Effectiveness of reserved bus lanes in Arterials

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ABSTRACT

There were two main goals in this investigation; first, modeling capacity for articulated buses in Arterials, and, second, the analysis of the representative parameters and their interrelationships in relation to the degree of reserve and bus lane segregation. Two cases in Madrid-Spain are considered, and a third in Merida-Venezuela: In Madrid, bus lines 27 and 70, and bus line 1 of the Trolleybus Transport System (TTS), unique line in Merida. These systems are selected under basic criteria that simplify the analysis: similar mode that suppresses inherent factors from vehicle design; bus stop infrastructure using two fare payment methods; and bus-lane with different reserve degree and segregation elements. The available methodology in the Transit Capacity and Quality of Service Manual (TCQSM) was used, and a solid bus dwell-time assessment due to boarding and alighting passengers—as the most influential parameter in the capacity—was measured. These new prediction laws were considered in the methodology. Results show the effectiveness of each system and allowed the calculation of the maximum theoretical capacity and its variability range in robust form. The work is part of a wider project to analyze the influence of reserved bus lane in operational parameters.

Key words: modeling capacity; urban public transport; articulated bus; dwell-time model; effectiveness of reserved bus-lane; trolleybus transport system; segregated bus-lane, operational parameters.

INTRODUCTION

The Urban Public Transport Systems (UPTS) play a primary role in personal mobility in metropolitan areas. Bus operations must be planned with sufficient accuracy to optimize resources at peak periods. Several parameters can be used to characterize them, but perhaps the most useful in service organization and follow-up of capacity. That is: "the maximum number of passengers that can be transported with reasonable certainty over a length or critical section of the route, during a given period of time, under specific operating conditions, without that experience delays, risks or unpredictable restrictions" [1]

Capacity is influenced by such aspects as the number of boarding and alighting passengers at bus stops, signal timing, and interference with the rest of traffic, among others. One way to minimize this interference is providing of certain degree of reserve to the bus lane, varying from a regular lane on a street, open to traffic, to a fully segregated facility, for buses or trams. There is a great variety of intermediate situations: simple bus lanes, physical separators, and so on. This research shows the capacity assessment of bus lines with different degrees of reserve, which involves, first, an analysis to quantify its variability depending on the passenger demand at bus stops; second, improving the delay estimation from
boarding/alighting passengers at bus stop, and, third, new laws to predict overall behavior. The cases studied were bus lines in main routes with high demand, ensuring a solid assessment of the bus dwell time at stop. These systems were selected because they had different layouts—in road and bus stop—with different degree of reserve, two different payment methods and various physical separators.

The analyzed bus lines are: Line 70 is the sample for non-reserved bus lane with mixed traffic; Line 27 is, in general, semi-reserved; and Line 1 of the TTS is completely segregated, but with intersections, representing here the highest level. All these bus lines use similar vehicles—articulated buses—which eliminates other sources of diversity, and helps the independent assessment of passengers transfer and the effect of the fare payment method [2] allowing a more consistent comparison of delays, and demand thresholds define the efficiency of each system.

The capacity curve obtained by applying the TCQSM methodology with an average dwell time does not cover the variability range that occurs in a transport systems that interact with a variable demand. Accordingly, the dwell time prediction models are useful to estimate not only a peak value, but also the capacity range as a function of bus stop demand. The inability of the Merida trolley bus to by-pass may affect the results and this should be explored in the future.

The sampling techniques implemented in each bus route are simple tools that provide sufficient data of dwell time and travel speed to quantify its variability according to the level of bus lane segregation, an important aspect that influences the service’s reliability. This last evaluation proves that the more efficient bus lane separator reduces the speed variability, while other delay factors around the bus stop in combination with the closest traffic signal, suggest that the complex effect of combined delays requires further study.

The results shown later can be useful for planners and managers of similar urban transport bus system, since it establishes a solid infrastructure categorization according to the capacity and its most representative operating parameters. The capacity curves serve as decision-making support, and a better way of implementing similar bus systems where there is a certain level of demand. The effectiveness of each system it thus measured and these results can be generalized if similar conditions of passenger transfer are met.

**ANALYZED SYSTEMS**

An ascending order of infrastructure level has been established, highlighting each UPTS according to the relevant aspects of analysis, such as: reserve degree, existence of a physical separator, fare payment method, passenger transfer process, and control. See table 1.
### Table 1. Infrastructure and other characteristics in the analyzed UPTS

<table>
<thead>
<tr>
<th>UPTS</th>
<th>Reserve and operation</th>
<th>Segregation</th>
<th>Payment method</th>
<th>Transfer process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 70 (TMC)</td>
<td>non-reserved mixed traffic non-skip-stops</td>
<td>not defined</td>
<td>bus ticket validation (inside)</td>
<td>boarding by front door and alighting through rear doors</td>
<td></td>
</tr>
<tr>
<td>Line 27 (TMC)</td>
<td>semi-reserved (other lines, taxi, and motorcycle) non-skip-stops</td>
<td>marking, continuous and discontinuous curb/separator</td>
<td>bus ticket validation (inside)</td>
<td>boarding by front door and alighting through rear doors</td>
<td></td>
</tr>
<tr>
<td>Line 1 (TTS)</td>
<td>total reserve non-skip-stops contraflow lanes</td>
<td>channelized lane with curb and median</td>
<td>prepaid (outside)</td>
<td>boarding and alighting by all doors</td>
<td></td>
</tr>
</tbody>
</table>

There are two different payment methods: inside and outside the bus. Similarly, the transfer process of passengers is determined by the bus stop design and operation in each UPTS. See figure 1.

In general, both TMC lines are 8.24 km long, and have an average of 25 bus stops in each direction. This implies a mean distance of 343 m between bus stops, while the mean distance travelled by passenger is 3.1 km [3]. The vehicle used is an articulated bus with low floor. Traction is supplied by an internal combustion motor.

Bus line 70 is a peripheral line with major frequency on weekdays, and connects areas not directly communicated by the Madrid subway network, reaching a neighborhood called *Ciudad Lineal*.
Its route has a very low reserve degree and buses run through different street types, from local streets to arterials with parking restrictions. Bus line 27 has a high demand and runs through Madrid CBD, along high capacity arterials. In its first stretch it is furnished with bus lanes with a semi-reserved condition, as the circulation of taxis and motorbikes is allowed, as well as other bus lines. Later, a different type of segregation can be found: continuous curb in sections with few lateral accesses in some stretches; a separation consisting of a combination of continuous PVC fins and curbs; other stretches where the fins are interrupted often, as there are a significant number of major lateral accesses; and longitudinal road markings, a most vulnerable separating element that does not prevent access to other vehicles. It has an average of 220 buses per day in each direction (mon-fri) and carries over a million passengers a month, being the bus line that moves most people in Spain.

Bus line 1 of the trolleybus system is also run with articulated buses under electric power, although they also have internal combustion engines for emergencies. In a completely segregated-reserved lane in each direction, it is 10.0 km long, and runs through the main arterial existing in Mérida-Venezuela [4]. The bus stops are spaced 730 m on average, and consist of a central island admitting the one bus by direction on each side, a feature that does not allow overtakings at bus stops. The transfer process of passengers is granted through the connection of the vehicle with the platform by access ramps that guarantee at-grade entrance of travelers.

**STUDY METHODOLOGY**

This section shows three key aspects of the research: capacity methodology, data collection method and sampling.

**Capacity methodology**

The most widely used and better scientifically supported capacity methodology is covered in TCQSM, where a deterministic model using a formula to measure traffic volume in the accesses to an intersection is developed [5]. Bus lane capacity is adjusted using the following parameters: a variability coefficient "Cv" of dwell time; busy bus-stop probability –failure rate-- "Za" [6]; close traffic signal effect "g/C"; and other factors that are simplified here, since they do not apply to the lines under analysis (See equation 1)

\[
C_{bl} = \frac{3600(g / C)}{t_c + (g / C)d_t + (Z_a C_v d_t)}
\]  
(1)

Where:

- \(C_{bl}\) = bus lane capacity (bus/h/l)
- \(d_t\) = average dwell time at bus stop in seconds
tc = average clearance time at bus stop in seconds

Data collection method

Having noted the essential parameters needed to apply the methodology, data collection can begin, in sufficient numbers to have a good analysis. Thus, a plan was proposed, covering route inventory, stop locations and other road details; delay measurement including passenger boardings/alightings, and other travel delays—caused by intersections and traffic—, including incidents; speed determination using a GPS; road segmentation according to homogeneous infrastructure conditions and reserve degree, and sections with uniform geometric and operational conditions. The data should ensure a relevant degree of randomness. The use of two observers on the bus and GPS data was decided, using manual data to check the GPS data quality.

Sampling

Sample sizes were determined so that the error derived from the sample was controlled, as usual. There reasons to apply sampling techniques are saving time and energy. The sampling was performed in two phases: first, or exploratory, to define the dispersion of travel speed data "St" and dwell time at bus stop "dt", and, second, the final phase, to expand the sample and bring the error down to allowable values. The minimum size “n” and the maximum error are obtained through the use of normal distributions (this was checked) for a confidence level of 95%, obtaining an adequate sample size. See these results in table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Line 70 – TMC</th>
<th>Line 27 – TMC</th>
<th>Line 1 – TTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>St (km/h)</td>
<td>dt (s)</td>
<td>St (km/h)</td>
</tr>
<tr>
<td>maximum error (ε)</td>
<td>± 2.0</td>
<td>± 8.0</td>
<td>± 2.0</td>
</tr>
<tr>
<td>deviation (SD)</td>
<td>2.27</td>
<td>21.68</td>
<td>2.31</td>
</tr>
<tr>
<td>minimum size (n)</td>
<td>5</td>
<td>28</td>
<td>5</td>
</tr>
<tr>
<td>sampling (n)</td>
<td>30</td>
<td>854</td>
<td>30</td>
</tr>
<tr>
<td>deviation (SD)</td>
<td>1.86</td>
<td>11.9</td>
<td>1.85</td>
</tr>
<tr>
<td>absolute error (ε_a)</td>
<td>± 0.7</td>
<td>± 0.8</td>
<td>± 0.7</td>
</tr>
<tr>
<td>relative error (ε_r)</td>
<td>± 0.046</td>
<td>± 0.048</td>
<td>± 0.056</td>
</tr>
</tbody>
</table>

Table 2. Results of the sampling in two phases: exploratory and definitive

Dwell time estimation and main parameters

Dwell time was based on passengers boarding (as shown in Moreno et al, 8) the laws and results are included in table 3.
Main parameters and results

<table>
<thead>
<tr>
<th>UPTS</th>
<th>Average dwell-time, $d_t$ (s)</th>
<th>Clearance time, $t_c$ (s)</th>
<th>Variability coefficient, $C_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(found prediction models)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line 70 TMC</td>
<td>$d_t = 6.29996 \times P_b^{0.65162}$</td>
<td>$9^*$</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$14.6^{**}$</td>
<td></td>
</tr>
<tr>
<td>Line 27 TMC</td>
<td>$d_t = 6.2864 \times P_b^{0.6523}$</td>
<td>6.83</td>
<td>0.60</td>
</tr>
<tr>
<td>Line 1 TTS</td>
<td>$d_t = -0.0046N^2 + 0.6447N + 34.222$</td>
<td>7.2</td>
<td>0.20</td>
</tr>
</tbody>
</table>

(*) Clearance time at simple bus stop (**) Clearance time at multiple bus stop (3 loading areas); $N=$ total passengers ($P_b + P_a$); $P_b=$ boarding passengers; $P_a=$ alighting passengers

Table 3. Main parameters in each line

It is important to highlight certain aspects arising from the analysis of these parameters shown in table 3:

- dwell time at bus stop is not linear behavior in any of the instances
- the high delay variability experienced after a certain demand threshold for lines 27 and 70 (Madrid, TMC) proves that there is a border for efficiency
- The Merida TTS bus line shows much lower delay variability, with a lower growth of dwell time due to boarding passengers [7]. This is due to the use of all bus doors on passenger boarding and alighting.

The models were corrected for homoscedasticity and normality. A logarithmic transformation was applied to the data to find a good fit [8]. As shown in figure 2, the Madrid system is more effective for up to 20 passengers boarding. If the number is higher, the Merida system is more effective. Clearance times in Madrid were on average 9 s for simple bus stops and 14.0 s in more complex bus stop, such as those with three loading areas and no overtaking allowed. This will cause the development of two capacity curves to estimate each situation in bus line 70. It is also noteworthy that for simple stops all three clearance times are similar. This comparison shows that the operational parameters are independent of the engine used in each system. Finally, the variability coefficient of dwell time at bus stop shows greater variability in the Madrid cases, 40% and 50% more than as shown in Merida, probably due to the high degree of reserve.

Also, it can quantify the impact that has off-board fare collection of Merida and proof-of-payment in Madrid (on-board mechanical validation of ticket) on dwell. The delay grows at a rate of 0.07 s per passenger in TTS and 1.00 s per passenger in TMC lines. The difference between two processes is estimated at 1.03 s per passenger. The curves that represent these trends correspond to boarding-alightings (L1–TTS) and boardings (L27 and 70 –TMC). See Figure 2.
Figure 2. Bus dwell time models by regression. Bus stop infrastructure effectiveness.

As proven in (8), a unified model can be developed for lines 27 and 70. The Merida case, as noted, is different. The threshold value for which system is more effective is 20. If many stops have higher demands, the Merida system is better; if the opposite is true, the Madrid system is more effective. In line 70 a demand of 5 to 20 passengers was seen in 86.06% of the stops, with frequencies high enough to prevent, in general, the crossing of this boundary. This figure rises to 97.03% for line 27.

The TTS has a minimum dwell time of 34.22 s, which is high. This is due to the additional time by open doors of 8.02 s, and access ramps of 15.6 s. The access ramps have a significant effect as it can be seen any on-demand. It should also be added 10.6 s by regulation time found in passenger’s net flow time “tba”.

CAPACITY ESTIMATION

In modeling capacity, the best fit was obtained considering the adjacent traffic as red. However, the factor for effective green (g/C) applied in the denominator of the equation (1) could cause bad results in cases where the likelihood of retention by traffic signal is high, according to what was observed in the field. Similarly, this effect may vary when the number of load areas at bus stops increase, as the TCQSM model shows. These results show a decrease of the traffic signal effect in the capacity when the stops have more load areas with no overtaking. This requires further study, given the different bus stop configurations that may exist. More detailed data and the use of microsimulation would allow exploring different scenarios, something that escapes the scope of this research. Therefore, the calculated capacity...
does not incorporate the effect of traffic signals.

Figure 3 shows the capacity behavior applying the TCQSM methodology, adjusted using the delay prediction models in table 3, rather than a fixed value for average dwell time. The data have a maximum of 40 passengers in a single stop. Terminals stops have a different behavior, not considered here. TTS capacity can be increased 35% if the effect by access ramps to the bus is eliminated, i.e. it passes of 54 to 73 buses per hour per lane.

![Figure 3. Bus lane capacity for each UPTS](image)

Figure 3 clearly shows a capacity increase according to an infrastructure level. The “clearance time” has low variability, comparing the measured values between reserved and semi-reserved bus lane. The variability is considerably higher, as expected, if there is no reserve, showing two different mean values for different bus stops: simple –one loading area--; multiple –three loading area--; and bus blocked when ready to exit the stop, when the driver most likely looks for a gap in the adjacent lane to exit the stop. In general, clearance time variability shows little influence on capacity when there is high demand, when the results achieved their extreme values. The maximum values of capacity, and consequently, the minimum interval required to achieve these bus intensities are shown in table 4.
In any UPTS it is important to maintain good standards of service that will ensure adequate traveler mobility in congested cities. On the other hand, most users value the quality of service according to the speed, which traditionally defines the efficiency. Knowing the performance of this parameter not only helps operational management, but it also allows the identification of points or sections causing high delays. There are many methods to measure the speed, and among the most frequently used are: loop detectors, electronic devices, radar, and a combination of video cameras and radars, among others. These devices are called fixed detectors and have limitations, since they capture point speeds along the route. A better method is to use GPS in the vehicle, a preferred system to the high costs of installation and maintenance of fixed detectors. Telematics allow a quick and easy diagnosis of the operation.

The validation method—absolute navigation mode—requires configuration under the precision system WAAS/EGNOS to provide real-time differential corrections; and a manual record of the time carried out in parallel to calibrate the telematics measurement. Thus, satisfactory results are achieved.

The data collected showed that there is a need for data correction when the bus is stopped. The lack of local precision in GPS data can introduce notorious distortions due to clearly wrong location. This depends only on the selective signal availability—SA—at the time of the measurement, or other factors that the instrument does not self-correct. In short, it was proven that path location is reasonably adjusted to the road axis when the bus is in motion, so data in motion are preferred to data from stopped vehicles.

Inconsistent speed records—illogical values—given its low frequency, constitute a minor problem that can be corrected assigning average speeds of adjacent values to the point in

<table>
<thead>
<tr>
<th>UPTS</th>
<th>Minimum interval (s)</th>
<th>tc (s)</th>
<th>Cv</th>
<th>C (bus/h/l)</th>
<th>C (pax/h/l)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 70–TMC</td>
<td>70</td>
<td>9</td>
<td>0.00</td>
<td>32</td>
<td>4480</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td></td>
<td>31</td>
<td>4340</td>
</tr>
<tr>
<td>Line 27–TMC</td>
<td>70</td>
<td>7</td>
<td>0.00</td>
<td>34</td>
<td>4760</td>
</tr>
<tr>
<td>Line 1–TTS</td>
<td>53</td>
<td>7</td>
<td>0.00</td>
<td>54</td>
<td>7560</td>
</tr>
</tbody>
</table>

(*) 140 passengers per articulated bus.

Table 4. Capacity and others parameters in UPTS

In table 4 some values have been rounded for easier interpretation. Also, person capacity is obtained taking a maximum amount of travelers by articulated bus of 140 passengers under conditions of relative comfort. Reached capacity is similar in both cases of TMC lines when there is high demand, and the bus lane TTS has almost double capacity according to the found values in lines 27 and 70.
consideration. Speed data captured with GPS receiver require a proper post-processing to reduce initial errors, which were in the order of 7% under conditions of few interruptions in the line –bus line 1 TTS–; and 12% for the cases with more interruptions –bus lines 27 and 70 TMC–. These percentages were obtained comparing manually measured speeds and GPS speeds on each trip. Bus stop times manually registered were synchronized with the GPS clock, which allowed a data calibration with an error of less than 1%. Thus, a large and robust database of speed records was gathered with measurements every second for each trip. Figure 4 shows the good correlation reached between real speeds measured manually and GPS speeds, after corrections, something that validates the use of telematic methods. This result compiles data from all lines and represents a sample of 190 trips.

![Graph showing real travel speed vs. GPS travel speed](image)

**Figure 4. GPS method validity.** $r^2 = 0.98$ for speeds up to 24 km/h

Given the large size of speed records, and considering the difficulty of manually grouping the data, a cluster technique was tried. Thus, clustering was used to identify homogenous groups within the speed data. The fuzzy c-means tool –FCM– is one of many advanced clustering techniques originally introduced by Bezdec [9] that allows a large database to be divided in clusters, where each speed point belongs to a cluster center.

A set of centers is initially required to apply the fuzzy logic function. This initial set is taken from the data. The FCM function then calculates the average position of each cluster center, and assigns to each speed point a belonging degree to a cluster center. Then, by iterative update of cluster centers and membership degree of each speed point, the FCM moves each cluster center to its correct position. This iteration is based on the function-objective minimization that represents the distance from any speed point to a cluster center, weighted by their membership level. The results are summarized in table 5, where the function-objective is sufficiently minimized in 100 iterations, resulting in speed clusters for each stretch of...
homogeneous performance.

<table>
<thead>
<tr>
<th>UPTS</th>
<th>Direction to</th>
<th>Stretch (km)</th>
<th>Speed cluster (km/h)</th>
<th>Delay (min/km)</th>
<th>Mean travel speed St (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L70 – TMC</td>
<td>San Blas</td>
<td>0 – 2.0</td>
<td>14.0</td>
<td>1.0</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 – 5.0</td>
<td>14.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0 – 8.0</td>
<td>13.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plaza Castilla</td>
<td>0 – 2.0</td>
<td>17.0</td>
<td>1.0</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 – 4.0</td>
<td>12.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.0 – 7.0</td>
<td>13.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0 – 9.0</td>
<td>16.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L27 – TMC</td>
<td>Plaza Castilla</td>
<td>0 – 2.0</td>
<td>11.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 – 5.0</td>
<td>13.0</td>
<td>2</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0 – 8.0</td>
<td>14.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Glorieta Embajadores</td>
<td>Total</td>
<td>14.0</td>
<td>2</td>
<td>14.0</td>
</tr>
<tr>
<td>L1 – TTS</td>
<td>Northeast</td>
<td>0 – 2.0</td>
<td>12.0</td>
<td>1</td>
<td>19.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 – 5.0</td>
<td>30.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0 – 8.0</td>
<td>16.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.0–10.0</td>
<td>17.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Southwest</td>
<td>0 – 2.0</td>
<td>14.0</td>
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<td>19.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.0 – 5.0</td>
<td>16.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.0 – 8.0</td>
<td>29.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.0–10.0</td>
<td>16.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. FCM cluster analysis applied to speed GPS data

**AVERAGE SPEED AND DEGREE OF RESERVE**

There’s little speed variability between homogeneous stretches in bus lines 27 and 70, TMC, and greater variability in the TTS. The distance between stops and high retention by traffic signals determine a lower performance with an average delay of 1.0 min/km and a speed of 14 km/h in Madrid, TMC. As the speed is highly valued by users, the knowledge of variability reasons is of great interest to public transportation managers [10].

In this sense, the speed variability depending on the level of reserve and bus lane separator was analyzed. Also, the speed parameter in each homogeneous stretch through prior recognition of bus lane is studied. See table 6 and Figure 5.
The use of segregated bus lane reduces 50% of speed dispersion of the cases where the buses are not segregated. Fins placed in discontinuous way are an ineffective measure to lower speed variability. On the contrary, if fins or curbs are configured continuously, the results show a much improved behavior of the buses, with smaller dispersion in semi-reserved bus lanes, equal to that seen in infrastructure of higher segregation level, represented by reserved bus lanes and continuous curbs or separators.
Therefore, not only speeds increase with reserved bus lane (column M in table 6, from a continuous increase from 24 km/h –normal lane, shared– to 36 km/h –total reserve, continuous curb–), but, and perhaps more important, the variation coefficient (figure 5) is lowered from 0.01–0.04 –low degree of reserve– to 0.07 –high degree of reserve–.

CONCLUSIONS

- The number of boarding passengers is determinant in estimating bus dwell time of TMC bus lines.
- A general potential dwell-time model can be proposed for both Madrid lines.
- A threshold of 20 passengers at bus-stop is found, for which, the implementation of certain infrastructure –TMC or TTS– achieved greater efficiency in terms of dwell-time.
- TTS capacity can be increased 35% if the effect by access ramps to the bus is eliminated, i.e. it passes of 54 to 73 buses per hour per lane.
- Changing from current fare payment method –ticket validation box– to a method without contact in TMC bus lines can improve the bus dwell-time at stops, to such an extent that is similar to that obtained in the TTS without considering the lost time due to access ramps.
- The TTS capacity doubles the values found in TMC lines. The impact of traffic signals and by bus-stop occupations cause a noticeable decrease in the capacity of TMC systems, despite the good performance observed in passenger board/alight operations.
- The telematics method used to measure speeds can be applied in the operations diagnosis of urban public transport, according to the results achieved.
- The FCM cluster method correctly identifies the homogenous stretches for average speed performance.
- Not only speeds increase with reserved bus lane (a continuous increase from 24 km/h – normal lane, shared– to 36 km/h –total reserve, continuous curb–), but, and perhaps more important, the variation coefficient (figure 5) is lowered from 0.01–0.04 –low degree of reserve– to 0.07 –high degree of reserve–.
- The inability of the Merida trolley bus to by-pass may affect the results and this should be explored in the future.
- An exploration could be done to increase the capacity of the BRT application, dispatching double headers (bus platoons) as an example, assuming that they could be accommodated with longer platforms.

REFERENCES

2. DUEKER, K. J., KIMPEL, T. J. and STRATHMAN, J. G. (2004). Determinants of Bus...


