Estimation of Cordon Based Marginal Congestion Cost for Greater Mumbai Road Network

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Abstract:

  Road user is associated with many externalities during one's travels. In this study externalities like congestion and environmental costs of urban transport are evaluated with respect to their marginal effects on others. Marginal costs are analyzed for different Level of Service in terms of Volume to Capacity ratio for urban road network. Marginal cost pricing methodology is developed and applied to the Greater Mumbai city road network to estimate marginal congestion effects. GIS based transportation planning software, TransCAD and GISDK is used for data storing, displaying and analyzing. Analysis results are compared to different operating conditions. The congestion cost for complete Greater Mumbai road network for the present traffic flow condition is found as 163.12 million Rupees.

Keywords**:** PCU, Level of Service, V/C Ratio, Cordon line, TransCAD., Value of Time

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1. Introduction

   In India, the urban population per decade has grown from ten percent in 1901 to twenty eight percent in 2001. Out of total urban population, around 38 percent people are living in metropolitan cities (population of one million and more) that numbers about 35. This high growth in population within a limited area of these metropolitan cities resulted in insupportable densely populated mass dwelling in a screeched environment. In-addition to growth in population, the economic of India is also rising steadily; lead to heavy commercial activities are occurring in the cities. Travel demand has increased many folds because of a surge in public and commercial vehicles after the economic liberization policy adopted during the early nineties. The private owned vehicles has evolved from an expensive luxury for a few to become an important tool for the everyday lives and employment of the majority of people, a status symbol and a hobby. For which in developing countries like India, people in metropolitan areas are facing lot of problems because of heavy traffic congestion during peak hours.

   For many years congestion was little more than a localized problem. Today it has become endemic, not just in major cities but even in many small towns. The rapid growth of traffic congestion on urban roads and the resulting impediment to urban mobility is a serious concern to

urban management professionals and decision makers. In attempting to alleviate the congestion on urban roads, it is commonly found that the improvement of roads is restricted by increasingly tight fiscal and physical constraints. However, addressing the problem through rational traffic management measures like restricting the entry of certain types of vehicle during peak periods of traffic flow or enforcing congestion pricing is considered to be a more acceptable alternative.

Congestion is the inconvenience caused due to over-utilization of road infrastructures. Congestion pricing is the increased costs that travelers bear while using their vehicles on the road network. Congestion pricing either acts as a deterrent to the use of over-used roadways by imposing fees on the use of such infrastructure. This fee may vary depending on location, time or occupancy in the vehicle. It offers a priced substitute to an existing congested road that facilitates the motorist to reduce the total travel time. These fees are intended to reduce congestion and decrease externalities by persuading people to change their travel patterns by shifting to off-peak periods, less congested travel routes, higher occupancy vehicles, or a different mode of transport (for example public transit). There are several congestion pricing measures which may be implemented such as variable tolls, high occupancy vehicle (HOV) lane permits, vehicle miles traveled (VMT) fees and parking fees.

Greater Mumbai Region (GMR) is considered as the study area in this research. Mumbai, is the financial, commercial and entertainment capital of India as it generates 6.16 % of total GDP of the country . It is the most populous city in India, and the fourth most populous city in the world, with a total metropolitan area population of approximately 20.5 million. It is also one of the World's top 10 centers of commerce in terms of global financial flow and accounting for 25% of industrial output, 70% of maritime trade in India and 70% capital transactions to India's economy. Hence, the study region has generated a high level of demand for travel by motor vehicles; however to match the increasing travel demand, commensurate efforts have not been made to develop the mass transport systems. Sub-urban surface rail service is available to reach most part of the study region. Since there is a big gap between the demand and supply in the public transport service commuters are forced to use their own vehicles. Few studies on mass transport suggest that the existing facilities provide poor levels of service (D, E, F) to users. Greater Mumbai is confined by Arabian sea from three sides, hence there is limited opportunity to develop additional mass public transportation system on the surface. In order to discourage commuters to use their privately owned vehicles during peak hours, additional toll in terms of marginal congestion cost is one of the suggestion which can be implemented to streamline the traffic. As the study area is very large, monitoring of all the vehicles within the area is a difficult part, for which implication of area-based pricing is not easy . The research methodology for congestion pricing and its implementation strategies are well established in India. In this study cordon based pricing methodology is followed where the only vehicles entering to the cordon area are taken into account for calculation purpose. Traffic data such as volume, speed and capacity of nineteen different types of links are collected and macros in TransCAD are developed for the assessment of marginal delay on link types which are used for the estimation of congestion cost. For the estimation of congestion toll, the average value of time (which includes waiting time, travel time and discomfort level) per trip is taken from the stated preference (SP) survey conducted. The average value of time for road user is estimated to be 45 rupees (   ) per hour.

The Greater Mumbai road network is divided by six screen lines and one outer cordon line. The congestion toll is estimated on these six screen lines (treated as inner cordon lines) plus a

cordon line. The current demand on each link is assessed based on the flow of traffic on each link which relate to their respective boundary screen line *V/C* ratio. The average of peak hour *V/C* of all station points of screen lines are calculated which represents the screen lines operating conditions. The marginal congestion cost is calculated for *V/C* raio of 0.7,0.75,0.80,0.85 and 0.90. The total cost of road network is calculated by using daily travel demand. From this study it is found that for Greater Mumbai road network the congestion cost should be fixed at 2.69 rupees ( ) per pcu-km.

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2. Review of Literature

Traffic congestion is a widely recognized transport cost. It is a significant factor in the transport system performance evaluation and affects transport planning decisions. To individual motorists, congestion is a cost they bear, but each motorist also imposes congestion on other road users. The existence of congestion can be explained by the fact that each additional vehicle imposes more total delay on others than they bear, resulting in economically excessive traffic volumes. Congestion pricing is designed to charge each motorist the marginal congestion cost they impose.

The principle of marginal cost pricing of urban transportation infrastructure has become increasingly politically acceptable. Recent studies have made great strides forward towards developing more detailed and realistic urban transportation network models and more accurate empirical estimates of marginal congestion costs (MCC). Precise estimation of congestion costs is important and policy-relevant for several reasons. First, they serve as status indicators that describe the current state and trends of congestion. Second, congestion costs provide a basis for cost-benefit analysis that assesses whether individual projects and programs are worthwhile investments. Finally and possibly most importantly, obtaining accurate marginal congestion costs is crucial for designing efficient transportation infrastructure pricing schemes. Worldwide, very few cities have implemented the congestion pricing programs. Recently London implemented an areawide value pricing. Singapore has long experience since 1975 in cordon based congestion pricing program. Road pricing on a particular facility exist in Toronto, France, Florida, New York, New Jersey, Sandi ego, California, and Houston.

It has been proposed that the toll should be lower the greater the damage a person suffers from congestion (Glazer and Niskanen, 2005). Inner-city residents living near congested areas should be charged a lower toll than is commuters. The toll on a car with multiple passengers should be lower than on a single-occupant car; trucks, which are inherently slow-moving even with no congestion, should be charged a higher toll than are fast moving cars. The authors illustrated how to determine the toll charge that satisfies the criterion of justice and suggested the character for the adoption of socially acceptable principle. A sound network model has been established for evaluating area-based pricing and to compare the effects of area-based pricing and cordon-based pricing (Maruyama and Harata, 2006). The authors found that area-based pricing can be more difficult to implement in practice than cordon-based pricing, especially if the charging area is large, because all cars within the pricing area have to be monitored, whereas with cordon-based pricing only cars entering the cordon area have to be checked. The authors have used a novel approach featuring a trip-chain–based network equilibrium model with non-additive

costs where drivers have to pay at most once per trip chain and they should make decisions to change their behavior in response to congestion pricing according to the trip-chain cost.

An in-depth research have been carried-out to evaluate the importance of a number of factors that contributed to the lack of acceptability of the proposed congestion charge scheme in Edinburgh, UK which ultimately manifested itself in the public's rejection of the scheme in the referendum (Allen et al., 2006). The authors examined the residents habitual choice and frequency of use of transport mode; their understanding of the details of the scheme; and their attitude towards congestion. The authors have suggested that more attention should have been paid to designing a simpler, more easily communicated scheme and convincing residents, particularly public transport users, of its benefits. Income seems the most relevant variable in road pricing because equity is often an issue when it comes to implementation of pricing measures and policy makers may want to compensate the lower income groups. It appears that lower income groups have a stronger preference to lower existing income taxes with revenues from road pricing compared with higher income people (Ubbels and Verhoef, 2006).

The Strategic Policy Niche Management (SPNM) framework is used to analyze the UK and Italian road pricing schemes which have helped and highlights a number of key issues in the process leading up to and implementing radical traffic control measure. The SPNM method is designed to explore, among other factors, the dynamics of the stakeholder networks involved in planning, introducing, marketing and managing radical urban Travel Demand Management policies. A flat kilometer charge affects social trips considerably more than commuting trips (Ieromonachou et al., 2006). Studies found that the relevance of road pricing would be enhanced as an experience in its use, especially when introduced in policy packages with other measures, builds up (Ieromonachou and Warren, 2008). It has been mentioned that despite the grand plans from early year 2000, the success of the London scheme, and despite growing congestion within and between England's larger urban areas, congestion charging has not yet been adopted more widely (Richards, 2008). However, it remains a core element of English transport policy, with successive transport secretaries speaking about the need for a national debate, but then failing to lead it. Analysis have been done about the behavioural responses to three different, policy relevant, road pricing measures and shows that depending on the type of measure and type of trip affected, they find reductions in the number of car trips of, on average, 11% (Ubbels and Verhoef, 2005). A model has been developed for traffic management on expressway networks in Barcelona metropolitan areas of Spain for congestion pricing which is based on marginal social cost theory, and it is used to quantify the maximum favorable change in social welfare (Salas et al., 2009). This model can also be adapted to several schemes of road pricing, including the typical cordon and kilometric pricing. In this case, the structure is accessible tariff plus a kilometric toll. TRUCEST, a quick response, low-budget model has been applied for evaluating the impacts of statewide congestion pricing scenarios for urban freeways by which, alternative congestion pricing situation was analyzed in an eastern state of the USA as a case study in a relatively short period of time (DeCorla-Souza and Luskin, 2009). The estimates were intended to provide a preliminary indication of the magnitude of revenues that may be generated through alternative statewide congestion-pricing scenarios. A new procedure has been proposed for the marginal-cost based congestion pricing, where the explicit expressions of the demand function are unknown where demand function is the behavioral relationship between quantity consumed and a person's maximum willingness to pay for incremental increases in quantity (Han and Yang, 2009). Also the authors enhanced a trial-and-error implementation scheme of the marginal-cost pricing on a transportation network, in the absence of explicit expression of the demand function .

It is observed that the road pricing is more likely to be implemented when equity issues of all kinds are addressed openly and efforts to educate the public are broad and sincere. Such efforts allow public and elected official's input to influence project design to address equity concerns, thereby broadening the political base of support (Taylor and Kalauskas, 2010). A comparison indicates that Chicago travelers are more willing to pay tolls and to use toll roads than travelers elsewhere in USA. This willingness may be because Chicago has a robust transportation system and has had toll roads for more than 50 years, and therefore Chicago travelers have more travel options and are more familiar with toll roads (Greene and Smith, 2010). However, Chicago travelers are similar in terms of their environmental attitudes and have comparable opinions of travelers in the other cities. A study focused on how the Metropolitan Planning Organizations, state DOTs of USA, and other key agencies interact, contribute, and cooperate in considering congestion pricing (Loudon et al., 2010). The research also produced information on methods to evaluate these strategies, including modeling tools and performance measures used. Federal grants used to fund studies on projects in the early stages of consideration of congestion pricing and equity effects are also taken into account and managed lanes in the 10 regions. A study has been reviewed, identified and assessed ways of making congestion pricing justifiable and fairness required related to implementation of congestion pricing and explored the equity issues that aroused in the context of cordon and area pricing systems (Ecola and Light, 2010). A Multi Criterion Dynamic User Equilibrium (MDUE) model is presented that explicitly considers heterogeneous users that seek to minimize three essential decision attributes, travel time, out-of-pocket cost, and travel time reliability, in the underlying path choice framework (Jiang et al., 2011). The MDUE problem is reformulated, via a gap function, as a nonlinear minimization problem and then solved by a simulation-based column generation algorithmic framework to obtain MDUE path flow patterns. The proposed MDUE model is capable of considering different vehicle classes, namely low-occupy vehicles and high-occupy vehicles and the model is applicable for analyzing a variety of road pricing scenarios. A way has been proposed to implement such a system, with separately priced lanes for premium-service motorists, regular motorists, and heavy trucks and also sketched out a possible evolutionary approach to implement such a system, in which each step can be justified on its own merits (Poole, 2011). the optimal toll design problem have been solved for the distance-based toll-charge method of cordon-based congestion pricing scheme and developed a Mathematical Programming with Equilibrium Constraints (MPEC) model for the toll-charge function with maximal total social benefits (TSB) value (Meng et al., 2012).

Congestion pricing though successfully implemented by few urban areas worldwide, many issues still remained to be tackled by the agencies to make it socially acceptable. In most of the studies, it has been suggested that more attention should be paid in designing a simpler congestion toll charging scheme. Some studies compared area-based pricing and cordon-based pricing and found that area-based pricing is more difficult to implement. Cordon-based pricing is convenient because only vehicles within the pricing area have to be checked. In the recent past marginal congestion cost is becoming more acceptable to users because it is based on the behavioral relationship between quantity consumed and a person's maximum willingness to pay for the extra.

3. Greater Mumbai Road Network

Mumbai is the commercial capital of India. Study area covers the Western Suburbs, Eastern Suburbs and Island City. Greater Mumbai has 468 sq. Km area with 12.5 million plus population. Vehicle ownership in the Greater Mumbai region during the 1991-2003 period has increased from 0.63 Million to 1.12 Million. Cars, taxis, public and private buses, auto rickshaws, two wheelers, trucks, and multi axle vehicles are the main modes of road transport available in Greater Mumbai. GIS based transportation planning software TransCAD and GISDK is used for data storing displaying and analyzing. Macros are built to estimate link based congestion effects. The available digitized road network of the Greater Mumbai region is adopted for the analysis of the collected data set in GIS environment. In the study area, nineteen different link types were identified by MMPG (Mumbai Metro Planning Group). Links are classified based on the link type, number of lanes, divided or undivided pavement, type of flow and free flow speed etc. These link characteristics of the road network are coded in the TransCAD. For each link type speed flow model parameters are assigned. Using a data view in TransCAD, this link database is given input to the GISDK macro. Analysis has been done by developing macros in GISDK. Figure 1 shows the Greater Mumbai road network with seven Cordon lines (1-7).
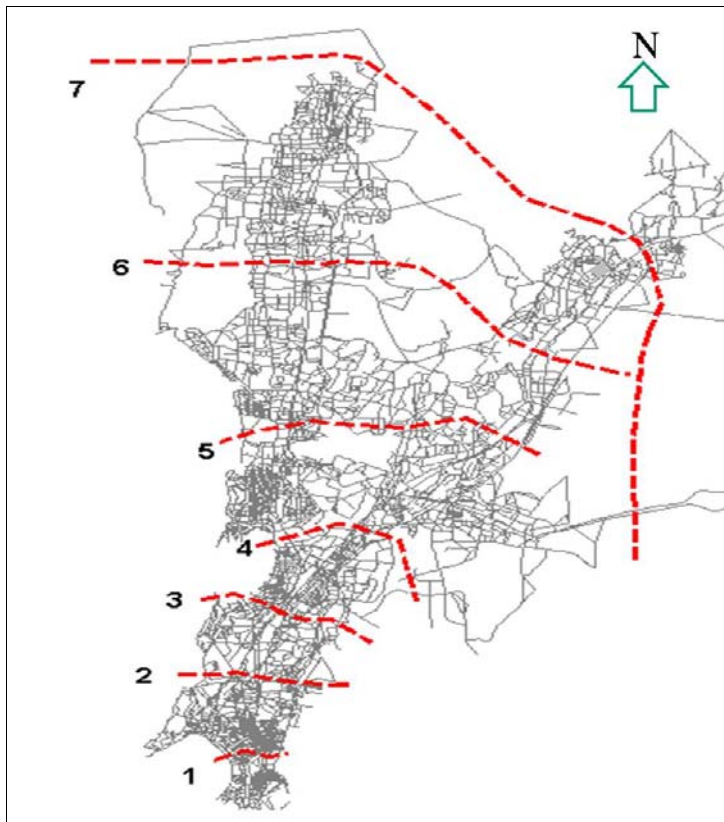

Figure 1: Greater Mumbai Roads Network Map with Screen and Cordon Area

4. Study Methodology

The selected methodology for this research work is based on evaluation of marginal cost pricing applied in the Greater Mumbai road network. Speed flow relationships in the study have been taken from the results found from similar kind of studies conducted in the study area. Detailed description about estimation of tolls and results are discussed in subsequent sub-sections. The methodology adopted in this study is shown in Figure 2 and explained subsequently.
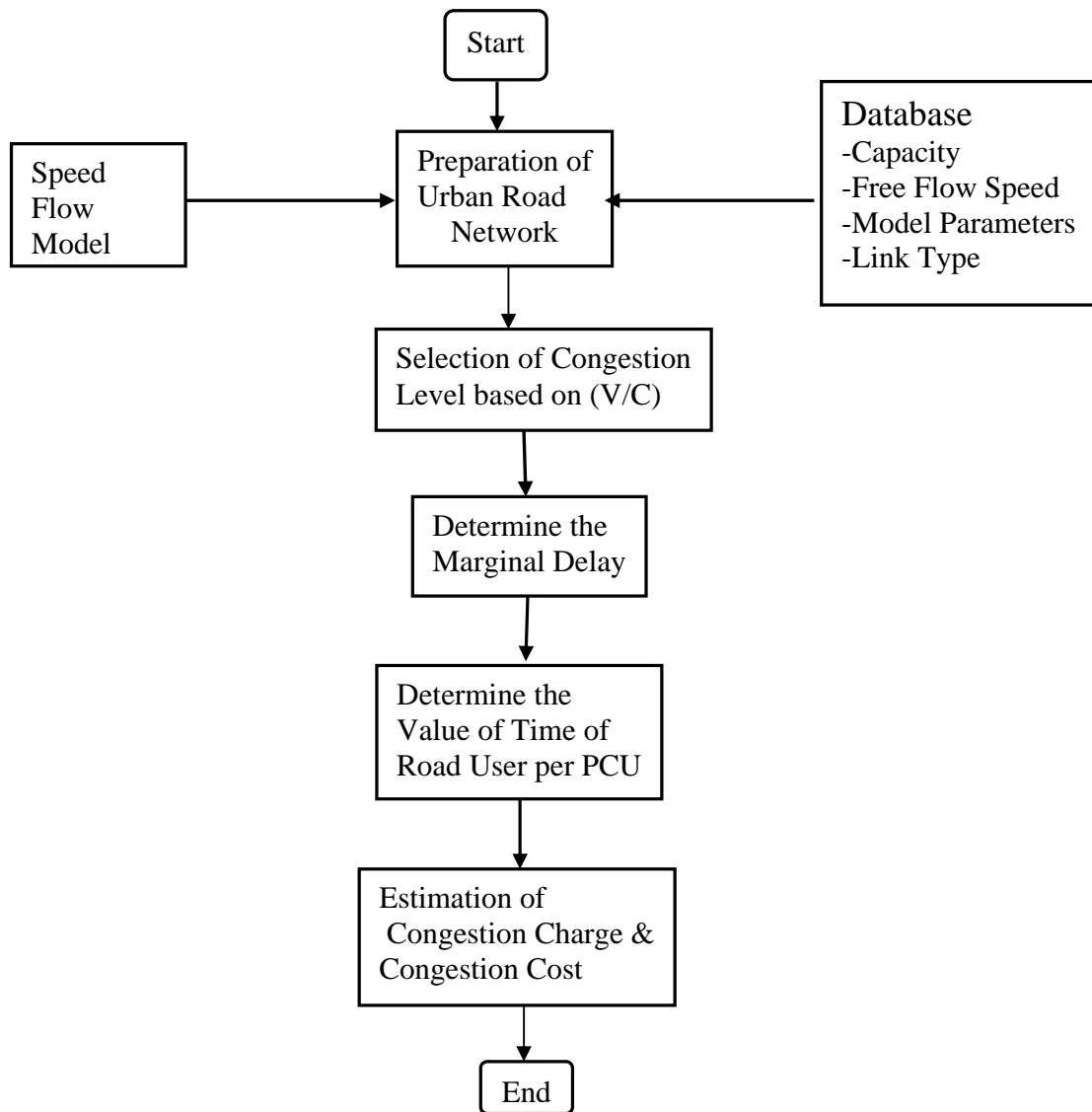

Figure 2 : Overall Framework of Study Methodology

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4.1 Speed-Flow Relationship

Estimation of marginal congestion cost requires speed flow relationship, which can show the building of congestion with respect to flow. For Greater Mumbai road network overall aggregate area wide speed flow relationship is not available. Many of the past studies on Greater Mumbai road network shows the single link based speed flow models are well suitable for the application purpose. For this study speed-flow equation developed in MMS (1997) is applied for congestion toll estimation.

$$S = S_f \left[1 - \alpha \left(\frac{V}{C} \right)^{\beta} \right] \tag{1}$$

Where,

S_f = Free flow Speed
S = Speed of the traffic stream
V = Link volume
C = Link capacity
α, β = Calibration parameters

4.2 Derivation of Congestion Toll

The practical relevance of three empirical elements, namely, the speed-flow relationship, the demand function, and the cost that the implementation of a congestion pricing system follows for Singapore (Li, 2002). The author derived the theoretical congestion toll estimate for a class of speed-flow relationship and further proposed optimal congestion toll based on this relationship. The calculation of congestion cost is illustrated through Figur 3. With traffic volumes up to V1, the lack of congestion means that these costs remain constant. Once the traffic volume on the road goes beyond V1, vehicles begin to slow one another down. This forces the marginal (private) generalized cost of the trip making to increase because of these slower speed journeys take longer time and vehicle costs to rise as drivers engage lower gears and begin to stop and start frequently to permit movement through the congested road.
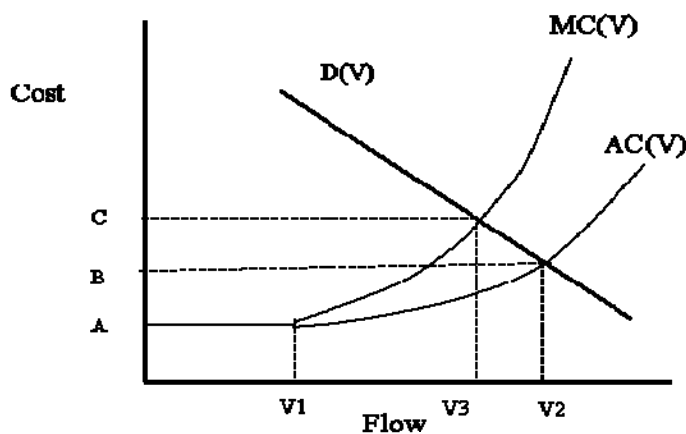

Figure 3 : Congestion Toll Estimation

(Source: Li, 2002)

External congestion costs occur when the presence of one vehicle increases the journey time of another. Each motorist will decide whether it is worthwhile making a journey along the road of contrasting the benefit he would obtain (as reflected by demand curve, it also indicates the willingness to pay) against the cost of the trip borne by him. Market conditions, therefore, the market equilibrium traffic volume would be at (V2). This is however not the optimal flow because the average social cost curve AC (also the marginal private cost) does not take into account the congestion costs the marginal motorist imposes on other road users. The difference between the marginal cost and the average cost is the congestion cost caused by additional vehicle. In Figur 3 MC curve depicts the marginal social cost and D is the inverse demand line. It is clear that the MC curve diverge from AC curve when congestion starts on the building.

At traffic volume (V2), marginal social cost of traffic exceeds the marginal benefits gained, i.e. MC (V2) >D (V2) . That means, there is excessive congestion imposing marginal costs of using on other motorists in excess of benefits gained by a marginal driver. In volume (V3), when demand for road space is equated with the full marginal costs of using it, at any volume above (V3) the additional overall cost of trip making is greater than the benefits gained. The difficulty is to make motorists aware most of the congestion costs they impose upon others and to effectively reduce the traffic volume at (V3).

Then average cost, Per Km.
$$AC(V) = c \times (D/S) = c/S \tag{2}$$
Hence, the cost of each additional vehicles i.e., Marginal Cost *(MC)* becomes,
$$MC(V) = \frac{dTC(V)}{dV}$$
$$= AC(V) - \frac{V \times c}{S^2} \frac{dS}{dV} \tag{3}$$
Where, *TC* is the total cost
Therefore,
$$TOLL = MC(V_3) - AC(V_3) \tag{4}$$

From equation 1, 2 and 3,

$$V = C \left[\frac{1 - \frac{S}{S_f}}{\alpha} \right]^{1/\beta}$$

$$\frac{dV}{dS} = -\frac{C}{\beta} \left(\frac{1}{S_f \alpha} \right)^{\left(\frac{1}{\beta} - 1 \right)}$$

According to derivation,

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$$TOLL = -\frac{Vc}{S^2}\Big/\frac{dV}{dS}$$

$$TOLL = -\frac{Vc}{S^2}\frac{\beta}{C}\left(\frac{1}{\left(\frac{1}{S_f\alpha}\right)^{\left(\frac{1}{\beta}-1\right)}}\right) \qquad (5)$$

The congestion toll can be estimated if the link characteristics and link parameters are known.

4.3 Toll Analysis for Mumbai Road Network

The Mumbai road network is divided into 19 different types of links. All these attributes are coded to the map layer in TransCAD. Equation (5) needs input as cost in terms of generalized cost. Generalized cost involves vehicle operating costs plus time costs. The major cost is the value of time, which is only considered for this work. For this study subjective values of time based on *SP* survey result were considered, which are as shown in Table 1. Where *WT, TT, DC* are waiting time, travel time and discomfort respectively.

Table 1: Subjective values of Time

Mode of travel	WT	TT	DC
Two Wheeler	44	36.5	27
Car	-	79	65
Bus	22.5	20	1.9
II Rail (Fast service)	15	13	1.5
I Rail (slow service)	24	20	2.8

For analysis of congestion toll, the average value of time of road based passenger (Two Wheeler, Car, Bus) is taken. Therefore the average value of time for road user in Mumbai is 45 Rupees ( ) per hour.

4.4 Screen line Toll Analysis

Greater Mumbai is an Island city with a linear pattern of transport network having predominant north-south commuter movements. Passengers move towards south for work trips during morning hours and return back towards north during evening hours. The complete network is divided into three parts namely Eastern sub-urban, Western sub-urban and Island City. Within the limited space maximum activities occur for office and commercial purpose, hence South Mumbai is the most congested one. All these areas got different growth, so it is not convenient to put single charge based on the whole network. The current road network is divided

by six screen lines (1 to 6) and one outer cordon line (7) as shown in Figure 1. Based on geography and travel characteristics of this city, it is decided to estimate tolls on each screen line (treated as the inner cordon lines in the area within). Screen line 1 cordons the area below it, screen line 2 cordons the network area between screen line1 & 2, screen line 3 cordons the network area between screen line 2 & 3, and vice versa. The complete network is divided according to screen line using the selection tool in TransCAD. All links are marked according to their screen line coverage by creating an extra field. Complete network data are analyzed by developing a macro in GISDK programming. For input, network data are called in macro from TransCAD dataview file. Congestion tolls were calculated for 6 screen lines plus a cordon line. The cost of congestion for the complete Mumbai road network was also estimated.

4.5 Congestion Costs

As has been discussed in the theory of congestion pricing, congestion cost is the difference between marginal cost and average cost on that link. In order to estimate present congestion costs, it is required to assess the present demand on each link. Demand estimation is a tedious process, so here some approximation is made towards current demand on each link; flows on each link are related to their respective boundary screen line *V/C* ratios (also represented as levels of service). Present network congestion costs were quantified based on the observed average *V/C* ratio. Adopted PCU values in this study are shown in Table 2. Traffic volume data for 6 screen lines and a cordon line was obtained from a study carried out by the research group. Each screen line has 4 to 8 volume count stations. Peak hour *V/C* ratios are calculated on each volume count station. Average *V/C* ratios of all stations were estimated to that screen line, as it represents screen line operating conditions. To assess flows on each link within the area between screen lines, the average *V/C* ratio of boundary screen lines is applied. The estimated *V/C* ratios on screen lines (1-6), cordon line (7) and V/C ratio for the area cordoned within screen lines are shown in the Figure 4.

Table 2 : Adopted PCU values for Different Vehicles

Sr. No	Vehicle Type	Adopted PCU Values
1	Car / Jeep/Taxi	1.0
2	Bus/Truck	3.7
3	Auto Rickshaw	1.2
4	Scooter, M/C, Mopeds	0.5
5	Cycle	0.4

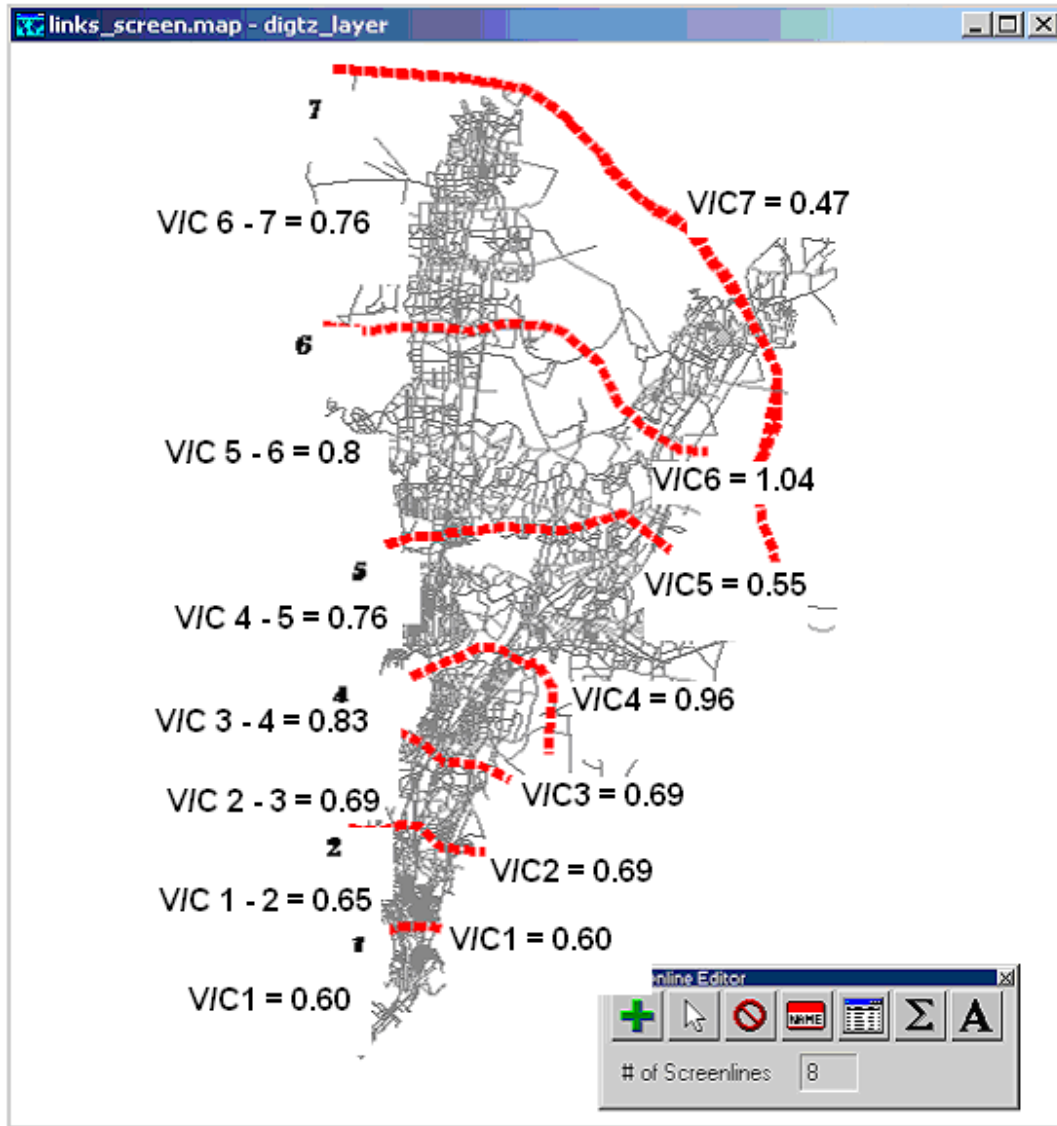Source: Indian Road Congress -106, 1990

Figure 4: *V/C* ratios on Screen lines and area within screen lines

5. Results

During peak period additional road user imposes a range of costs upon users and nonusers of the congested road network. The congestion cost of each link is estimated based on the value of delay that is shown by the speed flow model. The volume to capacity ratios (*V/C*) for each area is assigned as shown in Figure 4. These *V/C* ratios have given input to the GISDK program, through the user interface. Cordon line congestion costs are estimated in Indian National Rupees (   ) /PCU-Km as shown in Table 3.

Table 3: Marginal Congestion Cost on Cordon lines in Indian National Rupees (   )/ PCU-Km

Screen line/ Cordon line No.	V/C Ratio				
	0.7	0.75	0.8	0.85	0.9
Screen line 1	2.30	2.77	3.37	4.19	5.34
Screen line 2	2.21	2.64	3.21	3.97	5.04
Screen line 3	1.9	2.28	2.77	3.42	4.34
Screen line 4	1.98	2.38	2.89	3.57	4.53
Screen line 5	2.05	2.45	2.96	3.65	4.61
Screen line 6	2.09	2.50	3.03	3.74	4.72
Cordon line 7	2.07	2.48	3.00	3.70	4.67
Cordon line 8	2.18	2.61	3.17	3.91	4.94

For marginal congestion cost calculation, the *V/C* ratio of 0.7, 0.75, 0.8, 0.85, and 0.9 on screen lines and cordon line are considered. The tabulated result of cost analysis is shown in Table 3 above. The last row presents congestion cost for the complete road network in the Greater Mumbai region. These charges indicate the cost imposed by road user at particular operating conditions (V/C ratio). The total congestion cost of the complete road network is calculated by using daily travel demand in Mumbai. Total travel on the road network per day in the Greater Mumbai region is 2526593 PCU-Km (MMRDA 2000). In this study it is assumed that the peak hour travel is 8% of the commuter travel occurs within a day for 300 days in a year. Therefore total peak hour travel per year is 60.64 Million PCU-Km. According to this travel rate, congestion costs are quantified for selected *V/C* ratios, is as shown in table 4. Worldwide experiences show that the principle of marginal cost pricing of urban transportation infrastructure has become increasingly politically acceptable. In this study first best pricing is applied, which is based on static demand. Congestion marginal externalities were quantified. From Table 3, it is clear that as operating conditions goes on deteriorating congestion cost is also increasing. At present operating conditions, the congestion cost of the Greater Mumbai road network should be 2.69 repuees ( ) per pcu-km.

Table 4: Congestion Costs for Complete Road Network in Greater Mumbai in Million Rupees ( )

Costs	V/C Ratio					
	0.7	0.75	0.8	0.85	0.9	Present
Congestion cost	132.20	158.27	192.23	237.10	299.56	163.12

6. Summary and Conclusion

A worldwide experience shows that, the principle of urban transport congestion pricing has been gaining interest. Congestion marginal externalities is quantified on marginal cost pricing methodology is discussed. This study represents the conceptual economic modeling approach to estimate the marginal external cost within urban transport. The study has focused on the practical issues of congestion pricing implementation, with the given information on the engineering-based speed–flow relationship. Congestion tolls were estimated based on the speed-flow model for 19 different types of links in Greater Mumbai. Analysis is done in GIS based transportation planning software and with GISDK TransCAD programming. Congestion tolls were quantified for each screen line area network and also on cordon line for complete Greater Mumbai road network. Present demand on each screen line was estimated using observed average V/C ratios of all stations. Demand on the screen line area is average of observed V/C ratio's of boundary screen lines.

In this study we found that for Greater Mumbai road network private modes of transportation like car , two wheeler etc. are having high subjective values (waiting time, travel time, discomfort). But for public modes like bus and rail subjective values are less. Which clearly indicates that private modes provide discomfort journey to the commuters, and also becomes the cause of road congestion. To discourage this problem congestion cost should be adopted. From the study it is clear that as operating conditions goes on deteriorating i.e. with the rising V/C ratio, congestion cost increases. From the Peak hour marginal congestion cost of all considered V/C ratio's (i.e. 0.7, 0.75, 0.8, 0.85, 0.9, and present) is ranging from 1.90 rupees ( ) /PCU-Km to 5.34 rupees ( ) /PCU-Km. The congestion cost for complete Greater Mumbai road network for the present traffic flow condition is found as 163.12 million Rupees.

The main argument is that the speed–flow relationship, is still an average relationship, which implies that a system must tolerate some level of random variation. This issue is nontrivial and may need some further development. Along the same line of reasoning, additional work is needed on how to effectively coordinate the peak and off-peak congestion pricing by taking into account potential inaccuracies for different periods. Capturing development of congestion on single link using speed flow model is very simple. However limitation of the single link cost method is that it does not take into account the network effects. Link by link method can be utilized to compute the region wide average levels of marginal congestion costs and such average values could be applied to estimate spatially aggregate policies such as fuel tax or even cordon cost.

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