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This is an abridged version of the paper presented at the conference. The full version is being submitted elsewhere. Details on the full paper can be obtained from the author.

ISBN: 978-85-285-0232-9

13th World Conference on Transport Research

www.wctr2013rio.com

15-18 JULY 2013 Rio de Janeiro, Brazil

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ABSTRACT

The capacity of a Bus Rapid Transit (BRT) corridor is highly dependent on the capacity of its stations. Whilst a degree of saturation of a bus lane lower than 85% can guarantee that the operational speed is not significantly reduced, it is a common practice to design BRT stations with a saturation level not lower than 40%, as otherwise, high delays and long queues at bus stations are expected, reducing the operational speed of a BRT system, and thus its level of service.

In this paper, the operation of a BRT multiplatform station, with high level of passenger demand and high volume of buses, is analyzed using the microsimulation suite VISSIM. In the study, the impact of various saturation levels on the operational speed of the BRT corridor is analyzed, from which a relationship between commercial speeds and saturation levels is determined. Also, the relationships between saturation levels and queue lengths, and bus stopped delays at the station are analyzed. The analyses shows how bus speeds are reduced due to high levels of saturation at the station with and without the provision of an overtaking lane. As a result, the acceptable values for stations' saturation level are found out, which may be considered as a guide for providing an acceptable level of service to public transport users.

Keywords: Microsimulation, public transport, BRT stations, saturation level, bus stops.

INTRODUCTION

Bus Rapid Transit (BRT) systems have experienced a widespread implementation on many cities around the world, as they have proved to be efficient in terms of flexibility, use of road space, and relatively low construction and operational costs, providing high quality services to public transport users. The main cities on which BRT systems have been successful range from nearly five hundred thousand inhabitants to over ten million inhabitants.

According to Wright (2003) a BRT is a high quality mass transit system, oriented to users, which provides fast urban mobility, safety and favourable cost-benefit ratio. A BRT operates on a segregated corridor with fares charged outside of the bus, and its operation resembles to a metro system, but operated with high capacity buses running over a paved surface.

The main characteristics of a BRT system are their capacity and speed, which make them competitive against car users and the conventional bus systems. Experience has shown that the capacity of a BRT corridor can reach up to 42,000 passengers per hour per direction (Steer Davies Gleave (2003)), which is possible with the provision of a double lane corridor that allows overtaking of express lines at stations. A single lane corridor with no overtaking lane can reach a capacity of up to around 13,000 passengers per hour per direction. The commercial speed of the main successful BRT systems can be as high as 20 to 30 km/hr, Wrigth and Hook (2007).

High capacity and high speed can be conflicting concepts on the operational design of a BRT system. For having a high capacity system, we need to have a high frequency of buses, which in turn means high number of passengers and buses. This however can cause congestion on bus lanes, reducing the operational speed of the system. In general, a successful BRT system should reach commercial speeds as high as 25 km/hr; however depending on local circumstances, speeds of around 20 km/hr can be considered sufficient for a BRT system which is competing against car users and conventional bus users.

Achieving high capacity and high commercial speeds is greatly dependent on the level of saturation at bus stations. Thus, the success of a BRT system can be guaranteed if stations are designed so as to have “adequate” saturation levels.

In this paper, the operation of a BRT station with a high level of passenger demand and high volume of buses is analyzed with the use of the microsimulation model VISSIM, PTV Planung Transport Verkehr AG (2011). In the study, different alternatives for achieving adequate saturation levels at the BRT station are analyzed, which include the use of multiple lay-bys for simultaneous stops, and double bus lanes for overtaking vehicles. The impact of different saturation levels on the operational speed of the BRT corridor is analyzed. The impact of saturation levels on queue length formation and stopped delay of buses are also analyzed.

BRT STATIONS AND SATURATION LEVEL

The saturation level of a BRT station is the percentage of time that a bus lay-by is occupied by a transit vehicle. This concept is different from the degree of saturation of a road lane, which can be considered as the level that the number of vehicles congests the capacity of the road lane. For traffic engineers, a road’s saturation level lower than 85% means that the operational speed of vehicles has not been reduced significantly and the level of service can be considered acceptable for most road users. Just when saturation levels get higher than 85%, vehicular speeds reduce significantly. However, in the case of BRT systems, a saturation level of 30% or 40% may mean that the operational speed of buses is reduced significantly, Wright and Hook (2007).

In the operational design of BRT stations, it is a common practice for transport planners to use a saturation level of 40% as the maximum saturation that stations should reach, so as to have reasonable speeds for the system, ensuring an acceptable level of service for users.

Factors that influence on the capacity of BRT stations

In order to have high speeds on a BRT system, the operation on stations has to resemble to the operation on rail based stations. Thus, the main characteristics that stations have to meet are:

- Platform at the same level of the bus floor;
- Multiple doors for increasing the amount of passengers accessing to buses;
- Multiple lay-bys in case of high volume of buses;
- Automatic operation of station's doors, synchronized with bus doors; and
- Double lanes at station for overtaking buses, in case of the need of having express lines on the system.

In order to reduce the station's saturation level, the time that a bus is stopped at the station should be a minimum. The main factors that influence on the stopped time (dwell time) are:

- Volume of passengers using the station;
- Number of bus doors;
- Width of bus doors;
- Control system for opening and closing doors; and
- Acceleration and deceleration capacity of buses.

The volume of passengers that board and alight at the station defines the time that the bus line needs to stop (dwell time). The time that a passenger spends for boarding or alighting a bus is dependent upon whether the level of the platform station is the same as the level of the bus's floor. If this is the case, the time spend by passengers is minimum. At the same time, if the number of doors is three or more, and the width of the doors are wide enough, the number of passenger boarding and alighting per unit of time can be high, reducing the time that the bus needs to occupy the lay-by. All these elements should be considered for designing efficient BRT stations.

When the platform station has the same level as the bus's floor, then a passenger needs approximately one second for either boarding or alighting the bus. Thus, for a bus with three doors, three passengers can access the bus in one second.

Finally, the acceleration and deceleration capacity of the vehicle is also important in optimizing the dwell time for a BRT system. All these factors may have a considerably effect on the total dwell time.

USE OF MICROSIMULATION TECHNIQUES FOR SIMULATING THE OPERATION AT BRT STATIONS

The use of microsimulation techniques for assessing traffic schemes has become a common practice on many transport projects around the world, Fellendorf and Vortisch (2002). With improved microsimulation software, many transport problems can be tackled effectively, as some software provides quasi-real results, modelling not only the geometry of the transport infrastructure, but also the operational behaviour of vehicles and pedestrians on the motorized and non-motorized network.

During the design of a BRT system for La Paz city, a major corridor has been identified which needs to carry out around 150 buses per hour per direction on the opening year, and 185 buses per hour per direction on year 10 after opening. The demand model for the BRT scheme has shown that there was a particular station where passenger demand was quite high reaching up to 13,000 passengers per hour on the AM peak period. The high passenger demand and high volume of buses, coupled with the limited road space for the segregated corridor have requested the use of microsimulation techniques for modelling the operation at this station.

The microsimulation model has become a useful tool for analyzing different operational scenarios of the BRT station, which in turn has provided an operational assessment tool for analyzing the impact of various variables on the stations' saturation level.

Study Area

The study area for which the microsimulation model has been built includes the main BRT corridor in La Paz city, on a section where the high passenger demand station was located. The design engineers have foreseen that, due to the high number of boarding and alighting passengers, the station would need up to three laybys or platforms, so as to have an efficient BRT system.

The location of the platforms within the study area is shown in Figure 1.

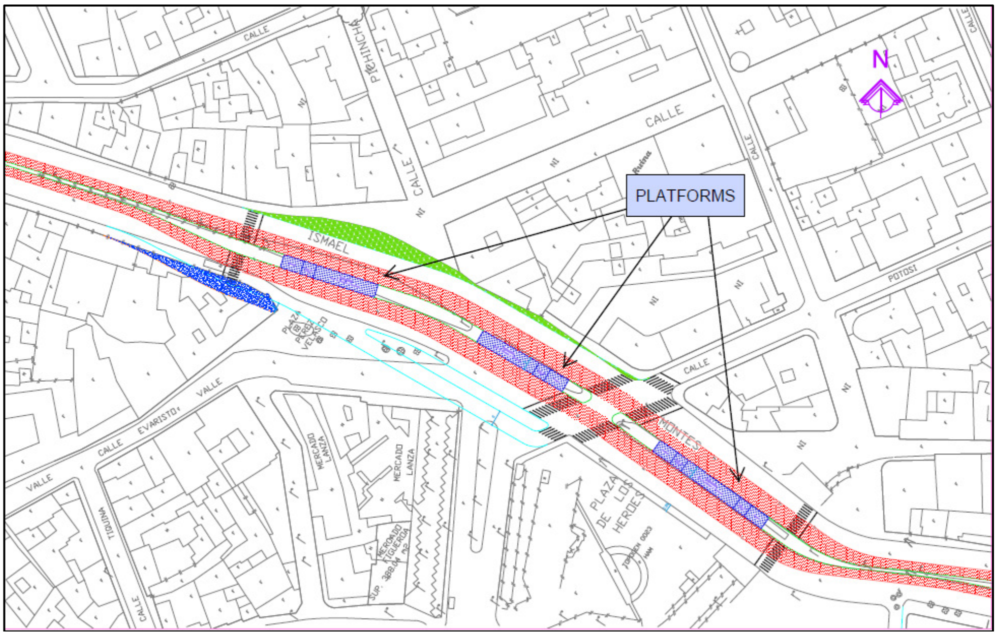

Figure 1 – BRT Station on the corridor under study

Due to the limited space available on the major roads in La Paz city, the BRT system has been designed to work with just one segregated lane on most of its corridors. However, due to the high volume of buses and passengers on the corridor under study, the geometrical design has included an alternative scheme with two segregated lanes on this section, so that an extra lane would be available for overtaking vehicles which may need to stop at the first or the second platform.

Demand levels

The passenger demand at the BRT station and the frequency of buses on the corridor, resulting from the operational design of the system, are summarized on Tables 1 and 2 respectively.

Table 1 – Passenger demand at the BRT station – AM Peak Hour

Year	Number of passengers (pax/hr)		
	Boarding	Alighting	Total
2014	3855	6746	10601
2024	4972	8777	13749

Table 2 – Headway of BRT Lines – AM Peak Hour

BRT Line	Headway (min)	
	Year 2014	Year 2024
p261pi	3	2
p301pi	3	3
p311pi	2	1.5
p401pi	3	3
p411pi	2	1.5
p501pi	3	3
p511pi	6	4

The analysis of the expected passenger demand and bus frequencies at the station led to the conclusion that it would be working at high levels of saturation. The levels of passenger demand and bus frequencies suggested that the station would need at least three platforms or lay-bys. Thus, in order to understand better the detailed behaviour of buses at the station, a microsimulation model was built. This model would also provide a tool for analysing the effect of saturation levels on commercial speeds of the BRT corridor.

Vehicle type

The vehicle type used in building the microsimulation model was an articulated bus similar to the Volvo BRT 7300 bus. This vehicle is shown in Figure 2.

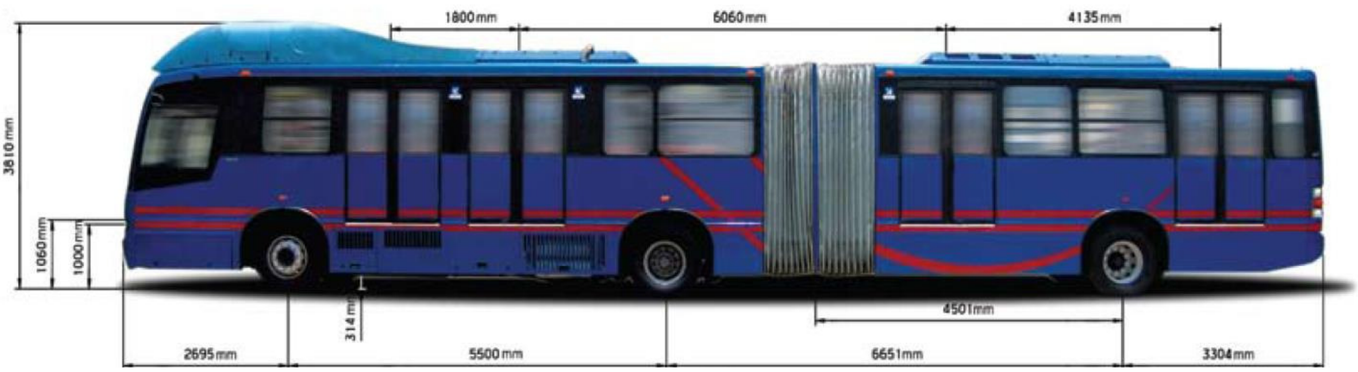

Figure 2 – Vehicle model Volvo BRT 7300

The main characteristics of the BRT vehicle included in the model were the following:

- Length of frontal element: 10.346 m
- Length of back element: 7.805 m.
- Width: 2.55 m.
- Total length: 18.10 m.
- Maximum acceleration capacity: 3.4 m^2/s
- Maximum deceleration capacity: -5.5 m^2/s.

Analysis of saturation level at BRT stations

In order to analyse the effect of the station's saturation level on the operational speed of the BRT corridor, two cases were modelled, using the microsimulation suite VISSIM, PTV Planung Transport Verkehr AG (2011): corridor with just one segregated lane, and corridor with two segregated lanes.

For the assessment, a flow of 150 buses per hour has been used (forecasted volume on opening year); each bus was supposed to stop at the station, distributing buses as uniformly as possible on all three platforms. The modelling in VISSIM included the forecasted frequency of bus lines, assuming that the total passenger demand would also be distributed uniformly on all buses and platforms.

So as to have different saturation scenarios, for analysing the effect of saturation level on commercial speeds, dwell time has been used as the main independent variable ranging from 15 seconds to 52 seconds per bus. Thus, the level of passenger demand has also been considered as a variable in the analyses.

The first set of simulation runs has been carried out assuming that the BRT corridor would have just one segregated lane, which would not allow overtaking of buses. Each bus, which is considered to be a 160 passenger articulated vehicle, would use one of the three platforms with a uniform dwell time.

The platforms' saturations were calculated using the following equation:

$$X = V(t_m + pt)/3600 \qquad (1)$$

Where:

X = Saturation level of BRT station
V = Volume of buses per hour that stop at the station.
t_m= Sum of dead times for stopping, opening doors, closing doors and starting (in seconds).
p = Average number of passengers that board and alight each bus.
t = Average time for a passenger to board or alight (in seconds).

The number of doors for the BRT articulated bus was assumed to be 3, so that the time for boarding and alighting passengers was 0.33 seconds per passenger. The total dead time t_m was taken to be 5 seconds for each stopping bus; which considers just the time for opening and closing the bus's doors, as vehicle's deceleration and acceleration times are modelled directly by the microsimulation model.

The microsimulation runs have provided various outputs, which include the average speed on the BRT network, the average stopped delay per bus, the maximum queue length and the average queue length. The last two parameters are measured upstream from the edge of the first platform station, which would provide the data for designing the separation between platforms.

It is important to mention that 5 runs were performed for each scenario in order to get average values for the output variables, Seaman (2006). Table 3 summarizes the results drown out from simulating the BRT corridor with one segregated BRT lane.

Table 3 – Saturation level and operational parameters for BRT stations (without overtaking lane).

Dwell Time (sec)	Saturacion Level	Average Speed (km/hr)	Average Stopped Delay per Bus (sec)	Max. Queue Length (m)	Ave. Queue Length (m)
15	22%	19.0	9.0	56	2
20	27%	18.5	12.2	56	3
25	34%	18.1	14.4	56	4
29	41%	17.6	20.6	56	4
33	45%	17.1	26.0	76	5
38	52%	16.4	33.1	94	7
43	60%	13.5	94.3	231	63
52	73%	8.6	260.3	517	260

From Table 3 it can be seen that, for saturation levels ranging from 22% to 73%, the average speeds varies from 19 km/hr up to 8.6 km/hr. It is important to mention that the average speed includes the speed on a section of the BRT corridor where the three platform station is located, and one signalized junction controls the output of the stream of buses into the next corridor section.

The relationships between saturation levels against average speeds, average stopped delays and maximum queue lengths are shown on Figures 3, 4 and 5 respectively.

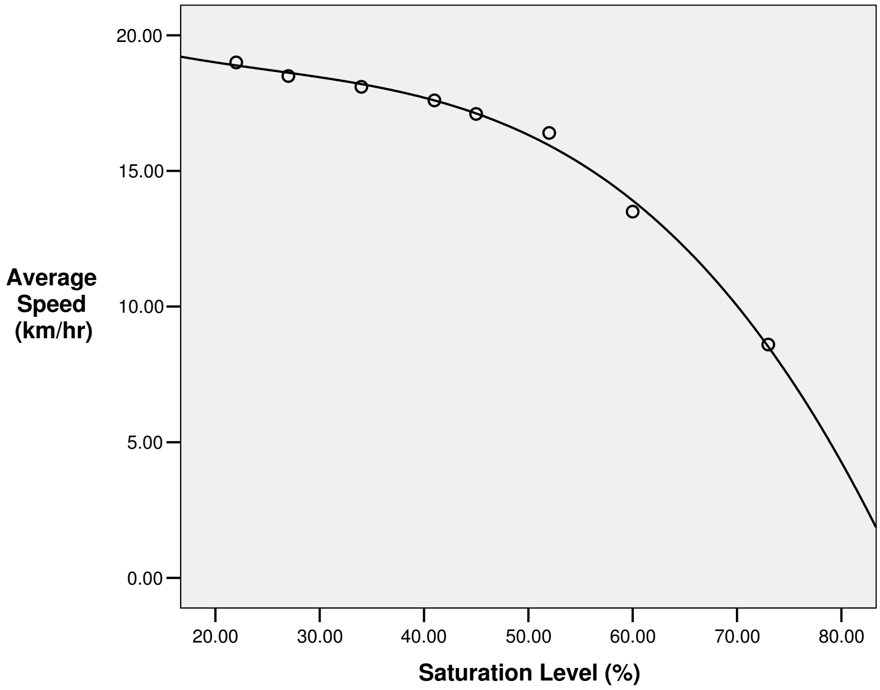

Figure 3 – Relationship between BRT commercial speed and saturation level (without overtaking lane)

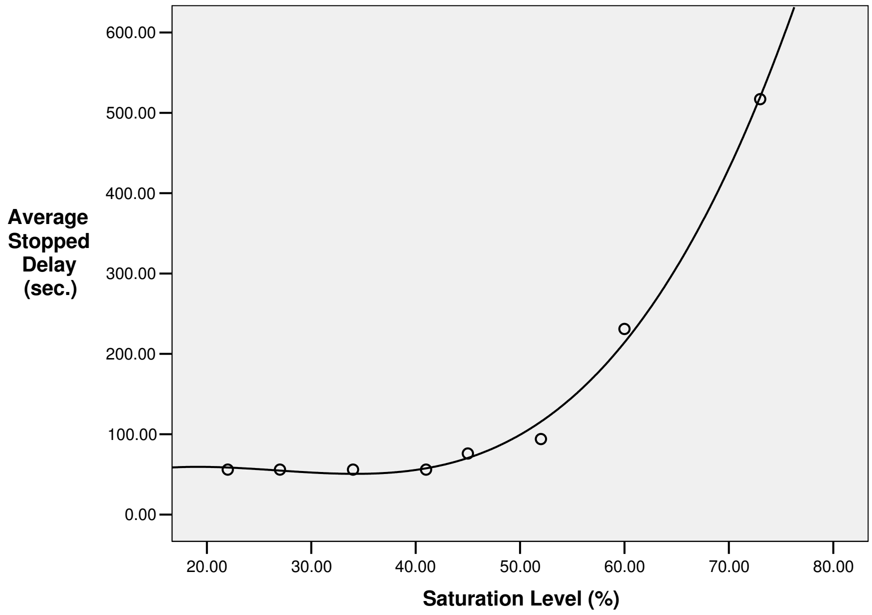

Figure 4 – Relationship between average stopped delay and saturation level (without overtaking lane)

From Figure 3 it can be seen that, for saturation levels lower than around 45%, the average commercial speed of BRT buses is not reduced significantly. From saturation levels higher than 45%, the reduction in commercial speeds is much more noticeable, and from saturation levels higher than 50% bus speeds reduce sharply.

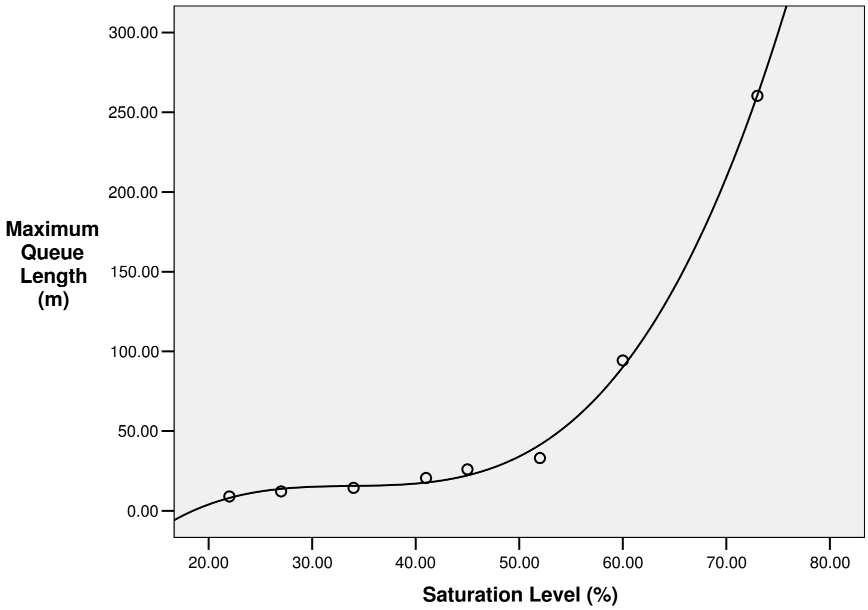

Figure 5 – Relationship between maximum queue length and saturation level (without overtaking lane)

The reduction of the average commercial speed of buses with the saturation level at stations is reflected on the increase of the average stopped delay of buses and queue lengths. From Figures 4 and 5, it can be seen that the values for these parameters are increasing sharply for saturation levels higher than 45%. As a matter of fact, for saturation levels higher than 45%, the maximum queue length gets higher than 100 meters approximately.

The relationship between the saturation level of stations and the commercial speed of the BRT corridor (with no overtaking lane) has been fit to the following equation:

$$S = 21.169 - 18.312X + 51.719X^2 - 69.026X^3 \quad ; \; R^2 = 0.9951 \qquad (2)$$

Where:

S = Average commercial speed of BRT buses (in km/hr)
X = Saturation level of station (in percentage).

In summary, the simulation results have shown that in the case of a BRT corridor with no overtaking lane, achieving saturation levels higher than 45% would increase significantly queue lengths of buses waiting to use or pass the saturated station, which may also block the upstream junctions and lead the system to a collapse.

In order to analyze how the inclusion of an overtaking lane influences on the operation of the BRT corridor, the microsimulation model was modified to include two lanes on the section of the three-platform station. Then, simulation runs were carried out for the same dwell times and saturation levels as in the former runs. The operational parameters for this case are reported on Table 4 below.

Table 4 – Saturation level and operational parameters for BRT stations (with additional overtaking lane).

Dwell Time (sec)	Saturacion Level	Average Speed (km/hr)	Average Stopped Delay per Bus (sec)	Max. Queue Length (m)	Ave. Queue Length (m)
15	22%	19.2	5.6	36	0
20	27%	18.8	7.25	36	0
25	34%	18.5	7.8	36	0
29	41%	18.3	8.9	36	0
33	45%	18.0	10.2	54	0
38	52%	17.7	12.4	56	0
43	60%	17.2	15.9	56	0
52	73%	13.1	100.3	253	31
57	80%	8.9	249.0	450	183

The relationship between saturation level and average commercial speeds is shown in Figure 6.

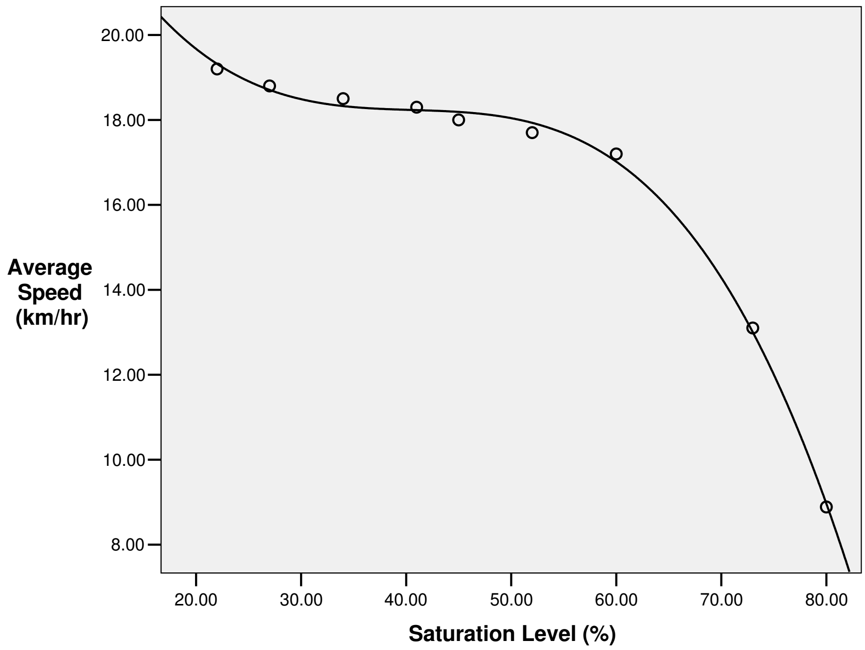

Figure 6 – Relationship between commercial speed and saturation level with additional overtaking lane

From Table 4 and Figure 6 it can be drawn out that, in case of having two lanes on the BRT corridor, the average commercial speeds can be considered acceptable up to a saturation level of nearly 60%, and just for saturation levels higher than that value the average speed is reduced significantly.

The results reported on Table 4 also show that the average delay per bus and queue lengths do not increase significantly for saturation levels lower than 60%, but above this value, these parameters may increase sharply.

The equation that best fits the relationship between saturation levels and commercial speeds, when an overtaking lane is provided, is:

$$S = 28.203 - 71.92X + 175.29X^2 - 144.32X^3 \quad ; R^2 = 0.9977 \quad (3)$$

Where:

S = Average commercial speed of BRT buses (in km/hr)
X = Saturation level of station (in percentage).

From the above results, it can be concluded that providing an overtaking lane improves significantly the performance of the BRT corridor, as stations can afford to be at up to 60% of saturation levels with no excessive reduction on commercial speeds, nor too high queues and delays.

CONCLUSIONS

In this paper, the relationship between the saturation level of BRT stations and the operational speed of buses is analysed with the microsimulation model VISSIM.

The study shows that the commercial speed of a BRT corridor is not reduced to excessive levels when the saturation level is lower than 45%. If saturation levels get higher than 45%, then the commercial speed of the BRT system may be reduced significantly, which in turn may lead to achieving a low level of service for public transport users.

Providing an extra overtaking lane at stations increases the value to which saturation level of BRT stations can be considered as acceptable. As a matter of fact, simulation has shown that the level of service can be considered acceptable up to a saturation level of nearly 60%. Just for saturation levels higher than this value, the resulting commercial speeds may be reduced significantly.

The analysis has also shown how the saturation level affects the queue length that may build upstream of the BRT stations, which is important for designing the BRT corridor. In fact, having a saturation level higher than 45% with one BRT lane, or 60% with two BRT lanes, may demand to have sufficient space for buses that would queue up in order to use the station.

Finally, it can be concluded that microsimulation techniques have proved to be a useful tool for analyzing the saturation at BRT stations and its effect on the commercial speeds of a BRT corridor. This study has shown that some useful relationships can be studied without the need of measuring these data on field, which on most practical cases might be very difficult.

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