encompasses a methodological frame work for the data collection, data base 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.

For traffic volume data collection, cameras mounted on a tripod were set on tall building near the intersection so that a good view of the intersection covering all the legs of the intersection was obtained. Data collected on a typical day from 7.00 AM to 11.00 AM and 3.30 PM to 6.00 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 data base created for traffic volume. Figure 1 depicts the observed value of traffic in the signalised intersection.

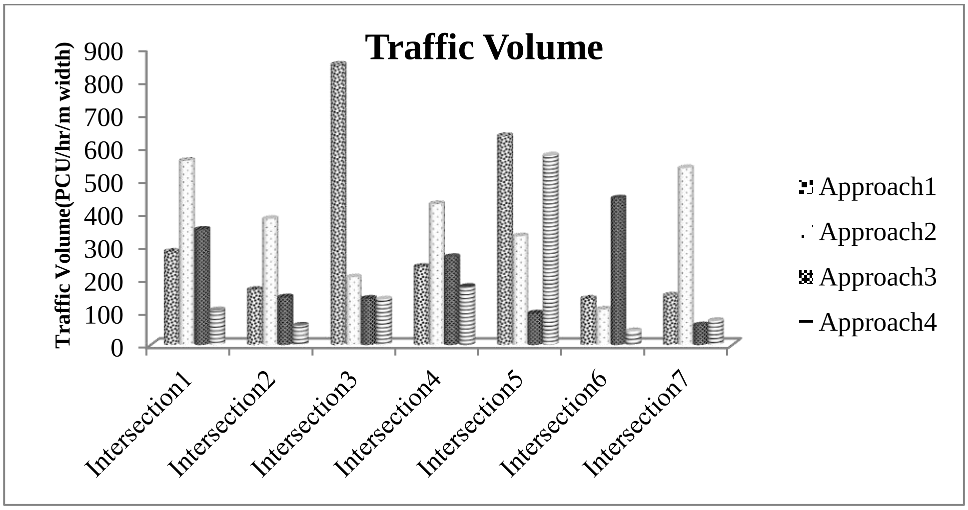


Fig 1: Traffic flow characteristics in the study sites

Delay data collections were carried out by video graphic method. Cameras are placed 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 2 represents the range of observed delay values in the each approach.

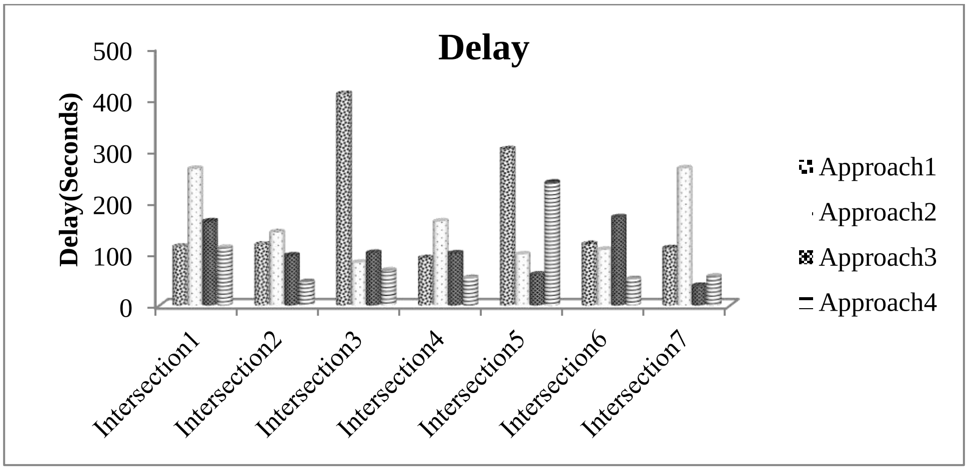


Fig 2: Observed Delay in the study stretches

Passenger occupancy of the vehicle is done by manual observations. Passenger occupancy survey was conducted for different vehicles which include car, two wheeler, auto rickshaw and bus, at two roadway section along the study intersection. For data collection, enumerators are positioned on the sites and noted down the person occupied on it for different mode of vehicles.

Data were collected on two study sites 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 signalised 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
Link 1	1.82	1.26	1.81	37.59
Link 2	2.02	1.4	1.97	45.95
Average Passenger Occupancy	**1.92**	**1.33**	**1.89**	**41.77**

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 signalised 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 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 the household size and other demographic factors are important in determining the value of travel time(Heckman, 1974). 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 which 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 equation (2)

$$U_i = \beta_{tt}TT + \beta_{tc}TC + \varepsilon \qquad (2)$$

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 maximum likelihood method. Hence, value of travel time for each alternative in each situation can be calculated from the Equation (3).

$$VOT = \frac{\beta_{tt}}{\beta_{tc}} \times 60 \text{ Rs/hr} \qquad (3).$$

The estimation of value of travel time was done using Logit model. Since, the respondents have more number of responses that influences their trip, multi nominal regression (MNL) was formulated. Final model was developed based on several iteration, and table 4 represents the parameter estimates of value of travel time.

Table 4: Value of Travel time Model

Variables	**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	-0.01175	-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 R2			**0.25**					
Akaline 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 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.

4. 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 approaches. Estimation of delay cost at the intersection 1 was estimated and presented in the Table 5.

Table 5: Delay Cost for Intersection

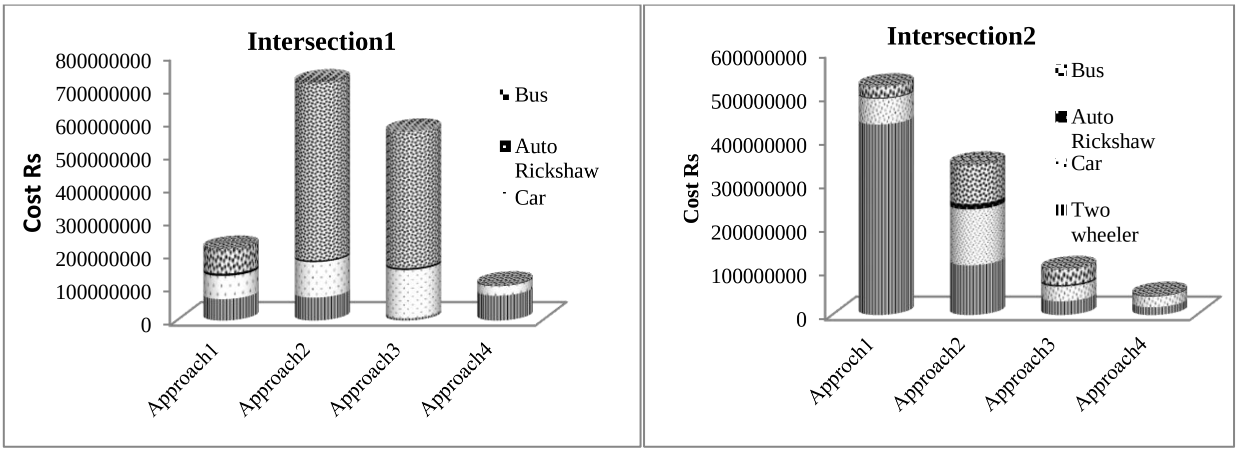
Intersection	Approach	Modes	VOT	Occupancy	DELAY	Volume	DELAY COST (Day)	Annual delay cost(Rs)
Intersection1	Approach1	Two wheeler	180	1.42	107.3	973	177903	64934428
		Auto	150	1.69	107.2	105	19023	6943264
		Car	240	2.11	107.5	526	190896	69677011
		Bus	60	42	107.6	114	206076	75217565
	Approach2	Two wheeler	180	1.42	92.14	920	144446	52722803
		Auto	150	1.69	93.9	80	12707	4638221
		Car	240	2.11	93.69	912	288463	105289092
		Bus	60	42	94.12	875	1383564	505000860
	Approach3	Two wheeler	180	1.42	70.12	183	21866	7980966
		Auto	150	1.69	71.3	131	15805	5768771
		Car	240	2.11	71.9	1660	402939	147072773
		Bus	60	42	72.51	933	1136551	414841022
	Approach4	Two wheeler	180	1.42	53.14	657	59500	21717409
		Auto	150	1.69	54.127	54	4940	1802965
		Car	240	2.11	55.01	450	83571	30503485
		Bus	60	42	55.98	8	7524	2746155

Passenger delay cost for two wheeler at approach 1 in Intersection1 = (107.3/3600)*973*1.42*180
=7413 Rs

Passenger delay cost per day for two wheeler at approach 1 in Intersection1 =7413*24
=177903 Rs

Passenger delay cost per year for two wheeler at approach 1 in Intersection1=177903*365
=64934428 Rs

Therefore 64 core rupees are wasted in the 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 Figure 3.



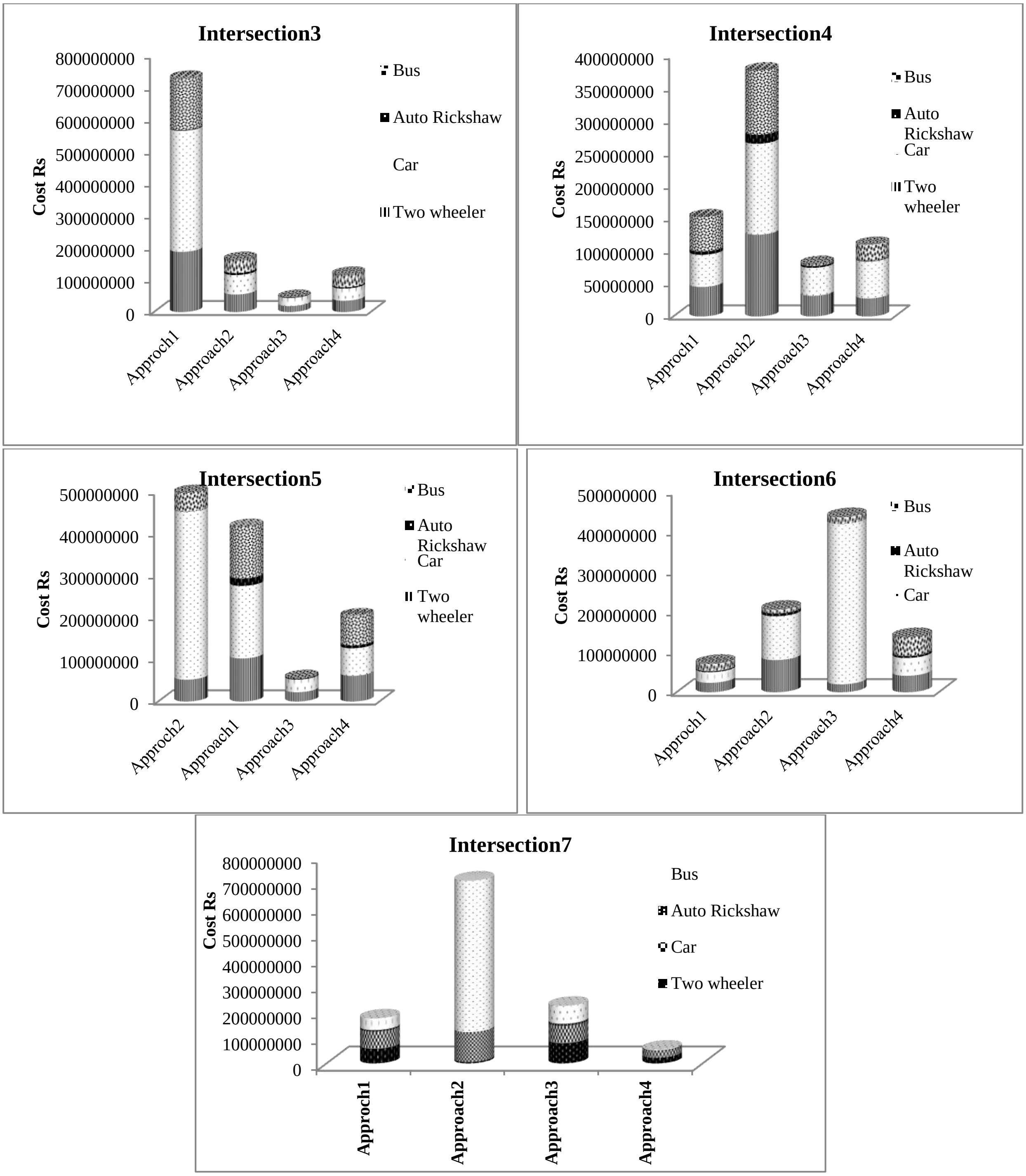


Fig 3: Observed Delay cost in the study stretches

From the figure 3, it is observed that there is a profound variation in the delay cost for different vehicle types in each approach.

5. Relief Measure

Traffic congestion is the impedance of vehicle 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 Thiruvananthapuram city accommodates more number of private vehicles. The traffic composition of different vehicles at intersection is presented in Table 6.

Table 6: Traffic composition of Vehicles in Intersection

SI No	Road name	TW (%)	Auto (%)	Car (%)	Bus (%)	LCV (%)	MCV (%)	HCV (%)	Cycle (%)
1	Intersection1	45	13	37	4	1	0	0	0
2	Intersection2	37	12	46	3	1	0	0	1
3	Intersection3	45	18	32	4	1	0	0	0
4	Intersection4	47	21	27	4	1	0	0	0
5	Intersection5	40	27	25	8	0	0	0	0
6	Intersection6	43	20	33	3	1	0	0	0
7	Intersection7	43	22	33	1	1	0	0	0
	Average	***43***	***19***	***33***	***4***	***1***	***0***	***0***	***0***
	Maximum	***47***	***27***	***46***	***8***	***1***	***0***	***0***	***1***

Note: TW-Two wheeler, LCV: Light Commercial vehicle, MCV: Medium Commercial vehicles

From the traffic composition of different vehicle of the study intersection, it can be inferred that Two wheeler (TW) constitute a maximum of 47%, 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 33%.The average percentage of the auto rickshaw in the study stretches is 19% and the bus is4%.

The non-motorized vehicle like light commercial vehicle (LCV), medium commercial vehicle (MCV) and high 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. Hence, an effort is made to shift mode share from private vehicle to public vehicles and the corresponding monetary valuation have to be assessed to find out the economic benefits. From the analysis, it shown that the two wheeler percentage is more and hence mode shift is fixed to shift a marginal unit from two wheeler to bus.

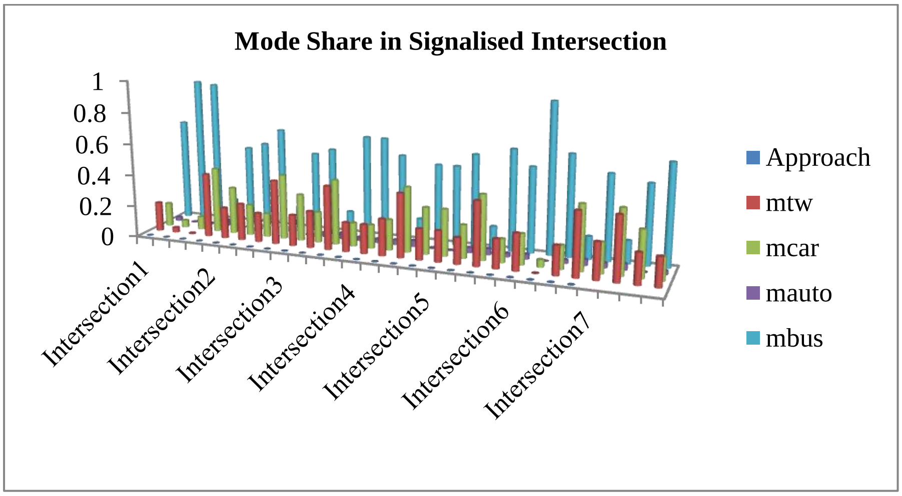


Fig 4: Observed Mode share of the study stretches

Table 7: Summary statistics of the Mode share

	TW	Car	Auto	Bus
Minimum	0.00	0.05	0.00	0.15
Average	0.23	0.24	0.02	0.50
Std.Deviation	0.12	0.12	0.01	0.24
Maximum	0.40	0.41	0.04	1.00

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 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 are calculated and compared with normal condition. The percentage reduction in the delay cost is observed and shown in following Table 8. Marginal reduction in the two wheeler volume and mode shifting to public vehicle in the Thiruvananthapuram city reduces the congestion cost as 38%.

Table 8: Percentage Reduction in the delay cost in signalized Intersection in in Mode shift Criteria

SI NO	Intersection	Approach	Percentage Decrease	Overall Decrease	Percentage
1	Intersection1	Approach1	53.88	**37.57**	
		Approach2	36.17		
		Approach3	6.37		
		Approach4	50.34		
2	Intersection2	Approch1	91.45		
		Approach2	53.31		
		Approach3	53.94		
		Approach4	50.34		
3	Intersection3	Approch1	41.75		
		Approach2	53.51		
		Approach3	50.24		
		Approach4	53.94		
4	Intersection4	Approch1	53.55		
		Approach2	53.53		
		Approach3	50.04		
		Approach4	41.09		
5	Intersection5	Approch1	77.49		
		Approach2	43.15		
		Approach3	50.31		
		Approach4	53.98		
6	Intersection6	Approch1	53.51		
		Approach2	50.28		
		Approach3	90.55		
		Approach4	53.87		
7	Intersection7	Approch1	52.04		
		Approach2	3.99		
		Approach3	58.51		
		Approach4	50.75		

Therefore, reducing the personalised vehicle 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 to Thiruvananthapuram.

6. Conclusion

The Present study estimated the traffic congestion cost at signalised intersection located in Thiruvananthapuram, an Indian city which prevail heterogeneous traffic condition. This study has taken into account both engineering and economic aspects while dealing with signalised intersection, and estimated passengers delay cost separately for each approaches in the signalised intersection. Seven four legged signalised intersection were considered and delay cost is estimated by considering its components such as delay, occupancy, traffic volume and value of travel time for different vehicle type. 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 approaches and the delay cost is expressed in terms of Crore Rupees.

Traffic composition of different vehicle of the study intersection reveals that the private vehicle, two wheeler constitute a maximum of 47%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 33%.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 form 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 38 % from original after mode shift process. Therefore, mode shift from personalised 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.

This study proposes a demand side policy to the Indian city along with the congestion cost estimation at signalised Intersection. The scope of the study is limited to the urban four legged signalised 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 analyse the various supply side and demand side strategies to the traffic congestion problem and thus can provide optimal solution to the Indian cities. This study pointed out that promoting the usage of public vehicle by reducing the personalized vehicle reduces the congestion cost to a great extent.

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