MODELLING THE MERGING PROCESS OF VEHICLE THROUGHPUT AT A PROPOSED TOLLING SYSTEM AS A LEVEL-OF-SERVICE INDICATOR

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ABSTRACT

Operations of toll-booths on any road network need to satisfy certain level-of-service (LOS) measures and the general processes of vehicle arrival, queueing, service and the subsequent departure all are influential in the driver-perception of the LOS of the toll system. Of these, the initial queueing on arrival and serving process have hitherto been considered predominantly past LOS analyses. However, it is essential that the scenario of this very system post the serving, while the vehicle throughput leaves the system and where a carriageway-narrowing and available lane-reduction occurs be also considered with significance. This paper aims to do so, using a model to represent the vehicle merging (and at times, conflicting) process that occur after the service stage at the toll plaza. If the total booth-exiting flow reaches downstream capacity, congestion occurs in the merging area. The study-area is a toll-booth system proposed to be built at the entrance to a major sea-link in metropolitan Mumbai that has been proposed to mitigate current suburban congestion. The service pattern of the queueing system is considered a general process, configuration being M/G/1. Since the link is still proposed, a traffic forecasting on the new network has been done using a simple capacity-restraint and cost-function based traffic assignment model in the transportation software suite Cube 5.0,. Models for time spent at merging turn out to be most influential in cases of high traffic volumes-like our toll site. Maximum time that can be allowed to be spent on the merging process is around 30 to 40 seconds, and corresponding number of toll-lanes are around 5 to 7 if acceptable LOS are to be maintained. This coupled with the inherent heterogeneous nature of Indian traffic has made drivers here too unyielding on the LOS measures of transportation systems available here. The time consumption in using a facility is a direct LOS perception, hence that particular component has been analysed here and an attempt has been made to make the most realistic computations of time by integrating the merging phenomena in the analyses. Traditionally, the lane-narrowing scenarios and merging time wastages are not always included, and results show that LOS measures are significantly affected when these are done so.

Keywords: merging, level-of-service, toll-booth systems, queueing models, Mumbai

INTRODUCTION

Transportation Scenario in Mumbai and Need of Study

The city of Mumbai, India in recent years has faced such a heavy traffic congestion that existing infrastructure and supply has fallen critically behind the demand. All forms of transportation systems like highways, local arterials, railway lines and even pedestrian facilities like sidewalks face over-usage and early disintegration. While public transit facilities like the bus and the local arterial railway system have always been over-crowded, at the same time there has been a surge in the number of private vehicle ownership due to the emergence of the urban middle class. This upsurge has increased the strain on the already stressed transportation networks. Simply adding new networks to the existing ones, or increasing capacity on them is not the panacea because the city already has limited open-space availability, so the other solution is smart expansion of the transportation networks within available spaces. From a sociological perspective, all this combines to instill a sense of general dissatisfaction among users and the population dependent on them. Talking of the traffic flow in general, volumes are at times too high to permit easy lane-changing, not much of a lane-discipline is observed, and in case of a diversion or a U-turn to be performed, it can only be performed by an extremely slow merging process, not without causing worse bottlenecks.

With lighter traffic, the ability to change lanes and the interaction between various features of the driving environment, make analytical techniques impossible in many urban situations. Factors such as turning movements, lane sharing with public transport and lane closures interact with each other and the general traffic, and outcomes are hard to predict. Thus in these situations, when computer simulation seems to represent a particularly straightforward approach to the problem, it becomes increasingly difficult to include the ever-critical component of level-of-service (LOS). From the user-perspective, it becomes even more crucial in the scheme of things when the facilities face over-usage, and there is a high level of congestion, delays and mounting frustrations as is exactly in the case of Mumbai. The local transportation regulatory body (Mumbai Motor Vehicles Department, 2010) estimates that there are almost 200 new cars and 300 new two-wheelers being added to the roads every day. From the policy perspective, there is an increasing lag in implementing proposals for system enhancements by the government and city-planning authorities (the Municipal Corporation). Shifting attention to the suburbs of the city, even though the sprawl has been enormous, the increase in the number of vehicles has been much faster than the growth in roadways, and couple that problem with narrow carriageways, rampant road-side parking, and the disintegration of pavements due to heavy and erratic rains and we get a situation almost beyond control.

Fig.1- Mumbai City Regional Transportation Network Map

The map of the city above forms a background for the study area and further analyses. Statistics show that population is more concentrated in the Western and close Eastern suburbs, than the South and the Northernmost parts of the city. Along the Western parts, we currently have the railway system of Western Railway and arterial roadway system comprising Western Express Highway and S. V. Road, and the Linking Road. But the S.V. Road has always faced heavy congestion all along its stretch beginning Bandra (beginning of suburban Mumbai). The Western Express Highway faces similar woes in evening peak hours and the access roads to this highway themselves are mostly narrow and congested. Currently ongoing road-blocks, diversions on the roads have exacerbated the problem. The additional north-south Linking Road in its current state is a non-contiguous (not continuous, different main roads connected by smaller ones to form a set of roadways, collectively and commonly known as Linking Road) roadway resulting in S.V. Road experiencing very high congestion levels during much of the day. Thus, in order to reduce traffic congestion and to improve existing roadway infrastructure in the City particularly in its western suburbs, construction of Versova - Bandra Sea Link has been envisioned.

The Sea-Link System

The Maharashtra State Road Development Corporation (MSRDC) is the designated nodal agency for implementing the construction of Versova - Bandra Sea Link Project on a Build-Operate-Transfer (BOT) basis. The Sea Link is envisioned to run over the Arabian Sea, just on the lines of the recently (almost three years old) functional Bandra-Worli Sea Link, connecting the congestion prone zones of Bandra and the South Mumbai region of Worli. The VBSL can be mapped as follows, where the three intermediate roundabouts are the planned connectors - indicating entry points in to the sea-link.

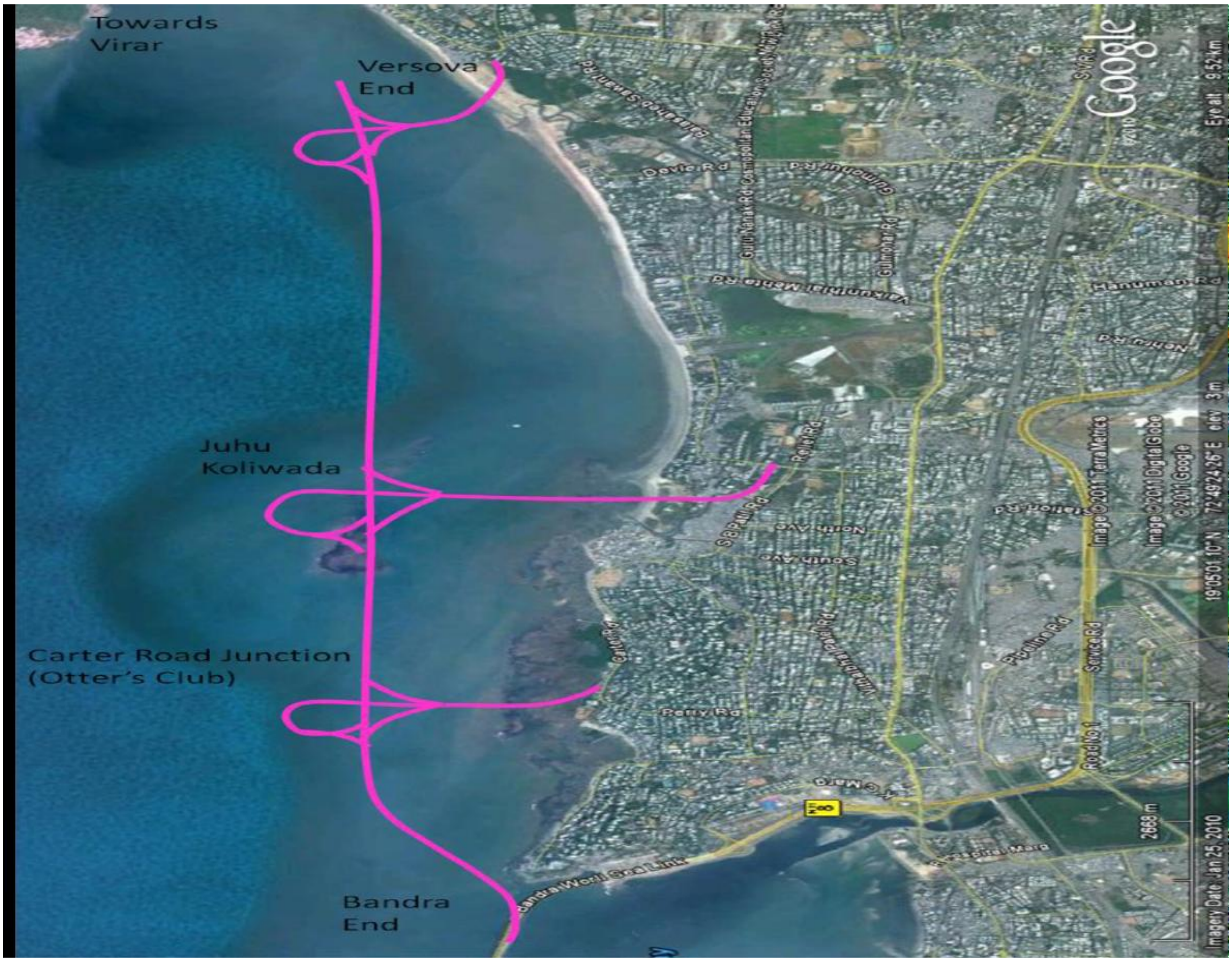

Fig 2 - Location Map (Source – MSRDC)

SCOPE OF WORK AND ORGANIZATION OF THE PAPER

The current scope of work is multi-step, starting with traffic assignment modelling in order to get the expected link traffic volumes. A forecast-based static traffic assignment model was generated using the transportation planning software suite Cube 5.0 We do not delve much into it in this paper since the focus of this work is on modelling the subsequent merging process and level-of-service analysis. The demand estimated demand for the input was obtained by means of extensive O-D surveys and demand-forecasting models. The output of the assignment, i.e. the link volumes obtained are used for further analysis in our methodology. The commencing section discussed the current transportation scenario of Mumbai City and the need and the objectives of the proposed sea-link (our site of study). The next section will set the background for modelling the vehicular queueing operations at the toll booths located at the entrance to this link. The section following that will model the vehicular operations occurring during the merging process once the vehicles pass the toll booth after paying the toll and try to get onto respective lanes. Based on certain parameters generated during the merging process, they coupled with the parameters from the serving process will be employed to generate a set of level-of-service measures as a function of time elapsed. Thus an all-inclusive level-of-service model, with the vehicle-toll plaza interactions and subsequent merging scenarios has been proposed and applied to the traffic flow of the VBSL. Concluding remarks, future research avenues follow towards the end. Thus, the paper contributes to the existing literature in the following manner-common LOS metrics for toll-plaza operations only use the vehicle-toll booth interaction factors and the time consumed therein in LOS analyses, but this paper tries to incorporate additional merging scenarios which follow those interactions and consume a non-trivial amount of time, thus making it crucial to incorporate them in LOS metrics. This helps make the most accurate and more realistic LOS assignments, since often a long-delayed merging process can significantly hurt the driver-perceived LOS measure of the facility.

MERGING OPERATIONS

Many research studies have been carried out on the merging behavior of vehicles, some of them are given under. Gipps [1986] and Yousif [1995] developed early models on lane-changing and merging behavior. These models were able to satisfactorily reproduce lane-change characteristics over a wide range of flow levels under normal conditions. Several models have been developed specifically for cooperative lane changing and forced merging behaviors. Wang et al. [2005] developed a model for motorway traffic merging behavior by explicitly simulating the interactions between the gap-acceptance behavior of the merging traffic and the cooperative behavior of the motorway traffic. Sarvi and Kuwahara [2007] developed the freeway merging capacity simulation program to evaluate the capacity of amerging section; the model was also employed to develop a varietyof intelligent transport system control strategies. Choudhury et al [2007] presented a combined merging model that has normal, cooperative, and forced merging components integrated into a single framework. Besides, Sarvi et al. [2005] have done studies on traffic behaviour and characteristics during the merging process under congested conditions, using ramp and freeway lag driver acceleration–deceleration behaviour modelling. This paper tries to analyze the merging phenomena as an integral component in level-of-service metrics.

Toll Booth Operations before Merging Occurrence

With the assumption that the mean arrival rate per lane type is uniformly distributed across each lane, the M/G/1 queueing model is used in our study. The arrival process of vehicles is the deterministic Poisson process, and service pattern of the queueing system is considered a general process, hence the M/G/1 model. We can determine capacity *N* of the toll booth, i.e., the total number of lanes, and it should be large enough to efficiently process transactions. The mean arrival rate per lane can be approximated dividing the mean arrival rate by the number of lanes utilized, and hence equals $\lambda i/ni$. It should also be less than the mean service rate in each lane to prevent bulking and avoid formation of infinite queues. Another parameter that arises in such models is the mean queue length, which may not always be a good criterion for performance comparison since services and lengths may differ over different lanes. Instead, the mean waiting time in the queue impacts the perception of service quality at the toll booths by motorists. However, our main research focus in this paper lies on the occurrences post this queueing and serving process, when the vehicles leave the plaza to join the main expressway, which is carried out in the next sub-section.

The Merging Phenomena

The framework of a standard merging process is shown in Fig 3*.* A vehicle joins the main traffic stream if the available gap (spacing between the back of the lead vehicle and front of the lag vehicle on the main road) is greater than the acceptable gap (critical gap) for normal gap acceptance. This is the standard driver-behaviour anywhere. If the gap is less than the critical gap (which can vary with drivers), the driver waits for the next gap. Gaps that are sufficiently large result in a limited extent of interaction between the subject and the lag vehicles. Critical gap is thus assumed to be normally distributed and is treated as a random variable, its mean being the function of several explanatory variables.

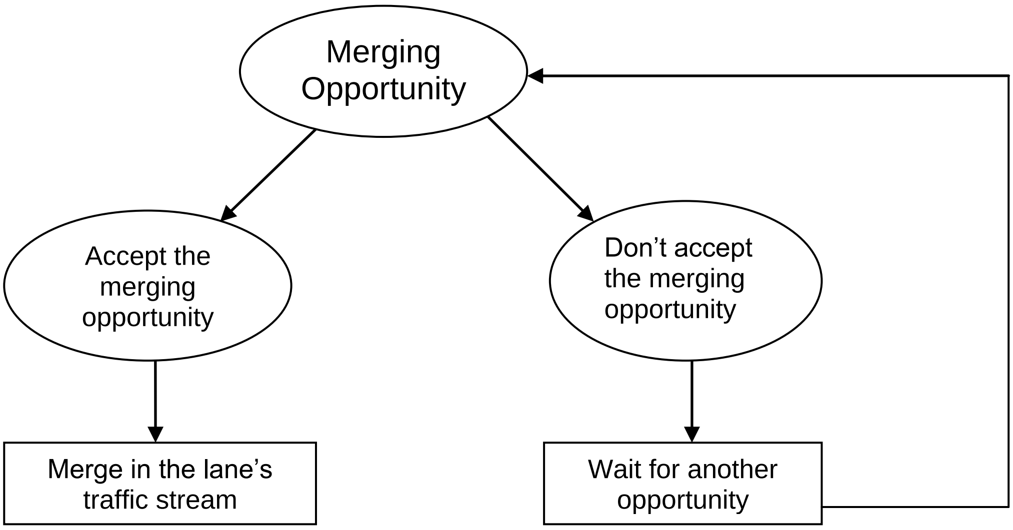

Fig.3- Common Driver Behavior While Merging

Once vehicles leave the tollbooths, the roadway must narrow back from a number of lanes equal to the number of tollbooths, to a number of lanes that fits in its normal width, and this happens at a section we call the merging area. How abruptly this happens varies tremendously in actual practice. Sometimes the extra lanes end almost immediately, forcing a sharp merge at a relatively low speed. In other cases, the additional lanes extend far enough for drivers to reach full highway speed before they are required to merge. We will generally suppose that, as a newly-designed toll plaza with minimal spatial constraints, our study toll plaza's merging area is sufficiently long to allow all vehicles toreach highway speed before merging. Additionally, different merging patterns are used when lanes begin and end.

With several lanes merging into one, all of the merging could occur at a single point, but this means that as many vehicles as there are lanes could interfere with each other at that point. For a smoother transition solutions involving only the merging of pairs of lanes are used. One common choice is to always merge out the rightmost (or leftmost) lane until the desired number of lanes is reached. This pattern is very advantageous for the side of the roadway where no merging occurs, but drivers on the other side could be required to merge many times. Another possibility is a “balanced" pattern where pairs of adjacent lanes all across the roadway merge repeatedly until the desired roadway width has been attained. This distributes the merges more evenly over the roadway. We will generally assume lanes merge out on one side, two at a time.

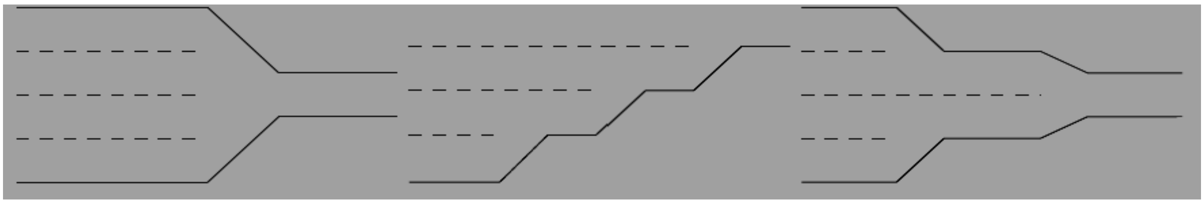

Fig.4 – Possible Lane-Merging Scenarios – 4-to-1, and sideway merging with different number of 2-to-1 merging points in each case

Time Factors in the Merging Process

The total delay by the entire merging process is more complicated to analyze. We shall first consider the simple merging process when cars from two lanes merge into one, called 2-into-1 merging points. When a driver on one lane arrives at the merging point, the delay time depends on whether there is another car on the other lane. If the other lane is empty, the driver can directly pass through, otherwise he has to stop and wait. For simplification, we treat the two incoming lanes as one queue. Since then we cannot distinguish between cars originating in either lane, the driver now must stop and wait whenever there is another car in the general queue that we noted. We define the service time of a car as the time it spends in order to pass through the merging area. Under this definition, let the service rate be equal to μ_B when more than one car is involved in the system, and μ_0 when the system has only one car (defined in more detail later). Therefore, the service pattern of this queueing system is a general function. As discussed earlier, the queueing configuration of the system is modelled as an M/G/1 process.

We consider the total merging process in the plaza as multiple 2-into-1 merging points. If there are T tollbooths and later the streams are merged back into N lanes, the total number of merging points would equal $(T\text{-}N)$. We have considered the arrival rate of a merging point equals the traffic flow it receives, which in our case is simulated in traffic assignment model in Cube Voyager 5.0. If a merging point receives traffic stream coming from k tollbooths, having a total traffic flow Φ, its arrival rate would be-

$$\lambda = \frac{k}{T}\phi \tag{1}$$

where,

k = number of linear streams (lanes) formed after the vehicles leave the toll booths

Φ =incident traffic flow in vehicles per hour
T =number of tollbooths physically present at the sea-link entrance

The values of *k* for merging points depend on the merging layout. For example, in a toll-plaza with a side merging layout which has *T* tollbooths, the first merging point takes a stream coming from two tollbooths, and the second merging point would take a stream from three tollbooths, etc. The overall average wasted time is the weighted sum of all averaged wasted time at each merging point, where the corresponding weight is the probability for a driver to reach that point, which is *k=T*. Suppose a toll plaza has *T* tollbooths, *N* lanes at the exit, and receives a total traffic flow *Φ*. Then, the arrival rate and corresponding probability at each merging point is shown by Table 1-

Table1 – Calculation for Arrival Rates and Merging Probabilities at Each Point

Merging Point	1st	2nd	…..	*(T-N)*th
Arrival Rate	$2\Phi/T$	$3\Phi/T$	…..	$(T-N+1)\Phi/T$

We model a merging point is modelled as a state-based Markovian system, where each state represents the number of vehicles in the system.The arrival rate is *λ*. Here we set the base for our LOS analysis which will be based largely on the time consumption aspect in merging process. Let P_n be the probability that there are *n* drivers in the system. When the system reaches equilibrium, the net probability of transition is zero for each state in which the toll plaza is. In addition, the sum of all individual probabilities must be one. Therefore we have,

$$\lambda P_o = \mu_o P_1$$
$$\lambda P_n + \mu_B P_n = \lambda P_{(n-1)} + \mu_B P_{(n+1)}, \forall n \succ 2$$
$$\sum_{i=1}^{n} P_i = 1$$

where,
μ_A = service rate at the toll booth
μ_o= service rate at a merging point when merging does not occur i.e. when there is only one car in the system
μ_B=service rate at a merging point when merging occurs

These equations when solved yield the merging-probability model for a general toll booth scenario with *n* total number of users-

$$P_n = \frac{2\lambda^2}{\mu_o(\mu_o+\lambda)}\left(\frac{\lambda}{\mu_B}\right)^{n-2} P_{o,} \forall n \geq 2$$

And we can calculate the expected number of drivers in the system:

$$L(\lambda) = \sum_{0}^{\infty} i.P_i$$

Solving the summation gives,

$$L(\lambda)=\frac{\lambda}{\mu_B-\lambda}+\frac{\lambda\left(\mu_B-\mu_o\right)}{\lambda\left(\mu_B-\mu_o\right)+\mu_o\mu_B} \tag{2}$$

By Little's Theorem, the average waiting time in the system $t_{sys}(\lambda)$ equals the expected number of drivers in the system $L(\lambda)$ divided by the arrival rate λ-

$$t_{sys}(\lambda)=\frac{1}{\mu_B-\lambda}+\frac{\left(\mu_B-\mu_o\right)}{\lambda\left(\mu_B-\mu_o\right)+\mu_o\mu_B} \tag{3}$$

The average wasted time of a driver at a merging point is the difference between t_{sys} and the time he spends on a normal lane. The expected time a driver spends when no merging happens is$1/\mu_o$. Hence, we write-

$$t_{diff}(\lambda)=t_{sys}(\lambda)-\frac{1}{\mu_o} \tag{4}$$

Where $t_{diff}(\lambda)$ is the average wasted time when merging occurs (difference in actual waiting time and the expected time).

Coming to the actual time consumption experienced on the toll booth during service and the subsequent merging, we have our final time-consumption model. From the arrival rate and service rate of the toll booth, the average service time of each toll booth is-

$$t_{service}=\frac{1}{\mu_A-\frac{\phi}{T}} \tag{5}$$

Then, based on the merging scenarios developed earlier, we can model the total time consumption at any general merging point. Referring to definitions given earlier, the arrival rate of each tollbooth is Φ/T. Using the equation (1) and the values computed in table (1), for a side merging scenario, the arrival rates at the merging points can be computed as follows,

$$\mu_{arrival}=\frac{2\phi}{T},\frac{2\phi}{T},\ \ldots,\frac{(T-N+1)\phi}{T} \tag{6}$$

The total merging time will be the summation of this time taken over all the merging points that are generated in the scenario. It is given as under-

$$t_{merging}=\sum_{i=1}^{T-N}\frac{i+1}{T}.t_{diff}\left(\frac{i+1}{T}\phi\right) \tag{7}$$

Therefore, based on this model and the ones for times wasted (consumed) for merging, we can write model the ‘total’ wasted time during service and subsequent merging in the next equation 7. Note that our LOS measures consider the time consumption in service as well as the subsequent merging process, whereas conventionally that is based just on service times at toll booths, where it becomes even more crucial in manual toll-booths due to addition of the human element in it. So, the total time consumption can be given by-

$$t_{total} = t_{service} + t_{merging} \tag{8}$$

which can be computed using the previous two component equations 6,7 for the service time and merging time consumption.

LEVEL-OF-SERVICE INDEXING

After having modelled the merging process of the vehicle stream leaving the toll plaza, we have the necessary components in order to design a level-of-service indexing for the toll-booth's general performance, based on the total time consumed during the entire service and merging operations. Numerous measures of effectiveness are available to evaluate a toll facility for its level of service, these include density, volume-to-capacity ratio, and delay. Based on field research and data analyses, delay is recommended to be the most credible measure of effectiveness for evaluating the level of service at a toll plaza. [Klodzinski et al., 2002]. There have been various measures-of-effectiveness (MOE) which are utilized in forming an LOS index and time-delay is the most important and identifiable MOE. This is by far the one drivers feel the most affected by and it effectively represents the driver's level of inconvenience. In our study, it is a direct result of traffic conditions on the sea-link which we are studying. The Transportation Research Board's standard publication Highway Capacity Manual defines level-of-service for signalized and unsignalized intersections as a function of the average vehicle control delay.It essentially provides a qualitative ranking of the traffic operational conditions experienced by users of a facility, and our methodology is on similar lines.

In order to set a good background for introducing a LOS analysis, we first take a short look at the commonly accepted HCM definitions in LOS categories for freeways and multilane Highways:

Level of Service A- It is the free-flow condition on the roadway. Individual users are virtually unaffected by the presence of others in the traffic stream. There is a good freedom to select desired speeds and to manoeuvre within the traffic stream.

Level of Service B-It consists of scenarios that allow speeds at or near free-flow speeds, but the presence of other users in the traffic stream begins to be noticeable. Freedom to select desired speeds is relatively unaffected, but there is a slight decline in the freedom to manoeuvre within the traffic stream relative to LOS-A.

Level of Service C- Speeds are at or near free-flow speeds, but the freedom to manoeuvre is too restricted (lane changes require careful attention by the driver). The general level of comfort and convenience declines significantly at this level. Disruptions in the traffic stream, such as an incident (like vehicular accident), can begin resulting in significant queue formation and vehicular delay.

Level of Service D- These give rise to conditions where speeds begin to decline slightly with increasing flow. The freedom to manoeuvre becomes more restricted and drivers experience reduced physical and psychological comfort. Incidents can generate lengthy queues because the higher density associated with this LOS provides little space to absorb disruption in the traffic flow.

Level of Service E-It represents operating conditions at or near the roadway's capacity. Even minor disruptions to the traffic stream, such as vehicles entering from a ramp or vehicles changing lanes, can cause delays as other vehicles give way to allow such manoeuvres. It is mainly a psychologically exhausting experience for the drivers.

Level of Service F-It describes a breakdown in vehicular flow. Queues form quickly behind points in the roadway where the arrival flow rate temporarily exceeds the departure rate, as determined by the roadway's capacity. Vehicles typically operate at low speeds in these conditions.

We try to replicate this LOS indexing for toll booth systems based on the time-delays occurring in merging in the following manner in Table 2 –

Table 2- Level-of-Service Indexes for Merging Scenarios

Level of Service	T_{total} value (from *8*)	Corresponding Existing LOS Indices by HCM [2000]
A_m	≤ 20	A
B_m	20-40	B
C_m	40-60	C
D_m	60-80	D
E_m	≥80	E

As mentioned earlier, existing LOS criteria are based on 'time in system' for the analysis of toll-plaza operations, which consists of the service times primarily. In our study, we have included the post-service lane-merging delays into our LOS indices in addition to the service times. Also, we wish to point out that stopped delay, which is similar to time-in-system for toll-plaza operations, has been commonly used in defining the levels of service associated with interrupted flow conditions. It is possible that motorists on expressways are less tolerant to delays than those at signalized intersections, since they are already paying tolls to get some travel-time savings, hence it becomes important to consider all possible avenues of time delay in the entire scheme of things, and as we shall see, merging time becomes one such significant component. Besides, on a sea-link whose main purpose is time-saving in suburban commute over travelling through the main-land, and when drivers are already paying substantial toll rates, it can be meaningful to set a high bar for its performance. Hence, the LOS A_m has been set to less than 20 seconds inclusive of the service and merging time, assuming that is the time in which the vehicle can merge into the traffic stream (that is be on a full lane) and accelerate to the desired speed of the driver.(of course at maximum to the speed limit prescribed on the VBSL). The last column gives the corresponding LOS indices that are in practice as given by HCM. The corresponding time values for all the LOS indices have been set based on stated-preference traffic surveys and standard user behavior at toll plazas, and from some past literature as well.

ANALYSIS FOR STUDY AREA AND RESULTS

We now apply the merging model to the study site, and use our assignment model to get the traffic flows incident on it. Going back to our models for delays in merging and service, we can now substitute the simulation values and other measures pertaining to the sea-link. Based on a an existing similar structure in Mumbai and taking certain parallels in them, number of incoming lanes (N) can be 5 and the typical range of number of lanes the sea-link (in one direction) can be 3.

The total traffic flow Φ as obtained from Cube simulation is 2000 veh/hour and the service rate at the tollbooth (μ_A) is taken as 300 veh/hour.

Further, service rate at a merging point: when merging does not occur (μ_o) can be looked at as the rate when there is just one vehicle in the system, meaning that when it moves past the toll booth, there will be no other vehicle in an adjacent lane waiting to merge. This also means that this is the time taken for it to pass through at its own speed without any waiting delays. We take that speed as 75 kmph = 20.833 m/s. Also, in physical space, the length of the space available for merging is the average car length plus a safety distance, which is around 15 + 6 *15 = 105 feet

Thus the average service time here is 105*0.3048/20.833 = 1.536 sec per vehicle, which becomes 2300 veh/hour in proper units. (1feet=0.3048 m)

Now, service rate at a merging point when merging occurs (μ_B) can be found out by considering the time a vehicle passes through the same area with zero initial speed. Under this speed the safety distance would be one car length, and the average acceleration of a vehicle is 5 m/s^2.

Using standard kinematic equations,

$$s=ut + 0.5at^2$$
$$t= (2s/a)^{1/2}$$

Hence we get the average service time is about 12 seconds and the corresponding service rate μ_B = 1040 veh/hour. Finally, we utilize all the above obtained service rates for various scenarios in our earlier derived models and try to estimate the possible time consumption values for merging scenarios on the sea-link, we get t_{total} as 40.86 seconds.

Additionally, analysis at similar locations was carried out from the field data collected to model the merging scenarios and compare the outcomes for our study area, and some additional test scenarios with a varying number of toll booths were tested. The following table 3 shows the outcomes,

Table 3- Level-of-Service Indices for Different Merging Scenarios and Comparative Analysis

Number of toll-booths (*N*)	Merging Time (s)		Service Time (s)	Total Elapsed Time (s)		LOS with Merging		Traditional LOS without Merging Model
	Actual	Analytical	Analytical	Actual	Analytical	Actual	Analytical	Analytical
2	0	0	51	51	51	C	C	C
3	0	0	32	32	32	C	C	B
4	14	17	21	35	38	B	B	A
5	29	31	12	41	43	C	C	A

From the results table, we see that for an area that has traffic conditions similar to the study area, the results show only a slight difference in the merging scenarios, however, what is of more interest is that the perceived LOS measures change dramatically from the standard ones for higher values of merging times, especially when we have a higher number of vehicle streams merging onto a relatively lower number of available lanes. The new LOS measures proposed thus help provide a more stringent and a more holistic set of LOS indices that consider merging phenomena, thus setting higher standards for the system in place. The indices are thus more realistic and a more accurate representation of the actual situation occuring in the system.

DISCUSSION

The application of the revised LOS indices shows that the VBSL is expected to operate at the level of service C_m, which is the moderate level [HCM, 2000]. Researches show that this moderate LOS is the one which is effective in majority transportation facilities that get utilized to near-full or full capacity. Note that at this LOS, speeds are expected to be almost near free-flow values, but the freedom to manoeuvre is not too high and free lane changes are not straightforward, especially during peak hours. This is not to say driving is a discomfort, but surely even the slightest degradation from this level will surely invite inconvenience, in the form of difficult lane manoeuvres. Also, general disruptions in the traffic stream, such as an incident (like vehicular accident), can begin resulting in massive delays; however that is subject to the occurrence of such an event and also the time of its occurrence. We note that one assumption we have made is that drivers which appear at the toll booth act logically (rationally) by choosing the booth which has the smallest perceived queue length or no queue, hence they have the choice of minimizing their arrival time delays, however in merging and serving scenarios, the choice of minimizing their time at their own free will does not become available as it is largely dependent on the other components of the system and the behavior of them as well.

CONCLUSIONS AND FUTURE SCOPE OF RESEARCH

Thus, the paper contributes to the existing literature in the following manner-common LOS metrics for toll-plaza operations only use the vehicle-toll booth interaction factors and the time consumed therein in LOS analyses. This paper tries to incorporate additional merging scenarios which follow those interactions and take time to pass, thus making it necessary to incorporate them in LOS metrics. This helps make the more realistic LOS assignments, since often a long-delayed merging process can significantly harm the driver-perceived LOS measure of the facility. But even though we obtained the anticipated LOS level of the Versova-Bandra Sea-Link as the LOS-C, there still are means to improve that measure. Since delay is the main essence of the level-of-service analysis, reducing the time delays faced my drivers is the most effective approach to improve the general LOS. Since our LOS analysis was based on service rates and possible traffic stream merging scenarios, it follows that improving service times on the sea-link or providing wider carriageways to vehicles can lead to that. By increasing carriageway width, we introduce the possibility of increasing the number of lanes available after the toll-booth at the entrance to the actual sea-link. In theory when the number of lanes will equal the number of servers available, then the need to wait for merging within a lane's stream does not even arise, the vehicles can just stick to the lanes on which they were at the toll-booth and continue on it. But we need to note here that this is not a free-way, but a bridge built over the sea in simplest terms (it would help to refer to the Figs. 1 and 2), so the freedom of acquiring adjacent land to be included in the carriageway is not there. Structural design considerations also play a huge role as expanding carriageway width will require piers and girders with higher compression and tensile stress respectively. Also, not just that, the soil bearing capacity of the under-water soil perhaps is the most critical factor, before we think of expansion over the sea-link, because any excessive loads than it can stably withstand can cause colossal damage.

So while our alternatives with regard to lane-addition and width expansion are limited, there is another novel way of improving service rates, without making structural changes. That way is changing the types of toll-servers and including electronic toll collection (ETC) systems, and if possible replacing the manual servers with those. This can lead to implementation of many auxiliary technologies like the automatic vehicle identification, classification, and communication technologies. It will enable automatic toll transactions that can be performed while vehicles travel at highway speeds. Because of these time-saving advantages provided by ETC technologies, an ETC system can generate potentially significant LOS improvements. It will possibly raise the LOS of the VBSL to a B surely and possibly A, depending on the number of such automated lanes provided.

However, just as the thing with any new technologies not native to that region, it will involve huge initial investment, and the cost-recovery will have to be carried out from the users, which can lead to potentially higher toll rates and it cannot be guaranteed that they will be too keen to do that. Nevertheless, the cost-benefit analysis of ETC installation, the electronic technology implementation challenges associated with it in the Mumbai scenario (where it has never been tried before) will be interesting issues to look at, pertaining to the Versova-Bandra Sea Link. And last but surely not the least, evaluating users' opinions on such an alternative will also be interesting, because Mumbai drivers, faced with vexing traffic conditions for most of the times may have inordinate demands from the new transportation system they are paying to use. ETC has seen successful implementation in developed countries like the USA (E-Z pass, read 'easy pass'), Germany, Singapore, Japan etc because traffic conditions are better and transportation systems are justifiably utilized, whereas in our case, as we mentioned in introductory sections, the situation in Mumbai is way too different, and that too, in all respects- be it traffic streams, traffic flow, available transportation systems in place, vehicle composition, public transport share on the road and also user traits and behaviour. Hence, it is hoped that this work and analysis is a positive contribution towards the infrastructure development process in emerging and developing nations like India.

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