Estimation of Demand for Bus Rapid Transit

Case Study for Galle Road from Moratuwa to Pettah

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***Abstract*— Bus Rapid Transit (BRT) is a high quality bus based transit system which has been identified by the Ministry of Transport, Sri Lanka as an effective transport solution for urbanized areas. Demand estimation for the BRT is a key element in operational planning as it becomes a primary criterion for selection of vehicles, scheduling of services, determination of fleet size and the design stations etc. This paper illustrates a methodology derived from traffic survey data for the estimation of demand for the proposed BRT corridor from Moratuwa to Pettah on Galle Road.**

***Keywords*—Bus Rapid Transit, Demand Estimation, Design of Passenger Flow**

I. Introduction

Bus Rapid Transit (BRT) is a high quality bus based transit system that delivers fast, comfortable and cost effective urban mobility through the provision of segregated right-of-way infrastructure, rapid and frequent operations and has to be accompanied with excellence in marketing and customer service [1]. The section of Galle Road from Moratuwa to Pettah with a distance of around 21.5 km has been chosen by the Ministry of Transport in Sri Lanka following the recommendation of the JICA funded CoMTrans Transport Study as being suitable for BRT operations [2].

The A002 or Galle Road is one of the primary arterials that feed the city of Colombo from the Southern Province as well as the Kalutara district and suburbs to the south of the city passing through well developed commercial and shopping areas in Colombo Municipal Council, Dehiwela - Mt. Lavinia Municipal Council as well as Moratuwa Municipal Council areas.

II. Objectives

Demand estimation for the proposed BRT system is an essential step in operation planning that is required for the determination of bus size and fleet size, scheduling of services, design of the running way, stations, terminals and depots and in fact every operational aspect of the BRT. Precise demand estimation ensures the correct design and achievement of the desired level of service. Underestimation can lead to overcrowding and delays while overestimation can lead to misallocation of road space, idling infrastructure, increased operational cost and a perception of inadequate demand.

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III. Literature Review

BRT ridership forecasts are required to design facilities for the opening year, and also the year when ridership reaches maturity usually 20 years into the future [3]. A city's demand profile for daily passenger trips provides the basis for the estimation of demand for a BRT system. Reference [1] presents two options for demand estimation: (i) Quick Assessment Method; (ii) Comprehensive Assessment Method. The Quick Assessment Method is supported by basic traffic counts including boarding and alighting counts for existing public transport services and hence allows estimation of the demand for a new BRT in a relatively short period of time at a modest budget. However, more precise estimation can only be achieved using The Comprehensive Assessment Method supported by transport demand models with the required input data which usually takes considerable time and money to collect. In the absence of transport demand models, direct boarding method and elasticity based methods can be used for estimation of demand for BRT [4]. Direct boarding method requires socio-economic, land use and transport data. This is recommended for corridors with no existing transit services. Elasticity based methods can be used for corridors with existing services. These methods are used to estimate the demand based on the changes in service span or other bus parameters such as in-vehicle travel time, frequency, fuel costs, fare changes or branding [5]. However these methods also require significant amount of transport and socio-economic data in relation to targeted corridor.

This research paper estimates the demand for the proposed BRT on Galle Road, utilizing data from boarding counts and origin-destination surveys and diversion models.

IV. Constraints

Inconsistency in lane capacity along the proposed corridor from Moratuwa to Pettah leads to consider it as 5 different sections, as shown in Fig. 1, for the purpose of geometric design as unconstrained widening of the Right-of-Way required for the implementation of the BRT is not possible. Furthermore it has been decided not to allow existing bus services when the BRT is in operation as the operation of more buses in the general traffic flow would make the capacity for other traffic inadequate. Moreover the incompatibility of ticketing, station and other infrastructure designs for the BRT would cause simultaneous operation of two systems difficult.

V. METHODOLOGY

Demand for the proposed BRT is estimated based on the data collected for both current bus and private vehicle users as described in Sub-section A of Section VI. Bus passenger data are used to estimate the preliminary design flow for BRT operation in base year 2015 as illustrated in Sub-Section B of Section VI. The preliminary design flow in base year is further adjusted to include diversion from private vehicles and generated passengers as described in Sub-section C and D of Section VI respectively. Once the final design flow with all adjustments is established for 2015, forecasting for the target year of operation 2025 is made with appropriate growth rates given in Sub-section E of Section VI.

VI. DEMAND ESTIMATION

A. Data Collection & General Analysis

Field surveys including Bus Volume counts (BVC) were conducted in July 2014 at 9 survey stations, together with Classified Vehicle Counts (CVC) and Private Vehicle Interviews (PVI) at 2 locations so that estimating current passenger flows for each section considered. Survey stations by type of survey are shown in Fig. 1. BVCs were conducted for 15 hours on a Thursday, Friday and Saturday whereas CVCs and PVIs were conducted simultaneously at the same locations but for 12 hours and only on a Tuesday.

Table I shows the number of vehicles and passengers observed at Moratuwa and Dehiwela which is the entry and the mid-point respectively of the proposed BRT corridor from Moratuwa to Pettah on Galle Road. This shows that there are around 111,000 passengers carried by 29,000 vehicles at Moratuwa which increases up to 127,000 passengers and 32,000 vehicles at Dehiwela. Taking into account rail passengers of around 35,000 entering to the city on the coastal line running parallel to the Galle Road, it can be assumed that nearly 162,000 passengers enter the Colombo Municipal Council area along the Galle Road Corridor on a daily basis.

TABLE I. DAILY INBOUND VEHICLE & PASSENGER FLOW, 2014

Modes	Vehicles /day (inbound)		Passengers/day (inbound)	
	Moratuwa	Dehiwela	Moratuwa	Dehiwela
Private vehicles	22,788	26,534	45,779	44,307
Public buses	1,874	2,209	55,096	72,666
Non-motorized	739	133	739	133
Freight vehicles	283	2,358	4,530	3,528
Bus (other)	3,020	311	4,475	6,228
TOTAL	28,704	31,545	110,619	126,602

Hourly variation of the vehicle flow from 6.00 am to 5.00 pm at Dehiwela, shows that the peak demand in the inbound direction is between 7.00 am and 8.00 am whereas the outbound peak is between 5 pm and 6 pm. The flow in the inbound direction reduces steadily during the course of the day while the flow in the outbound direction keeps increasing. The directional equilibrium is reached between 9.00 am to 11.00 am.

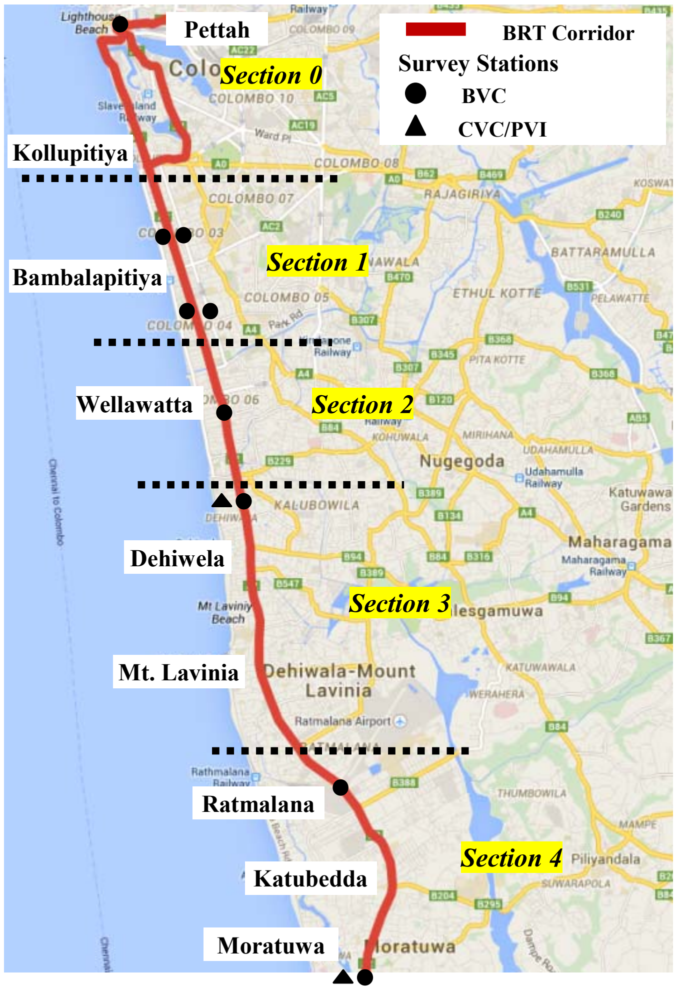

Fig.1. Proposed BRT corridor, sections & survey stations

This pattern is similar to the hourly flow variation observed along the entire corridor with a slight lagging of peak hour in the both the inbound and outbound directions.

B. Preliminary Design Passenger Flow for BRT in 2015

Passengers currently using the existing route buses are assumed to be fully diverted to BRT by terminating all services entering the Galle Road at Moratuwa and at intermediate points such as Katubedda, Ratmalana, Dehiwela, Bambalapitiya etc. The analysis of hourly flow observed from the BVCs conducted for 15 hours over 3 days at 9 stations is used to determine the number of existing bus passengers using each of the sections on the proposed BRT corridor.

The passenger flow used for the design of the BRT should ensure a high degree of reliability in the adequacy of the supply [1]. The design passenger load is calculated using the hourly passenger flow variation for a given level of confidence. For this purpose a 98% level of reliability which translates to the risk of the BRT design capacity being exceeded twice every 100 hours of operation is sued. This would mean that the system capacity is expected to exceed twice a week. The computation of preliminary design flow for 2015 is shown in Table II for both inbound and outbound direction for each section considered. The highest 98th percentile flow of inbound and outbound direction is thus selected as the design flow for each section.

C. Adjustment 1: Diverted Passenger from Private Vehicles

Data collected for CVCs and PVIs at Moratuwa and Dehiwela are used to estimate the possible diversion to the proposed BRT from private vehicles for year 2015.

PVIs which were conducted for about 3% sample of private vehicles provided origins and destinations of their users. Fig. 2 shows Origin Destination (OD) matrix developed for Motor Cycles at Dehiwela. Similarly OD Matrix for other private vehicle types including Three Wheelers, Cars and Vans were developed for both locations. These OD matrices were combined to establish the corridor flows for all types of private vehicles users. Adjustment was made to compensate for travel within Colombo on basis of flows between other OD pairs.

The diversion to BRT from each private vehicle was estimated using the LOGIT model formulation given by Eq.(1) [6].

$$P_{im} = \frac{\exp(C_{im})}{\exp(C_{im}) + \exp(C_{in})} \tag{1}$$

C_{im} *- generalized cost associated to mode m for individual i*
C_{in} *- generalized cost associated to mode n for individual i*
P_{im} *- Probability that mode m will be selected by individual i*

The generalized cost for current mode and alternative BRT was derived using access time, waiting time, travel time, vehicle use cost and fare for each OD pair. Thereby model finds the corresponding diversion factor for BRT for each OD pair present for different kinds of vehicles. For an example model expect 30% of diversion for BRT for the Motor Cycle users travelling between Moratuwa and Wellawatta.

TABLE II. PRELIMINARY DESIGN PASSENGER FLOW , 2015

Sections		Inbound (Passengers/Hour)			Outbound (Passengers/Hour)		
No.	Name	Mean	Std. Dev.	98th P Flow	Mean	Std. Dev.	98th P Flow
0	Kollupitiya-Fort	1,930	745	3,833	2,363	571	3,475
1	Bambalapitiya-Kollupitiya	3,200	903	5,022	3,046	882	4,507
1	Wellawatte-Bambalapitiya	3,898	1,523	7,768	3,889	1,151	6,188
2	Dehiwela-Wellawatte	4,094	1,634	7,627	3,620	1,343	6,372
3	Ratmalana-Dehiwela	4,441	1,749	8,684	4,402	1,629	7,774
4	Katubedda-Ratmalana	3,523	1,516	7,258	4,797	1,532	8,128
4	Moratuwa-Katubedda	3,239	1,469	6,578	3,792	1,211	6,193

This translates 67 passengers would divert to BRT for that particular OD pair. Same calculation was repeated to derive probable diversion to BRT from each vehicle type in relation to all OD pairs present.

The resulting diversion rates for each mode were calculated assuming that the BRT would have a travel speed of 25 km per hour and fare of 25% more than bus fare. Generalized costs for private vehicles were computed from Vehicle Operation Cost model of the University of Moratuwa. Unit cost for vehicle operation and user travel time is calculated based on [7] with appropriate adjustment factors to represent current values.

The total passenger diversion thus expected to divert to BRT from each vehicle type has been summarized in Table III on link basis. The largest amount of diverted trips is observed between Dehiwela and Wellawatta, with Ratmalana to Dehiwela also recording high flows of over 7,500 passengers per day diverted from private vehicles to BRT.

	Peliyagoda & Beyond	Colombo N/Maradana	Fort/Pettah	Kollupitiya	Townhall	Bambalapitiya	Cinamon/Borella/Dematagoda	Battaramulla/Kolonnawa & Beyond	Wellawatta	Narahenpita/Kirulapone	Dehiwela/Mt. Lavinia	Kohuwala/Nugegoda	Ratmalana	Moratuwa	Kesbewa/Piliynadala & Beyond	Panadura & Beyond
Peliyagoda & Beyond																
Colombo N/Maradana																
Fort/Pettah																
Kollupitiya																
Townhall																
Bambalapitiya																
Cinamon/Borella/Dematagoda																
Battaramulla/Kolonnawa & Beyond																
Wellawatta																
Narahenpita/Kirulapone									56							
Dehiwela/Mt. Lavinia	56	392	448	448		560	56		784	56	112					
Kohuwala/Nugegoda																
Ratmalana				112	56	112			56	112	112	56				
Moratuwa			224	112		112			224		112					
Kesbewa/Piliynadala & Beyond			168	56		168			168							
Panadura & Beyond		56	56	112	56	112	56		112	56						
Total	**56**	**448**	**896**	**840**	**112**	**1063**	**112**	**0**	**1399**	**224**	**336**	**56**	**0**	**0**	**0**	**0**

Fig. 2. Origin – Destination Matrix for Motor Cycle at Dehiwela

TABLE III. DIVERSION FROM PRIVATE VEHICLES TO BRT, 2015

Sections		Calculated passenger diversion from private vehicle to BRT/day (one-way)				
No.	Name	Motor Cycle	3-Wheeler	Car	Van	Total
0	Kollupitiya-Fort	823	1,308	604	595	3,330
1	Bambalapitiya-Kollupitiya	884	1,408	611	631	3,534
1	Wellawatte-Bambalapitiya	1,437	2,818	1,174	1,112	6,541
2	Dehiwela-Wellawatte	1,794	3,621	1,344	1,285	8,045
3	Ratmalana-Dehiwela	1,945	3,345	1,169	1,122	7,581
4	Katubedda-Ratmalana	1,607	1,666	712	771	4,755
4	Moratuwa-Katubedda	1,438	1,143	426	680	3,686
Total		9,929	15,308	6,039	6,196	37,471

Reference [8] and [9] indicates that peak hour passenger flow carried by private vehicles account for 10% of total daily flow and hence 10% of total diversion per day is expected to use BRT during the peak hour.

D. Adjustment 2: Generated Passenger Trips for BRT

The generated passengers referred to the additional new trips that can be expected to be attracted to a new mode of transport that provides a higher mobility than any of the existing modes. This is therefore based on the reduction in utility value experienced by people who are not travelling now. In the absence of a user preference survey, the experiences reported in other countries [10], [11], [12] were used in determining the share of generated trips. Such experiences show that share of generated trips vary from 7% - 20% from actual demand for BRT. Considering the fact that the corridor is already well served by public transport and population density is also high a low estimation of around 7% is expected as the share of generated trips for year 2015.

E. Design Passenger Flow for Base Year and Design Year

Preliminary Design flow given in Table II is adjusted with estimated diverted and generated trips to reach the final design flow for base year 2015 as shown in Table IV. An analysis of the passenger flows for the last 10 years indicates that there is an average annual growth in passenger demand of 2.5% on Galle Road [8]. Assuming that the same growth will continue over the next 10 years, the demand for the design year 2025 is calculated for each section. Table IV shows the calculated design passenger flow for 2025.

The highest passenger demand is for the section between Ratmalana and Dehiwela. As such 13,380 passengers per hour per direction would be considered as the demand capacity in 2025. The required capacity at the commencement in 2015 would be for 10,197 passengers per hour per direction.

VII. COMPARSION WITH INTERNATION SYSTEMS

Fig. 3 summarizes peak hour passenger demand and corresponding supply in terms of the number of buses [13]. The highest demand of 10,197 passengers in 2015 falls between the demand for BRT in Cali and Xiamen. In accordance with the number of buses used for those two cities, proposed corridor may require at least 140 bus trips, which can

TABLE IV. DESIGN FLOW FOR BRT

Sections		Demand for BRT (Passenger/hour/direction)				
		2015				2025
No.	Name	Preliminary Design Flow (Bus)	Diverted Passengers (Private Vehicle)	Generated Passengers	Final Design Flow	Design (@2.5% AAGR)
0	Kollupitiya-Fort	3,833	330	333	4,496	5,899
1	Bambalapitiya-Kollupitiya	5,022	353	430	5,805	7,617
1	Wellawatte-Bambalapitiya	7,768	654	674	9,096	11,934
2	Dehiwela-Wellawatte	7,627	804	674	9,105	11,947
3	Ratmalana-Dehiwela	8,684	758	755	10,197	13,380
4	Katubedda-Ratmalana	8,128	476	688	9,292	12,192
4	Moratuwa-Katubedda	6,578	369	556	7,503	9,844

be jointly provided by standard and articulated buses, during the peak.

The highest peak demand of 13,380 in 2025 is close to the current demand for the BRT in Lima which operate 101 articulated buses during the peak hour. Therefore the requirement would be more or less same for the proposed BRT on Galle Road to clear the peak hour in 2025. This places the proposed BRT having to be designed in par with the top ten BRT systems in the world. By comparison it will rank as one of the heavy flowing systems and requires to be designed accordingly.

City	Peak Flow/Hour/Direction		Bus Types Used [a]
	Passenger	Buses	
Bogota	37,700	312	Art/Bi-Art.
Guangzhou	27,400	350	Std./Art
Istanbul	18,900	137	Art/Bi-Art.
Lima	13,950	101	Art.
Cali	11,100	164	Std./Art
Xiamen	8,360	104	Std./Art
Brisbane	7,700	247	Std.
Mexico	7,550	56	Std./Art./Bi-Art.
Zhengzhou	7,230	129	Std./Art
Urumqi	6,950	87	Std./Art
Chengdu	6,650	64	Art.
Lanzhou	6,550	87	Std./Art
Dalian	6,430	86	Std./Art
Hangzhou	6,300	80	Art.
Quito	6,000	60	Art.
Johansburg	4,510	64	Std./Art
Hefei	3,600	55	Std./Art
Yinchuan	3,600	63	Std./Art
Jakarta	3,400	40	Std./Art

[a] Art. for Articulated Buses; Bi-Art. for Bi-articulated Buses

Fig. 3. Peak hour flows for worldwide BRT systems

VIII. CONCLUSION

Design flow for proposed BRT is estimated at 98th percentile of hourly bus passenger flow estimated for each section of the proposed corridor considered. This is further adjusted for passengers diverting from private vehicles and generated trips. The highest estimated design flow is recorded for Ratmalana- Dehiwela section for 2015 as 10,197 passengers per hour per direction and 13,380 in 2025. Such design flow would be able to be supplied BRT services using around 100 articulated bus trips in design year of 2025.

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