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Micro-simulation based evaluation of Queue Jump Lane at isolated urban intersections: an experience in Kolkata

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Abstract

Poor service quality is one of the major causes for declining share of buses in urban India. Improvement of bus travel time by implementing bus priority measures at intersections is well regarded as an effective instrument to improve bus service by reducing the travel time. However, only a few research works have been reported in the literature on bus priority strategies in Developing countries such as India. This paper documents an experience of using micro-simulation software VISSIM© to evaluate the impact of providing Queue Jump Lane (QJL) as a bus priority strategy for three representative four-arm isolated signalized intersections in Kolkata, India. The study shows that QJL is expected to be beneficial even in a heterogeneous traffic environment that is prevalent in Indian scenario. The effectiveness of QJL is found to be influenced by various factors such as traffic volume, vehicle composition and road geometry. The study encourages further investigations in terms of validation of results based on field implementation of QJL and identification of the domain of applicability of QJL in signalized intersections of urban India.

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Introduction

The travel demand in urban India is growing steadily due to rapid urbanization and growth of private vehicle ownership. On the other hand, the scope of augmentation of road infrastructure in urban India is often limited due to physical constraints. As a result there is a growing imbalance between the demand and the supply of road transport which is aggravating congestion and pollution in urban India (Maitra & Sadhukhan, 2013). Public transit has the potential to alleviate the negative externalities and achieve the goals of urban traffic management (Atkins, 2004; Kirchhoff, 1995). It is, thus, necessary to increase patronage for the public transport facilities like bus, metro, etc. Buses are one of the most flexible, space-efficient and cost-effective means of public transport in urban areas (Hensher, 1998; Hess et al., 2005; Mackett & Edwards, 1998). Bus ridership may be improved if the bus is made more efficient by making the journey time comparable to that of cars (Beirão & Sarsfield Cabral, 2007). This can be accomplished by providing proper priority measures to the buses at intersections (Janos & Furth, 2002; Urbanik et al., 2002). Urban development and public transport prioritisation should go hand in hand for ensuring a stable and sustainable road environment in urban India. However, adequate investigation has not been conducted to understand where bus priority should be implemented and what could be the expected benefits in urban Indian scenario.

There are several potential issues pertaining to effective implementation of bus priority techniques in Indian scenario. Although, a dedicated bus lane is expected to be an effective priority treatment (Arasan & Vedagiri, 2009), due to lack of road space, a bus lane for the entire route is not a feasible option for most of the Indian cities. However, it is still necessary to segregate buses from the heterogeneous traffic mix in order to realize maximum benefits from priority at traffic signals. In this aspect, a Queue Jump Lane (QJL), which is a short bus lane upstream of a traffic signal that enables buses to travel through congested areas (TRB, 2013), appears to be a more practical solution for providing priority to buses at signalized intersections in India as the requirement of road space can be reduced significantly and partial lane discipline only needs to be enforced at intersection approaches. This paper documents an experience of evaluating the impact of providing QJL in urban Indian scenario and demonstrates its potential for improving the bus service without affecting the non-priority traffic significantly.

Traffic simulation models play a major role under different scenarios as they have the potential to provide a cost-effective, objective, and flexible approach to assessing the alternatives (Chang & Ziliaskopoulos, 2003; Rakha et al., 1996). In comparison to analytical models, microscopic traffic simulation models are helpful in realistic representation of complex traffic behaviours, capturing the detailed aspects of the system and are essential for estimating certain quantities that may not be easily measured or observed from the field (Dale et al., 2000). VISSIM© (PTV, 2011) is one of the most widely used microscopic traffic simulator which was developed initially for European traffic conditions and is now finding increasing applications in developing countries such as India (Bains et al., 2012; Mathew & Radhakrishnan, 2010; Siddharth & Ramadurai, 2013). VISSIM© has also been successfully employed to evaluate bus priority impacts under different scenarios (Dale et al., 2000; Kamdar, 2004; Ngan et al., 2004; Zhou & Gan, 2005). In the present paper, VISSIM© 5.40 has been used to model traffic operations in Indian conditions in order to develop a rational estimate of the impact due to provision of QJL with reference to three representative four-arm isolated signalized intersections in the Kolkata metro city. The evaluation is carried out on the basis of changes in delay to different modes of vehicles including buses under different traffic and pedestrian volumes.

The present paper has been divided into four sections. The first section deals with the description of the study area and database for simulation model development and analysis which have been elaborately discussed in Sections 2 and 3 respectively. Finally, the major findings from the present study and future scope of the work have been discussed in details.

1. Study Area and Database Development

Three representative four-arm intersections of different geometrical configuration and traffic composition were selected in the Kolkata metro city as part of the study. The intersections are Exide Intersection, Hazra Intersection and Rashbehari Intersection. Figure 1 provides the schematic diagram, peak hour turning movements and the phasing sequence of the intersections. The descriptions of these intersections are given below.

The Exide intersection is a four-arm intersection with fast moving motorised traffic. The West and North approaches have one way vehicle movements. The traffic flow is heterogeneous with lack of lane discipline. Being located in one of the busiest areas in Kolkata, the level of pedestrian interference with the traffic flow is also high, thus causing additional delays to the traffic. The common modes of transport that are operational are buses, mini buses, taxis, passenger cars, motor cycles and light commercial vehicles. No heavy vehicles are allowed to enter the intersection during the normal commute hours. Data was collected during the morning peak hour which included cycle lengths, traffic volumes and vehicle composition, turning movements, control delay, passenger occupancy and longitudinal stopping distance. The percentage of buses in the intersection ranges from 7 to 11% of the entire traffic volume. The bus volume varies from 60 to 150 buses per hour from each approach during the peak hour. The control delay was estimated based on field measurements of vehicles-in-queue and number of vehicles arriving (TRB, 2010). Hazra and Rashbehari intersections are four legged intersections. All the approaches are two way approaches with the major traffic flow in the North and South direction. In addition to the vehicle types found in Exide intersection, Hazra has three wheelers plying as an intermediate public transportation mode and Rashbehari intersection has three wheelers and tram. As it is commonly seen in the Indian traffic scenario, there is no lane discipline on the intersections and the pedestrian interference is high. Similar traffic data were collected during the peak hour for these two intersections as well. The bus volume per hour varies from 30 to 120 in Hazra intersection and 40 to 130 in Rashbehari intersection. The percentage of buses in the intersection ranges from 2% to 6% and 7% to 20% in Hazra intersection and Rashbehari intersection respectively. Study was also conducted to find the intersection saturation flow rates. The saturation flow rates were found to be in the range of 1200 to 1400 PCU/hour/lane. U-turning traffic was considered as right turning traffic.

Since the characteristics of vehicles would affect the simulation outputs, data was collected to model the different vehicle categories. The data for performance characteristics are shown in Table 1. The vehicle characteristics data (acceleration-deceleration distributions, speed distributions, power and weight distributions), vehicle 3D models and driving behaviour data (longitudinal distances) were provided as inputs for calibrating the simulation model in VISSIM. In addition to the traffic data and vehicle characteristics data, vehicle category-wise passenger occupancy study was conducted in the three intersections. The purpose of the study was to estimate the average passenger occupancy for each vehicle category. Table 2 shows the passenger occupancy data obtained from the different intersections.

2. Model Development: Calibration and Validation

The traffic micro-simulation software VISSIM© 5.40 (PTV, 2011) was used to represent traffic operations at the intersections in a micro-simulation framework. Major considerations which were made during model development are discussed as follows. Lane Behaviour: The free lane selection and lane changing nature of Indian traffic was represented in the simulation model; Traffic Heterogeneity: The data collected from the site was used in each intersection to obtain the traffic heterogeneity. For conversion of heterogeneous traffic into homogeneous traffic stream, the PCU values suggested by Chandra (2008) have been used in the study for analysis purpose; Traffic Signal System: The cycle length, green time and the phasing sequence of the model intersections were taken as per the field condition; Longitudinal distance between vehicles was measured for 50 vehicles per intersection and average taken as the longitudinal distance between vehicles; Traffic Characteristics: The traffic volumes, turning movements and vehicle compositions for each approach were taken as per the field measurements during the peak hour; Vehicle Categories: Vehicles were categorised as bus, minibus, passenger car, two wheelers, three wheelers and tram. The dimension of a standard Indian vehicle was selected as the base model and a 3D model was developed and this model was used in VISSIM; Passenger occupancy: Average occupancy was taken from field studies as input to the VISSIM© model; Desired Speeds: The desired speeds were taken as per the field observations; Vehicle characteristics: Different vehicle characteristics was measured and used as the data for the micro-simulation model such as normal acceleration, maximum acceleration, normal deceleration, maximum deceleration, power and weight of vehicle; Pedestrian Influence: The volume and interference of pedestrians with the traffic flow were high for the study intersection due to unconstrained pedestrian movements both spatially and temporally. However, in the model such conditions could not be simulated and hence, equivalent number of pedestrians were allowed to cross only at the legal pedestrian crossing (i.e. zebra crossing) during the red interval for vehicular traffic.

The travel time delays have been measured for equivalent travel time sections considering the average queue length in each approach. The average control delay is estimated based on Highway Capacity Manual (TRB, 2010) procedure and does not consider the delay due to acceleration to desired speed from stop. Hence, the travel time delay obtained from the simulation results is expected to be marginally higher than the field estimates of control delay as the simulated delay is the difference of the actual travel time from the ideal/ theoretical travel time (PTV, 2011; Tian et al, 2002). The same is evident from the comparison of the control delays obtained from the field measurement and the travel time delays obtained from the simulation model. It is observed that the Root Mean Square (RMS) error in delay is 6.2 seconds for Exide intersection which is acceptable considering the difference in travel time delay obtained from simulation and control delay estimated from the field. The calibration parameters that have been used for Exide Intersection have again been used for Hazra and Rashbehari intersections for validation purposes. It is observed that the RMS error in delay for the other two intersections is a maximum of 10.2 seconds which is acceptable and thus confirms the validation of the models.

The model was then used to simulate both with and without priority scenarios to understand the effectiveness of the priority technique under different conditions. Figure 2 illustrates the two scenarios that were analysed: (1) Model without QJL (2) Model with QJL. 120 - 150 m length of the leftmost lanes of the existing roads was converted to QJL to allow priority for the buses. The length of the QJL is based on the observed maximum queue length of vehicles in each approach. For Exide intersection, QJL was provided to the North and South approaches to allow priority for left turning and/or through moving buses. The right turning buses were exempted from the use of QJLs in order to avoid the conflict of movement with the left turning or through moving non-priority traffic. For the North approach, the conflict of left turning vehicles and through moving buses using the QJL is avoided by giving more priority to the buses. The left turning vehicles can manoeuvre the left turn only when there is an acceptable gap between two successive through moving buses. QJL was not provided in the model for the East approach because the approach was narrow and the provision of QJL would result in excessive delay to the non-priority traffic.

Hazra intersection is a very narrow intersection with two lane road per direction in the north-south approaches and single lane approaches in the east west approaches. Majority of the buses (84%) travels in the North and South directions. Due the particular nature of the intersection, one lane each from the North and South approaches has been converted to QJL. Rashbehari intersection is a wide intersection with five lanes in the North and South approaches. The East and West approaches have three and two lanes respectively. There is a separate pedestrian signal phase to help facilitate pedestrian movement. Apart from regular vehicle movements, there are also tram operations in the North and South approaches.

3. Analysis of Results and Major Observations

In this study, delay is considered as the criteria for assessment. The attributes that have been measured are delay to buses, delay to cars, average vehicle delay and total passenger delay. The passenger delay was estimated considering an average of 48 persons per bus, 32 persons per mini-bus, 3 persons per car, 5 persons per three-wheeler and 1 person per bike (Table 3). For each scenario (i.e. without QJL and with QJL) simulation was carried out with 10 set of random seeds for a duration of 3600 seconds. The signal cycle length was kept unchanged; however the green time was optimized based on Webster's Delay model. The traffic volume is expected to vary during different hours of the day. Hence, to understand the dynamic effect of QJL, delays were estimated for traffic volumes at 100%, 90%, 75% and 50% of the observed peak hour traffic volume. The pedestrian volume was assumed to change proportionately with the traffic volume. Figure 3 shows the delay values obtained from the model in terms of Person delay, Vehicle delay, Bus delay and Car delay. The major observations from the analysis are discussed below.

The model reflects that with the reduction of overall vehicle volume, the delay reduces. This reduction in the delay is observed to be non-linear. This represents the volume effect on delay and shows consistency in all cases across all the intersections. It is observed that there is a benefit to person delay by providing priority with QJL at all the intersections irrespective of the variations in the intersection characteristics. The benefit from person delay shows variation across the intersections and traffic volume levels. The variation in benefit is due to the differences in road geometry, vehicle composition, share of buses, phasing sequence and the cycle times. In the Exide intersection (approach volume/saturation flow ranges from 0.67 to 1.18 , bus share ranges from 7% to 11%) there seems to be a decreasing rate of benefit with the reduction in traffic volume till finally the provision of QJL becomes a redundant for the intersection at 75% of present traffic volume and lower. The congested narrow Hazra intersection (approach volume/saturation flow ranges from 0.83 to 1.63, bus share ranges from 2% to 6%) shows an increase in delay at 100% traffic volume but an increasing effectiveness in the QJL in the lower traffic volumes. Rashbehari intersection (approach volume/saturation flow ranges from 0.75 to 1.47, bus share ranges from 7% to 20%) shows no benefit of QJL at 100% and 50% of current traffic volume but at 90% and 75% of present traffic volume, the QJL appears to be effective in terms of person delay saving. QJL is more effective for intersections where the bus volume is higher. It is also observed that at very low volume, provision of QJL is less effective. This is because the buses are forced to accept the queue jump lane even as the other lanes are relatively less congested. This is found to be consistent across all intersections and all traffic volumes with only two exceptions (i.e., the North and South approaches of Rashbehari intersection and the North approach of Exide intersection at high traffic volumes). In Rashbehari intersection, due to the wide approach widths (5 Lanes) in the North and South directions, a potential bus lane is generated even without the QJL. This is because buses prefer to keep left for easier access to bus stops while the fast moving vehicles use the remaining portion of the road and do not merge with the bus movements. Hence, the benefit to this intersection by providing QJL is lower as compared to the other two intersections. In the case of Exide intersection at 100% traffic volume, along with reduction in bus delay due to provision of QJL, there is also a significant reduction in the Car delay. This abnormality is due to the particular geometry of the intersection, which is too narrow for two buses to ply side by side. The provision of QJL shifted the buses to one side of the roadway creating adequate space for the cars to reach the intersection. This result is particularly interesting as there are many intersections in urban India which have non-standard lane widths. This could be a clear implication that, QJL, if implemented properly, can help in the streamlining of vehicles to some extent.

Conclusion

The study shows that QJL is likely to be instrumental in reducing person delay in an urban intersection with heterogeneous traffic operations that is prevalent in Indian scenario. The study also reveals that the QJL may not be equally effective in every intersection under every scenario. The effectiveness of QJL decreases with the decrease in traffic volume till it becomes ineffective and a detriment. Also, in all cases it is observed that the provision of QJL is effective at traffic volumes which are neither very high, nor too low. The performance of bus priority with QJL is a function of volume of traffic, vehicle composition and road geometry.

The present work is a pilot study aiming to evaluate the effectiveness of QJL in Indian scenario with the results being case-specific. However, the findings encourage further investigations to improve the rationality of model development with respect to driving behavior, vehicle-pedestrian interaction, etc., and validate the realized benefit based on field implementation of QJL. Since the effectiveness of the QJL depends largely on several factors such as intersection geometry, traffic volume, bus share, etc., further studies are also required to understand the effect of each of these parameters on delay and identify the domain of applicability of QJL in urban India.

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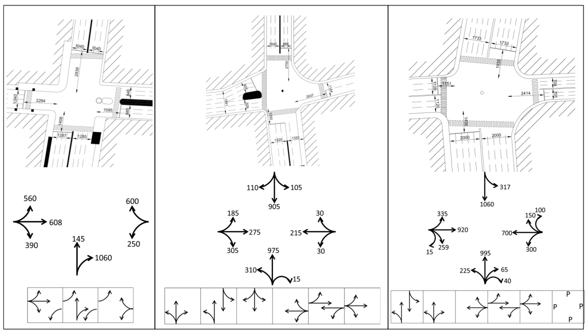

Figure 1 - (From top) Geometric layout, Peak hour Volume and Signal Phasing Sequence of (From Left) Exide, Hazra and Rashbehari Intersections

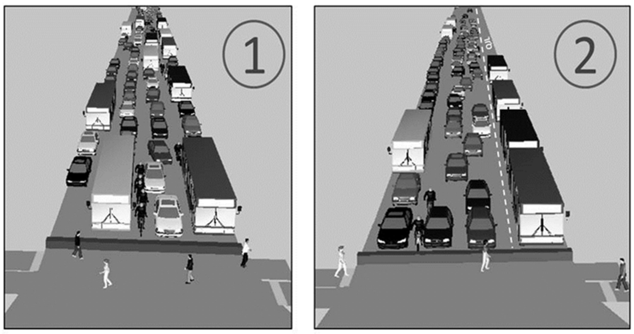

Figure 2 – VISSIM models (1) without and (2) with QJL

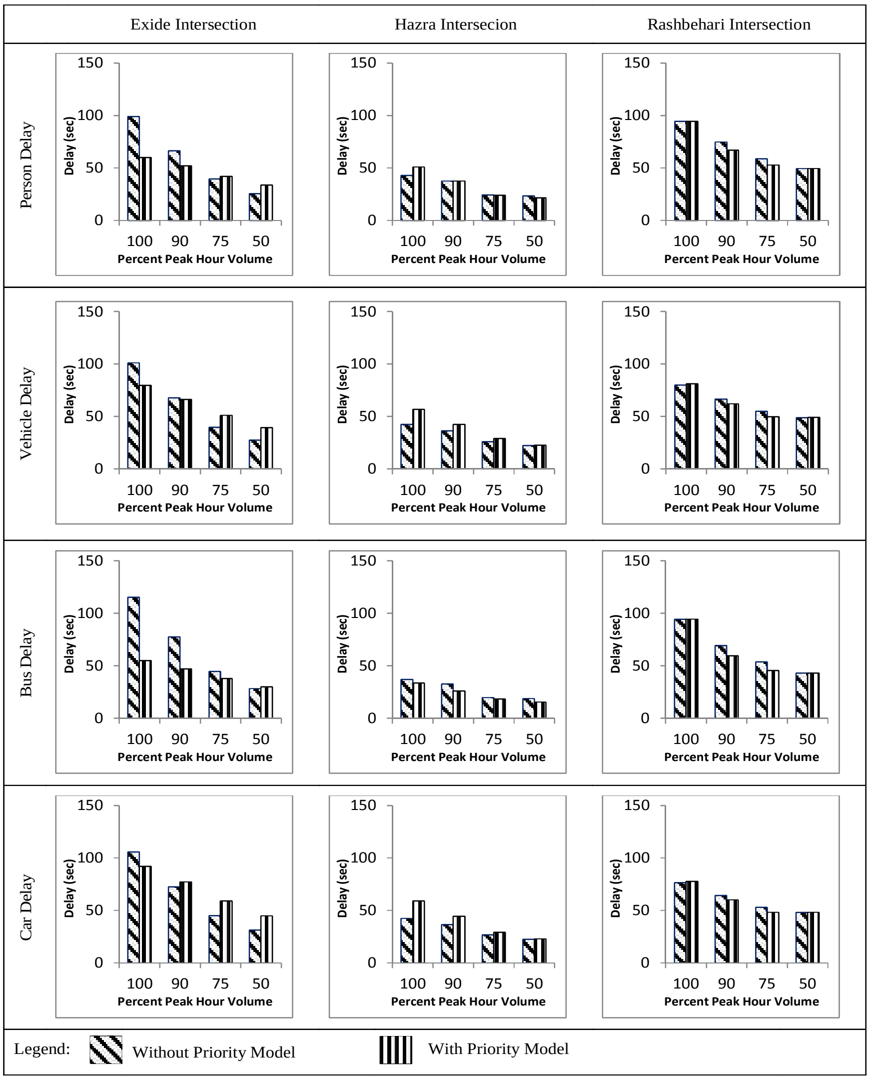

Figure 3 – Delay studies Without Priority and With Priority at the intersections.

Table 1 – Vehicle Characteristics Data for Modelling Traffic Flows at Intersections

	2 Wheeler	Car	3 Wheeler	LCV	Truck	Tram
Vehicle Type	TVSPhoenix 125	MarutiSuzuki Swift Diesel	BajajRE CNG	TataAce CNG	AshokLeyland 1616 HP	Kolkata tram
Acceleration maximum						
0 – 20 kmph	4.92	5.05	1.17	1.01	1.29	1.0
20 – 40 kmph	3.22	3.75	1.01	1.17	1.02	1.0
40 – 60 kmph	2.28	3.22	-	-	0.80	-
Normal Acceleration	0 -30 (6.7)	0 - 30 (2.77)	0 - 20 (0.89)	0 - 30 (2.77)	0 - 30 (0.83)	0.32
			0-30 (0.65)		> 30 (1)	
Deceleration maximum	3.6	6.5	6.5	6.5	5.94	0.1
Deceleration normal	3.2	2.62	2.62	2.62	2.46	0.1

Table 2 – Vehicle Category-wise Passenger occupancy

Intersection	Vehicle category	Average passenger occupancy
Exide	2 Wheeler	1.39
	Car	2.11
	Minibus	31.24
	Bus	47.03
Hazra	2 Wheeler	1.33
	Car	2.30
	Minibus	36.30
	Bus	49.93
	Three Wheelers	4.90
Rashbehari	2 Wheeler	1.41
	Car	2.22
	Minibus	33.52
	Bus	47.86
	Three Wheelers	4.92