TRANSMILENIO BRT CAPACITY DETERMINATION USING A MICROSIMULATION MODEL IN VISSIM

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ABSTRACT

The main objective of this research is to include stochasticity and randomness inherent to the operation of a bus transport system as well as the interaction between buses on the capacity calculation process. Congestion on the platforms, poor condition of the pavement and interaction between vehicles can affect the operation of the buses. Deterministic formulas are not able to include such phenomena on the capacity estimation.

For the development of this research, 3 VISSIM models were built and calibrated in order to calculate the capacity of 3 different locations on a BRT system. Each model corresponds to a Transmilenio component: 1) A Station 2) An intersection and 3) A section of a trunk corridor.

The research outcomes show how the use of formulas and deterministic conditions can yield very different results of the capacity of a transport system compared to the micro-simulation model results. This confirms the need for the use of stochastic elements in the estimation of a bus system capacity. Although this conceptual difference was already known in the literature, this study does quantify the differences in capacity when interaction between vehicles and randomness of bus system operation are included.

INTRODUCTION

Currently Transmilenio (TM) has 114 stations, 84 kilometers of segregated roads in operation, 1263 buses and 190,000 people moving around at rush hour (TM, 2010). What many people does not know is that this mass transit system of Bogotá is worldwide known as one of the BRT (Bus Rapid Transit) with greater capacity and one of the best examples of high-level BRT (Cain et al. 2007).

The HCM defines capacity as "the maximum hourly rate at which persons or vehicles can cross a point or uniform section of a road or rail for a defined time under prevailing road conditions, traffic and control conditions" (Agyemang-Duah & Hall, 1992).

On the other hand we must emphasize that capacity relates to prevailing road conditions. In this manner if road shows poor pavement quality or most of the time parked vehicles are blocking one lane of the roads, these conditions must be included on the capacity estimation process knowing that this condition is usual on the road and not only momentary.

Some authors (Shao, 2011) (Ozbay & Ozguven, 2007) claim that the traffic flow and capacity of a road should be based on stochastic concepts. Hwang et al. (2005) states that the capacity of a road stands as the aggregate result of each vehicle's individual behaviour. This research aims to include the intrinsic randomness of transportation systems, so as the behaviour of individual vehicles in the calculation of the capacity through a micro simulation model.

LITERATURE REVIEW

As previously mentioned, Hwang et al. (2005) states that the capacity of a road should be seen as the aggregate result of each vehicle's individual behavior. Microsimulation models represent an accurate option for representing individual vehicle's behavior. Additionally, these models contain random elements that help to successfully represent probabilistic vehicular traffic.

In the literature review for this research three helpful investigations were found (Arasan & Vedagiri, 2010) (Arasan & Vedagiri, 2008) (Chen, Yu Zhu, Guo, & Sun, 2010). These authors use micro simulation models to evaluate transport systems with dedicated lanes. Chen et al. (2010) even use these models to estimate the capacity of these systems. However these methodologies are applied to systems with bus lanes where buses are forced to interact with mixed traffic. This represents conceptual differences compared to a BRT system where bus traffic is completely segregated from the mixed traffic. Thus the mentioned investigations can be helpful, yet they cannot be replicated for a TM system analysis. As we know TM has total segregation of mixed traffic and there are some segments of the dedicated lanes where buses can overtake another buses, this operating condition requires a special analysis.

On the other hand Rangarajan (2010) use a micro simulation model to analyze a traffic situation before and after the implementation of a BRT system for the city of Pune in India. This research shows how BRT systems not only carry savings in travel time, but also represents a more efficient system compared to a system without segregated bus lanes. Although this document is proof of the effectiveness of BRT systems, the only evaluation parameter considered was travel time, thus the author does not know the capacity of the system; not even tried to use the micro simulation model to estimate it.

Another publication was found where authors use the concept of capacity together with a micro simulation model BRT. This study corresponds to a BRT operation in the city of Ottawa, Canada (Siddique & Khan, 2006). In this study authors wanted to evaluate the capacity of the system 20 years later. Three scenarios were built showing different numbers of buses and operating condition. This research shows as main result, differences up to 35% between the estimated capacity using the HCM2000 manual compared with simulation results. This outcome ratifies how the use of formulas and deterministic conditions can yield very different results from the capacity of a system compared to a micro simulation model and confirms the need for the use of stochastic elements in the process.

METHODOLOGY

Figure 1 shows a simplified diagram explaining the methodology used to develop the research. The main objective was to choose three locations corresponding to an intersection, a station and a section of a TM system trunk to be modeled and analyzed in VISSIM.

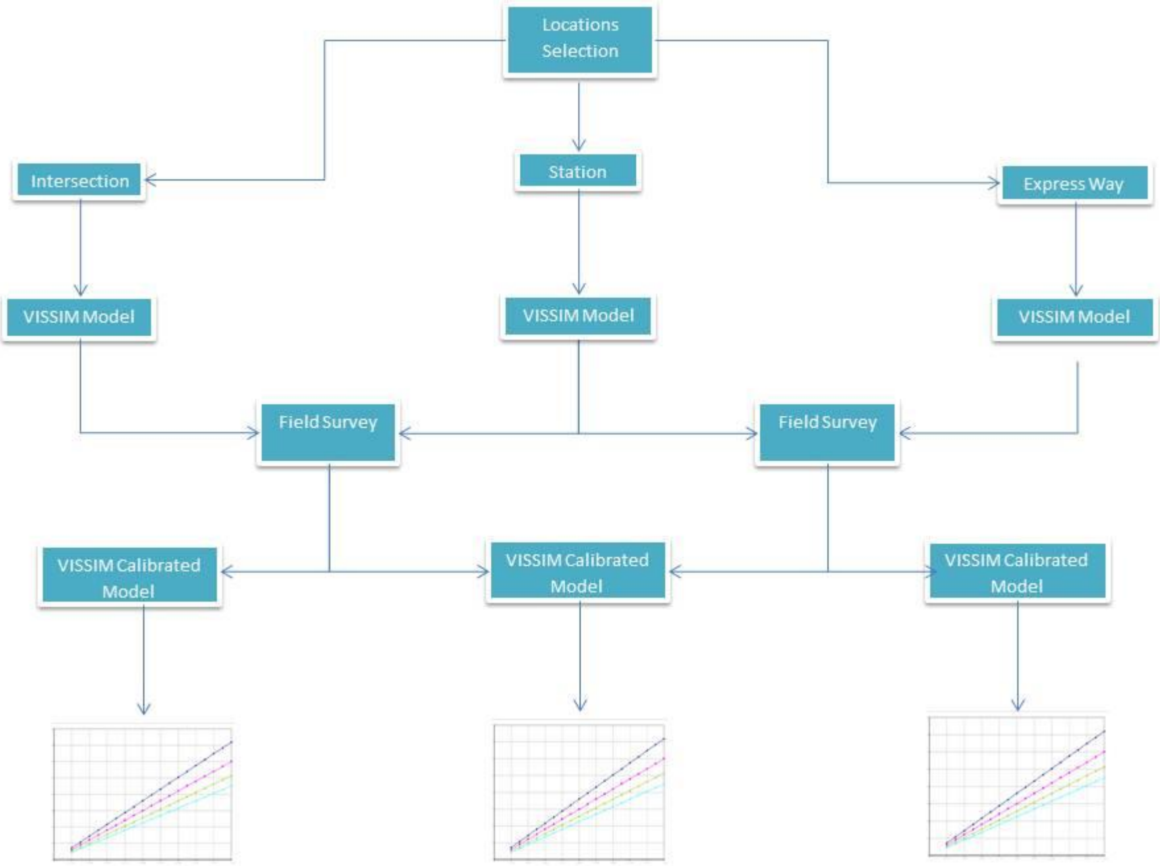

Figure 1 Research Metodology, Source: Own Elaboration

LOCATIONS

To choose the locations for the study, many trips throughout the system were made to identify possible flaws in the system as poor pavement quality, obstructed intersections, etc. The preliminary runs showed that the trunk with the worst pavement is the Avenida Caracas. According to this various points on this road were evaluated where visible impact on the operation of the system due to the pavement was identified. On these points buses were forced to perform maneuvers to avoid gaps resulting on significant reductions on their speed.

LOCATION #1

Figure 2 shows the characteristics of this chosen location, which correspond to one of the most important stations on the system, "Calle 100" Station. This station has 5 stop points on each direction and more than 20 routes stop on this location on the morning peak hour. The main reason for choosing this location is the high number of passengers that flow on this station every day.

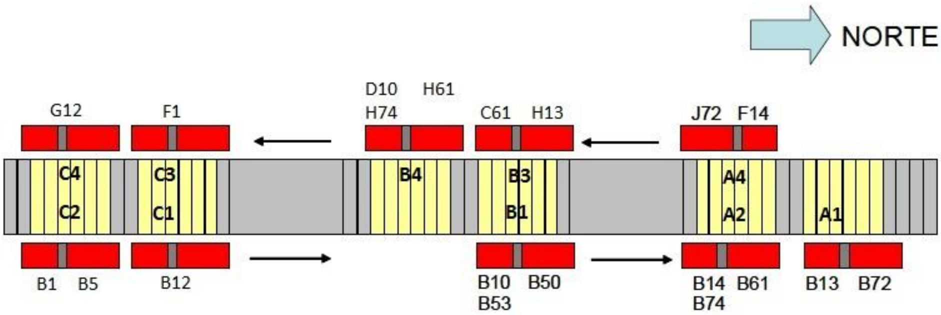

Figure 2 Location #1 Diagram, Source: Own Elaboration

LOCATION #2

Location #2 corresponding to the intersection of "Avenida Caracas" and "Calle 63" was chosen because of its high vehicular volume and heavy congestion, poor geometric design of the intersection affecting both private vehicles and TM's exclusive lanes.

LOCATION #3

Finally, as shown in SDG's study, road capacity is not the main bottleneck of the system; however the aim of this study is to model a section of the Caracas trunk in which the effect of poor condition of the pavement can be measured. According to this the section of "Avenida Caracas" between 57th Street and 59th Street was chosen as Location #3, due to bad condition of the pavement forcing vehicles to slow down. The photos below show the state of the pavement along this chosen stretch.


Figure 3 Photo of Location #1, Source: Own Elaboration

FIELD DATA COLLECTION

Once the locations were chosen, it was necessary to obtain the input data to be used in VISSIM, and the data that would allow us to calibrate the models. According to this a field survey was designed in line with SDG's study of TM capacity (2007) and the calibration methodology proposed by Yu et al. (2006) where they sought to determine the following variables:

- Number of Vehicles (3 Days, 2 Morning Rush Hours)
- Traffic Lights Cycles
- Arrival of Succesive Buses (3 Days, 2 Morning Rush Hours)
- Stop Time at Stations (3 Days, 2 Morning Rush Hours)
- Speed of Buses through GPS (At least 10 Trips in the Morning Peak Hour)

Location #1

The survey on this point was performed through an HD video camera that allowed to record with considerable detail the operation at this station. The videos were made during the morning rush hour and were carried from 7am to 9am during 3 days for each direction.

Table 1 Location #1 Station Stop Time and Time Interval between Buses, Source: Own Elaboration

Stop Point	Traffic Direction	Time Interval Between Buses (Sec)	Standard Deviation (Sec)	Average Stop Time (Sec)	Standard Deviation (Sec)
A1	SN	100	90	24	6
A2	SN	125	116	22	6
B1	SN	74	52	28	11
C1	SN	107	101	43	34
C2	SN	180	128	40	40
Express	SN	29	28		
A4	NS	170	149	26	9
B3	NS	189	112	31	14
B4	NS	196	156	24	9
C3	NS	210	208	31	14
C4	NS	117	103	24	10
Express	NS	21	20		

The time interval between buses was considered as the time since a bus clears the stop point until the next bus occupies the same stop point. Moreover the stop time is calculated from the time a bus occupies the platform until it clears it.

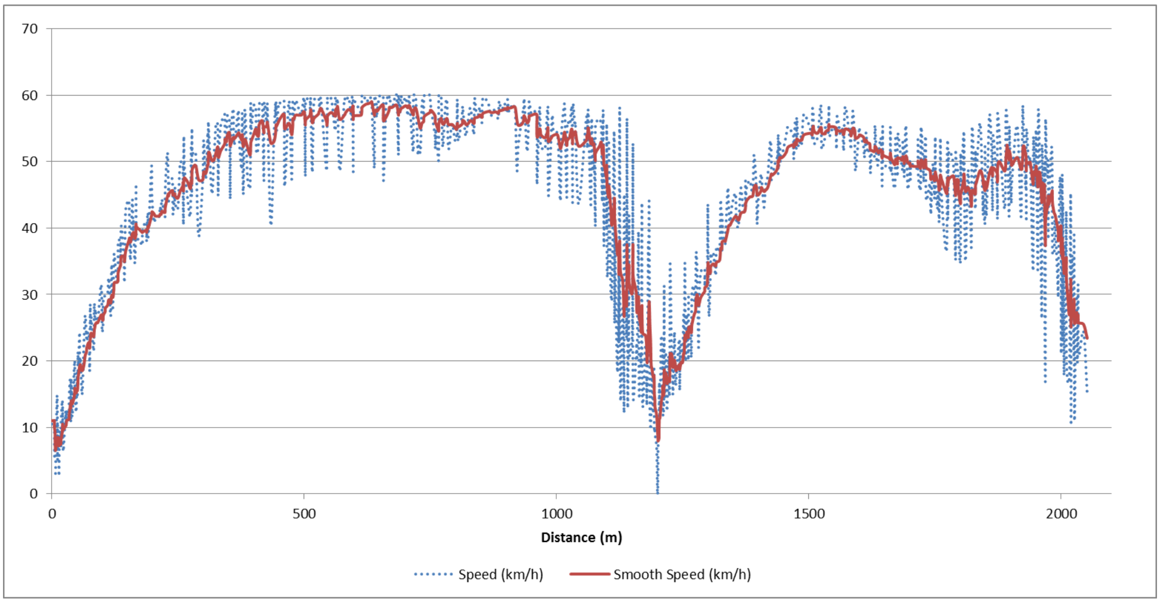

Figure 4 Location #1 Station NS GPS Course, Source: Own Elaboration

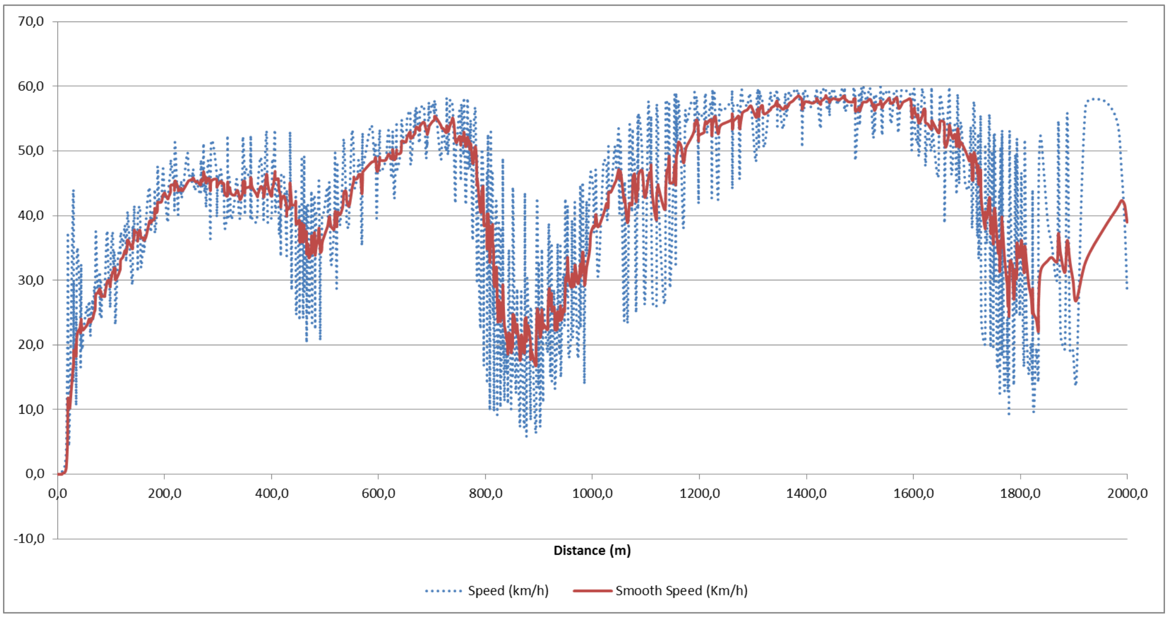

Figure 5 Location #1 Station SN GPS Course, Source: Own Elaboration

The GPS graph was performed from and to the two stations adjacent to the Location #1, ie between the "Virrey" and "Calle 106" stations. The blue curve indicates the average of 8 journeys made between 7am and 9am. All speed values above 60 km/h where erased because this value corresponds to the operation speed limit of buses TM. One can observe too much noise in the blue curve data. For reason it was necessary to use an Exponential Smoothing method to soften the data and have a more defined trend as this graph will be used later for the calibration process of the model. The red curve shows the result of applying the formula presented below.

$$\hat{x}(t) = \alpha \cdot x(t) + (1-\alpha) \cdot \hat{x}(t-1)$$

Location #2 and Location #3

For the Location #2 only the North-South's time interval between successive buses and GPS course was used. Table 5 shows the interval between buses where lane 1 is the western lane road.

Table 2 Location #2 and #3 Time Interval between Buses, Source: Own Elaboration

	Lane	Time Interval Between Buses (sec)	Standard Deviation (sec)
Location #2	1	12	22
	2	16	27
Location #3	1	13	23
	2	15	24

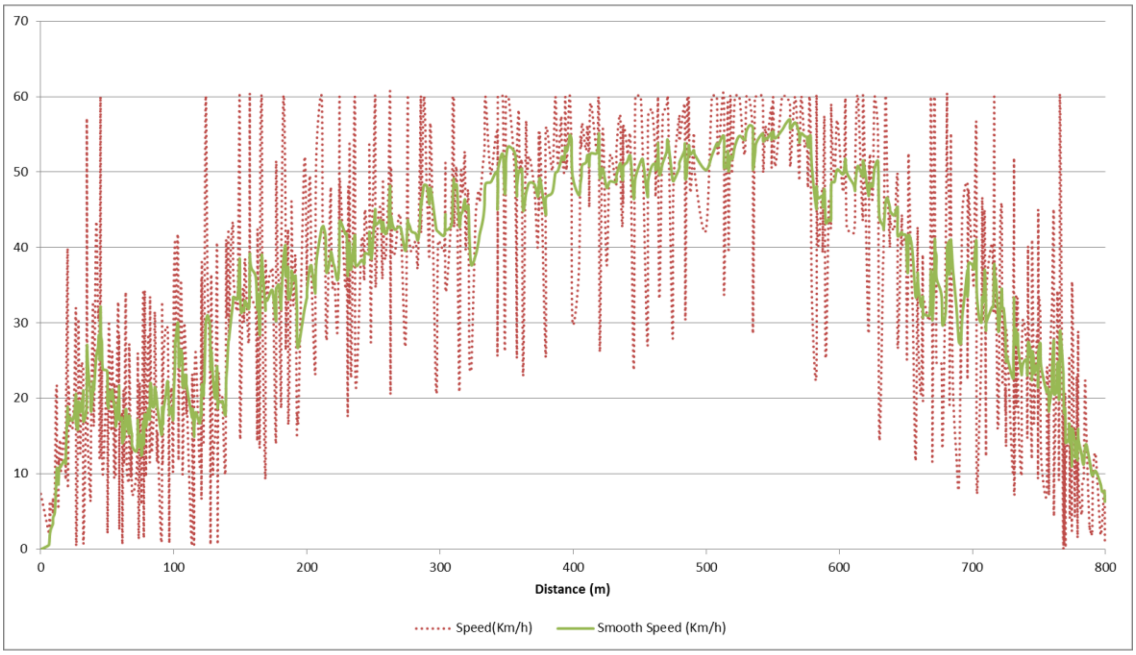

Figure 6 Location #2 NS GPS Course, Source: Own Elaboration

The GPS path at this point was also carried out between 7am and 9am between "Flores" Station and "Calle 63" Station in the North-South direction only. As in Location #1 Exponential Smoothing method was also used to smooth the data.
Same as in Location #2, at Location #3 only the North-South's interval between successive buses and GPS path was used. Table 6 shows the interval between buses where Lane 1 corresponds to western lane road. One can observe that the range is similar to that found in Location #2 so it can be confirmed that the data is consistent.

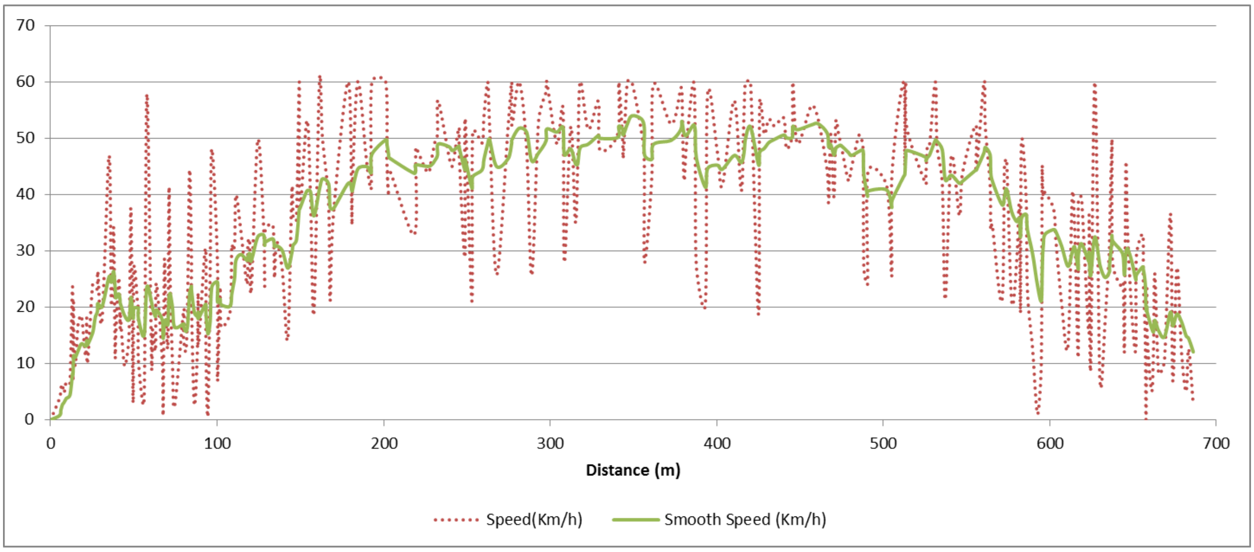

Figure 7 Location #3 GPS Course, Source: Own Elaboration

The GPS path at this point was also carried out between 7am and 9am between adjacent stations, i.e. "Calle 57" Station and "Calle 63" Station in the North-South direction only. As in Location #1 and Location #2 station Exponential Smoothing method was also used to smooth the data.

CAPACITY DETERMINATION

Location #1

As previously mentioned, the first capacity analysis performed was aimed to stop points operating individually. The result showed on Figures 8 and 9 remark the fact that saturation can take values greater than 1. When using traditional deterministic models for capacity determination saturation values greater than 1 should be discarded. Saturations greater than 1 are not common in reality; even operations near saturation are rare. Thus volumes for saturations greater than 1 were calculated just to show the behavior of these models under a hypothetic scenario. This is just one of the advantages of micro simulation models over deterministic models allowing the user to evaluate performance and system capacity under congested conditions.

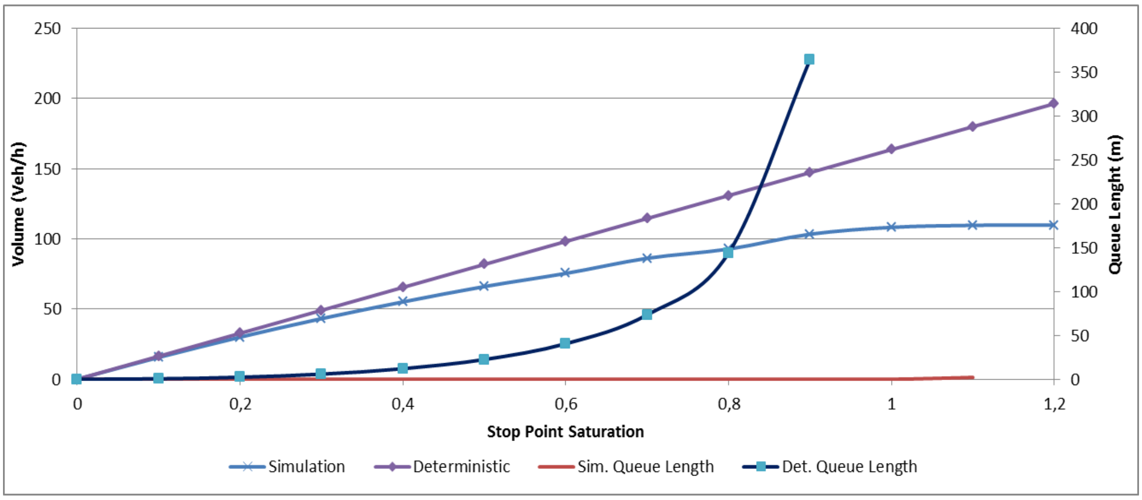

Figure 8 Location #1 Stop Point A2 Capacity Curve, Source: Own Elaboration

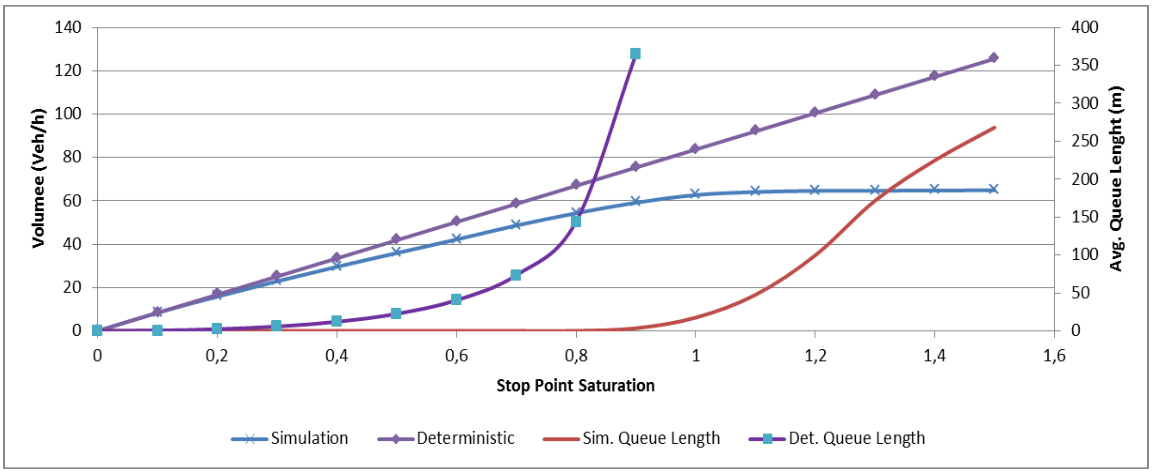

Figure 9 Location #1 Stop Point C1 Capacity Curve, Source: Own Elaboration

If we analyze the Figures 8 and 9 showing individual capacities of each stop point of the Location #1 Station on the left axis and queue length on the right axis, it can be seen the capacity is in fact affected by the stop time. Figure 8 shows the capacity curve for stop point A2 which has the lowest average dwell time with 22 seconds. On the other hand Figure 9 shows the stop point with greater stop time (C1) on average with 43 seconds. If we analyze both graphs one can see how effectively stop point A2, with less average stop time, reaches the highest volume of buses with 110 vehicles per hour compared to the 65 on point C1. According to this, differences in stop time of 11 seconds may represent differences in volume up to 45 vehicles per hour.

Table 3 Queue Length for an M/D/1 System, Source: Own Elaboration

	M / D / 1
L	$\rho + \frac{\rho^2}{2(1-\rho)}$
Lq	$\frac{\rho^2}{2(1-\rho)}$

Figures 8 and 9 also include the queue calculated for each saturation value based on deterministic formulas and simulation results. It can be seen that queue length estimated through deterministic formulas differs greatly from those obtained with the simulation. These differences between queue lengths estimated via formulas and obtained from a model can occur because:

1. Queue length cannot be estimated for saturations greater than 1 due to the limitations of the used formula
2. Formulas are not capable to include the interaction between buses given in a station.
3. Formula contemplates the time of service at the station as a deterministic value which is distant from reality.

Regarding calculated volumes, these were obtained using the following deterministic model:

$$Ca[personas/hora] = \sum_{i=1}^{Nsp} X_i \cdot \frac{3600[segundos/hora]}{Tsb_i[seg/bus](1-Dir_i)+To_i[seg/bus]} \cdot Cp[personas/bus]$$

This model only considers stop times and approach times on the capacity estimation process at a station. It also estimates the total capacity of a station as the sum of the individual capacity of each stop point in the season.

According to this, Figures 13 and 14 show the results for this location under 4 scenarios:

- ***Determt.*** Corresponds to the capacity calculated based on deterministic formula shown above.
- ***Simult***. corresponds to the simulation model results obtained under a simultaneous operation of every stop point.
- ***Sum.*** Corresponds to the sum of the individual capacities of every single stop point obtained by the simulation model.
- ***Express.*** shows the results including the express services on the simulation model.

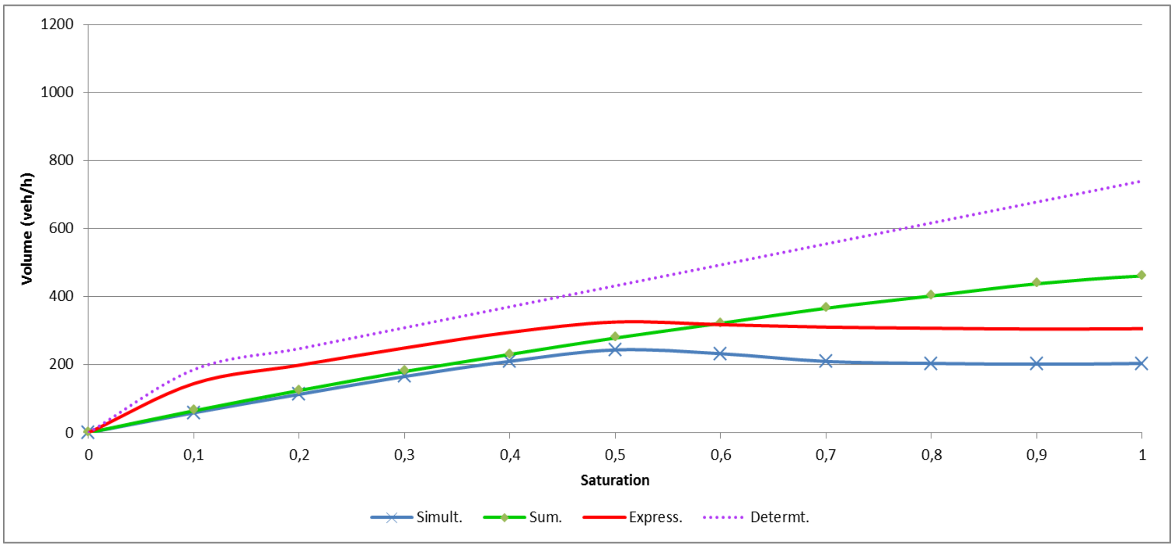

Figure 10 Location #1 South - North Capacity Curve, Source: Own Elaboration

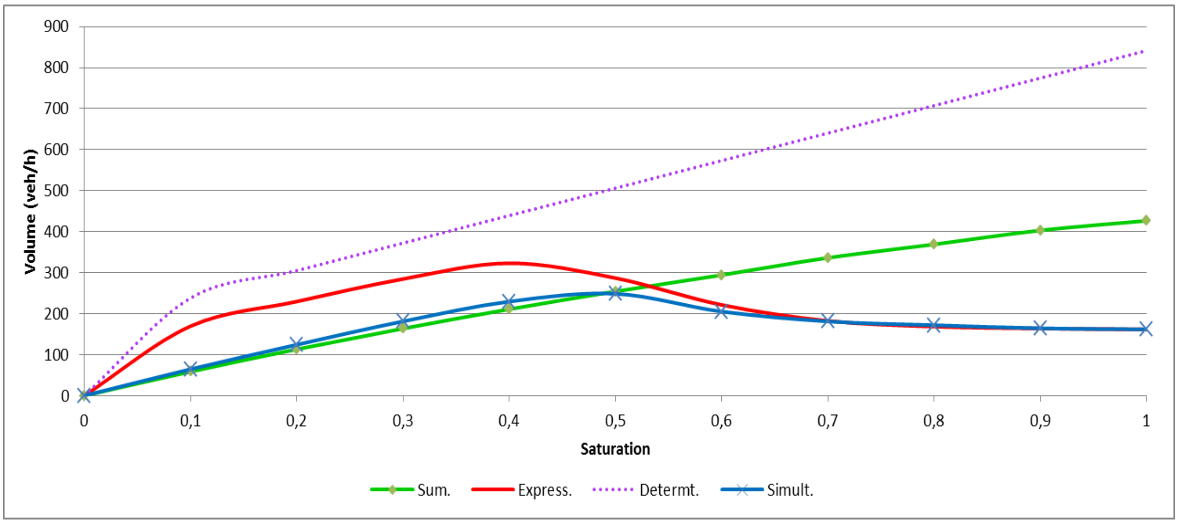

Figure 11 Location #1 North - South Capacity Curve: Own Elaboration

According to this Figures, it can be seen how the sum of the individual capacities (sum) differs from the curve obtained under a simultaneous operation (simult.) of every stop point. This results show the important role of interaction when many different stop points are included under a simultaneous operation. On the other hand, interaction between vehicles not only changes the capacity behavior but also may cause differences from up to 200 vehicles on the volume. It is important to note that in the graphs showing total capacity per direction, when the graph shows a capacity corresponding to a saturation value of 0.6 this means that each stop point is operating under a saturation equal to 0.6.

Express services were included in the model so this important characteristic could be included on the capacity analysis. In the South-North direction a 124 Bus/h flow was introduced. These buses do not stop at any of the stop points of the station but yet are important since they occupy the passing lane. On the north-south direction a 171 Bus/h flow was introduced. These express services volumes correspond to the volumes measured in the field survey and bring the model conditions even closer to reality. Depending on the number of express services that are incorporated to the operation, the capacity curve may or may not change compared to the curve without express services. Consequently it is justified the addition of express services to determine the new total capacity of the station including the buses that do not stop at the stop points.

		Volume (Veh/h)					
Direction	**Saturation**	**Simult.**	**Sum**	**Express.**	**Determt.**	**Diff.**	**Diff. %**
SN	**0**	0	0	0	0		
	0,1	59	65	145	186	127	**68%**
	0,2	113	124	199	247	134	**54%**
	0,3	165	180	249	309	143	**46%**
	0,4	210	230	295	370	160	**43%**
	0,5	244	279	326	432	188	**44%**
	0,6	232	322	318	494	261	**53%**
	0,7	210	366	311	555	346	**62%**
	0,8	204	402	307	617	413	**67%**
	0,9	202	438	305	678	477	**70%**
	1	204	461	306	740	536	**72%**
	1,1	211	469	307	802	590	**74%**
	1,2	212	471	306	863	651	**75%**
	1,3	215	471	306	925	710	**77%**
	1,4	216	471	305	986	771	**78%**
	1,5	220	471	302	1048	828	**79%**
NS	**0**	0	0	0	0		
	0,1	65	59	170	238	173	**73%**
	0,2	124	113	230	305	181	**59%**
	0,3	181	164	285	372	191	**51%**
	0,4	230	211	323	439	210	**48%**
	0,5	249	254	287	506	258	**51%**
	0,6	205	294	222	573	368	**64%**
	0,7	181	336	183	641	459	**72%**
	0,8	172	369	168	708	536	**76%**
	0,9	164	403	164	775	610	**79%**
	1	162	427	162	842	680	**81%**
	1,1	162	436	160	909	747	**82%**
	1,2	160	438	159	976	815	**84%**
	1,3	160	438	159	1043	883	**85%**
	1,4	160	438	159	1110	950	**86%**
	1,5	160	438	159	1177	1017	**86%**

Table 4 Location #1 Deterministic Volume Results Vs. Simulation Volume Results. Source: Own Elaboration

Table 4 allows us to see the difference between the capacity obtained from the sum of the individual capacities (sum) compared to the capacity obtained under a simultaneous operation (simult.) of every stop point. Additionally it compares the results between a deterministic model vs. simulation results that include a simultaneous operation and express services on the station. The last column on the right, presenting the percentage difference between deterministic vs. simulation results, shows capacity differences up to 80%. This difference confirms the need of including stochasticity and interaction on the capacity calculation process on a station to obtain more reliable and more accurate results.

Location #3

At this point standard deviation was included on the arrival of the buses therefore the maximum flow of vehicles which can pass through this point stops holds near saturations greater around 0.9. Under these operating conditions the maximum number of buses that could go through this point is close to 1100 vehicles per hour.

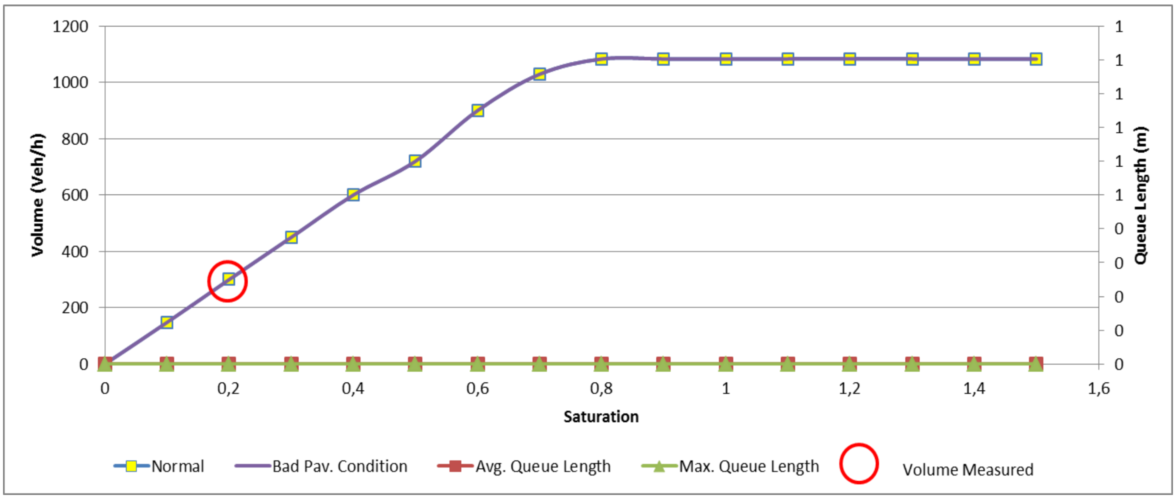

Figure 12 Location #3 North - South Capacity Curve, Source: Own Elaboration

If we take into consideration the number of buses that were measured in the field survey, represented in Figure 15 as a red circle, it can be seen that the segregated lane is operating roughly at a saturation around 0.5. The road could mobilize many more buses per hour if so required confirming that the bottleneck of the system does not correspond to the roads where buses travel. The final analysis performed at this point was the worst scenario which includes a gap in the road forcing the buses to decrease their speed from 50 km/h to about 15 km/h. Probably the poor condition of the pavement is uncomfortable for passengers and drivers and many holes along the trunk might have effect on the capacity, but as seen in Figure 15, an isolated gap has no effect on the system capacity.

CONCLUSIONS

The results of this research show that including randomness in the arrival of buses and stop times in a single station, plus the interaction effect of the buses being driven on a trunk road, may result on significant differences on the capacity of a station and the individual stop points. Additionally micro simulation models provide information about the behavior of the system and the queue length under saturations greater than 1. As known it is not possible to calculate the queue length for saturations greater than 1 through deterministic models

It is confirmed through micro simulation models how the capacity is affected by the stop time at stations. Stop points with lower stop times have higher capacities compared to the points with high downtime. A difference in stop times of 11 seconds may represent differences on volume of up to 45 vehicles per hour in the case of individual stop points.

It was confirmed that the sum of the individual capacities of each stopping point differs from the capacity obtained under a simultaneous operation of the entire station. Although the curve of the sum of individual skills includes randomness in arrivals of buses and stop times, the obtained difference when including simultaneous operation may be attributed to the interaction that occurs between buses operating simultaneously on different platforms.

By including express services capacity is not affected as it had thought. Depending on the number of express services the form of the capacity curve can have a different behavior. It was evident that the increase in capacity which occurs is not equal to the number of express buses entered into the model.

There was no procedure performed for calibrating the queues building process at the station. It can be established that the model is able to successfully replicate the velocities along the roads; however there is uncertainty on the queue length's accuracy. According to this queue building analysis is performed only as a theoretical exercise that can provide a first approach to the problem. It is necessary to redefine the calibration methodology and to complement the methodology with a queues calibration process. This process would allow be complete sure in the results given at this point, especially on analyzes related to storage distances.

Finally it was confirmed that the pavement condition has no effect on the system capacity. It is probably inconvenient for travelers and drivers and may have implications on the level of service, but for system capacity purposes these flaws on the pavement have no importance.

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