Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 71 (2023) 252–259

Transportation Research Procedia

www.elsevier.com/locate/procedia

XV Conference on Transport Engineering, CIT2023

Experimental verification of the methodology to estimate transit dwell time from the Transit Capacity and Quality of Service Manual

Yaiza Montero-Lamas[a], Alfonso Orro[a], Margarita Novales[a], Graham Currie[b], James Reynolds[b]

[a]*Universidade da Coruña, Group of Railways and Transportation Engineering, ETS Ingeniería de Caminos, Canales y Puertos, Center for Technological Innovation in Construction and Civil Engineering, A Coruña 15071, Spain*
[b]*Public Transport Research Group, Institute of Transport Studies, Monash University, Clayton, 3800, VIC, Australia*

Abstract

This study compares the theoretical and actual dwell times of urban buses in A Coruña, Spain, and trams in Melbourne, Australia, to evaluate the accuracy of the Transit Capacity and Quality of Service Manual's estimations. The theoretical dwell times were calculated using a methodology based on the Manual, following the steps indicated in the provided spreadsheet. Actual dwell times were obtained through processing of video recordings and transit database. The results show that the estimated dwell time for A Coruña buses is higher than the actual time, while the theoretical estimation for Melbourne trams seems to be underestimated. The possible reasons for these differences have also been analyzed. This study identifies and suggests several possible improvements to the Manual methodology and spreadsheet, such as reconsidering default values and the application of boarding lost time within the dwell time. In addition, the passenger service time formula in the spreadsheet could be refined to more accurately reflect the Manual's description. Overall, the study provides insights into the reliability of TCQSM estimations and proposes some easily traceable and fixable changes to improve the Manual's next edition and future transit planning studies.

Keywords: Dwell time; bus; tram; Transit Capacity and Quality of Service Manual; transit operation

1. Introduction

Public transit systems play a crucial role in urban mobility, providing affordable and sustainable transportation options for millions of people worldwide. To design and operate efficient and reliable transit services, accurate estimations of transit performance measures such as dwell time are essential. The Transit Capacity and Quality of Service Manual (TCQSM), third edition (Kittelson & Associates, 2013), is an American reference widely used by researchers and transit agencies for estimating transit performance measures in North America and beyond. Therefore, it is relevant to evaluate the accuracy of the Manual's estimations, especially outside North America, and identify areas for improvement.

10.1016/j.trpro.2023.11.082

The TCQSM states that there are three possible methods for estimating dwell time: field measurements for existing routes, default values for planning new routes without estimated passenger data, and calculation when boarding and alighting counts or estimates are available. In this study, we will compare the actual results obtained from field measurements and database with the theoretical results obtained from the spreadsheet provided with the Manual for performing the calculations used in the bus capacity methods. The comparison will be performed on urban buses and trams to evaluate the accuracy and potential enhancements of the Manual's estimations of transit dwell time in two cities on different continents.

The structure of the study is as follows: first, a review of relevant research literature is presented, followed by the presentation of both case studies and methodologies. The results obtained are then presented and discussed, finishing the study with conclusions and future work.

2. Literature review

In recent years, the optimization of bus and tram operations has gained significant attention, and the analysis of dwell time has become a key factor in the evaluation of transit system performance (Christoforou, Chandakas and Kaparias, 2020). The reduction of dwell time can contribute to reducing travel time, increasing frequency, and improving reliability, among other benefits. The TCQSM defines dwell time as follows:

$$t_d = t_{pf,\max} + t_{oc} + t_{bl} \tag{1}$$

Where t_d= average dwell time (s); $t_{pf,max}$= maximum passenger flow time of all door channels (s); t_{oc}= door opening and closing time (s), 2-5 s typical; t_{bl}= boarding lost time (s).

The t_{bl} is an update made in the third edition based on Jaiswal's (2010) research, which relates this time to the number of loading areas available in the stop. The Manual sets: 0 s (one loading area); from 4 to 4.5 s (three); a range of 0 to 4 s for two under the analyst judgment. Subsequent studies have analyzed this term and its influence on transit dwell time (Kathuria et al., 2016). Novales et al. (2021) concluded that t_{bl} could be increased by up to 1.64 s due to rain in loading area 1. The $t_{pf,max}$ term has the most weight in dwell time and is influenced by user demand, payment method, vehicle configuration, passenger load, door usage, and platform configuration. The impact of some of these factors on dwell time has been studied by Fernandez et al. (2010), Milkovits (2008), and Tirachini (2013).

The number of passengers waiting to board the vehicle and the payment method will have a significant impact on passenger flow time, as well as the presence of standees that hinder the passage (Currie et al., 2013). The Manual suggests adding 0.5 s per passenger if there are standing passengers. González et al. (2012) proposed a new model for predicting bus dwell time along an 8 km route in Madrid. They adapted Equation 1 to their case study, focusing on t_{oc} and passenger boarding time. Their findings indicated that the linear model between boarding passengers and dwell time is accurate up to 20 boardings, with boarding being the most important factor affecting dwell time.

Fletcher and El-Geneidy (2013) concluded that prepaid fare bus passengers board the fastest (2.2 s/p) since they do not interact with the fare box and only need to show their pass to the driver. On the other hand, magnetic swipe ticket users add 3 s to the dwell time, while cash users add 4.2 s, with all other variables at their mean value. Additionally, the authors found that passengers alighting at the front door extend the dwell time by 0.7 s more than those alighting through the rear door. Currie and Reynolds (2016) evaluated two ticketing systems, pay-on-entry (POE) and proof-of-payment (POP), in light rail transit. They concluded that POP systems are more efficient and cost-effective than POE systems, with POE systems increasing the journey time by an average of 15%.

The purpose of this study is to assess the accuracy of the TCQSM's approach for predicting dwell times for buses and trams in two different countries. While some previous studies have adapted Equation 1 proposed in Chapter 6 of the Manual to their case studies, this study thoroughly examine Chapter 6, proposing enhancements, identifying potential discrepancies, and justifying the differences between the actual and theoretical transit dwell times. Additionally, the study verifies whether the automated dwell time estimation spreadsheet provided aligns with the guidelines described in chapter 6. Ultimately, this study proposes potential modifications and improvements to be included in the next edition of the Manual. It is suggested that these updates should be adapted to each specific case study to enhance dwell time estimations.

3. Case studies and methodology

Actual and theoretical dwell times have been analyzed on the urban bus in A Coruña, Spain, and the tram in Melbourne, Australia. For both cases, the Bus Capacity Methodology from chapter 6 of the Manual has been applied, since the calculation of streetcar operating capacity can be determined similarly to buses as indicated in Chapter 8.

3.1. A Coruña urban bus

A Coruña, has a population of 244,700 and is served by 93 urban buses on 24 routes, carrying approximately 21 million passengers per year. Payment is accepted through cash or a smart card, and boarding and payment are only allowed through the front door, while alighting is usually only allowed through the rear door(s) when the bus is crowded. The transit company records the stop arrival time, boardings and payment methods. However, no information is registered in relation to alightings, door opening and closing time, or total bus delay associated with each stop, which makes it impossible to obtain the actual dwell time of urban buses from company records.

There are several surveillance cameras installed by the City Council of A Coruña that capture footage of various urban bus stops. While these videos can provide valuable insights into traffic and urban transit patterns, some of them do not provide enough detail or quality to measure dwell time. Nevertheless, a selection of bus stop footage with adequate quality and framing have been manually processed (with millisecond precision), recording bus arrival time, loading area, door number, door opening and closing times, passenger boarding and alighting times, number of passengers, and any exceptional situations. Finally, the comparison between the actual and theoretical dwell time has been performed at San Pedro de Mezonzo stop. It is a high-traffic stop located in the southwest direction of the city center, which is served by 6 urban bus lines. This is a bay stop with two loading areas and no traffic light after it.

Based on the data obtained from the recorded footage of this bus stop, the actual busiest door has been identified as the one with the longest time period between the complete opening of doors and the end of passenger flow. To calculate the actual dwell time, the corresponding opening and closing door's time is added. This excludes the time between the last boarding or alighting and the closing of doors, as is specifically stated in the Manual.

To estimate the theoretical dwell time, the spreadsheet based on Chapter 6 provided with the Manual is used. This template automates the dwell time calculation. For this paper, we will focus on "Step 0 – Dwell Time" sheet, considering reference values located on "Default values" and "Lookup" sheets. Table 1 lists the inputs required for A Coruña bus in column 2, and for Melbourne tram in column 3.

Table 1. Inputs required for Manual's dwell time estimations in both case studies.

Inputs spreadsheet	A Coruña bus dwell time	Melbourne tram dwell time
Average boarding volume per bus	Boardings per bus	Boardings per tram and stop
Average alighting volume per bus	Alightings per bus	Alightings per tram and stop
Boarding door (s)	Front	All
Fare payment method	Exact change	None
Boarding height	Level	Level
Standees present?	Yes	Yes/No
Number of doors	2/3	5
Available door channels	4/6	10
Percent of boarders using farebox	15%	0%
Door opening and closing time (s)	2.855	4.446
Number of loading areas	2	1

In our case, we will use the actual value of boarding and alighting counts per bus instead of the hourly mean value since we do not aim to determine the facility bus capacity. Urban buses have 1 or 2 rear doors, with two alighting flows each. Since only the front door is used for boarding and paying, we will use exact change as the default method of payment, a 15% of boarders using farebox through door channel 1, and an 85% using smartcard and door channel 2. In the reference table, Exhibit 6-4, there is no option for paying the driver, nor for cash without exact change. The option most similar to our case, payment in the farebox with exact change, has been selected.

Regarding the required input for door opening and closing times (t_{oc}), an average value has been used for all available records. Given that the analyzed stop has 2 loading areas, the template automatically adds 2 s of t_{bl} to the final dwell time. In Table 1, it also asks whether there are standees, as their presence makes the passenger flow more complicated and increases the time per person for boarding and/or alighting. Since urban buses are not equipped with Automatic Passenger Counting (APC) systems, there is no information about how crowded the vehicles are, but the presence of standees has been considered given the usual situation at that stop.

After entering the required input data for estimating the dwell time, we reviewed the automatic calculation in the spreadsheet for $t_{pf,max}$. The first step is to determine the passenger flow time for each bus door channel using Equation 2 for a given door channel *i*.

$$t_{pf,i} = P_{a,i} * t_{a,i} + P_{b,i} * t_{b,i} \tag{2}$$

Where $t_{pf,i}$ = passenger flow time for door channel i (s); $P_{a,i}$ = alighting passengers through door channel i (p); $t_{a,i}$ = average alighting passenger service time for door channel i (s/p); $P_{b,i}$ = boarding passengers through door channel i (p); $t_{b,i}$ = average boarding passenger service time for door channel i (s/p).

Regarding $P_{b,i}$, if the available door channels are greater than the number of doors (as is always our case), $P_{b,1}$ is automatically calculated as the total number of boardings times the percentage of boarders using the farebox. The rest of the boardings will be through door channel 2. This case is referred to in the Manual as "double-channel boarding, all fares paid or inspected upon boarding" and it can be assumed that a quarter of passengers who alight do so through the front door channel that does not have a farebox, while the majority (75%) use the rear door(s).

The average boarding service time for door channel 1 ($t_{b,1}$), is calculated as the sum of the corresponding value in Exhibit 6-4 for exact change (4.5 s/p), and an additional 0.5 s/p for standees on the bus. Additional time penalties could be applied if the bus were not level boarding. The same reasoning is followed to calculate $t_{b,2}$ but the payment method was changed to smart card (2.75 s/p). Regarding t_a, the spreadsheet differentiates by door channel and fare payment method. $t_{a,1}$ has no effect as $P_{a,1}$ is always 0. For the case of $t_{a,2}$, which refers to alighting through the front door, the spreadsheet indicates that if the fare payment method is not a smart card and the number of doors is different from the number of channels, an additional 2.50 s/p should be added to the 0.5 s/p for standees. For the rest of the door channels, $t_{a,3}$ and beyond, 1.75 s/p is applied regarding Exhibit 6-4 and no smart card check-out.

The spreadsheet's passenger service time formula includes a conditional that adds 20% to t_b and t_a if three times the number of alightings exceeds the number of boardings. This penalty is explained in the Manual as a way to account for passenger congestion at the door: "when more than 25% of the passenger flow through a single door channel is in the opposite direction of the main flow of passengers, increase both boarding and alighting service times by 20% to account for passenger congestion at the door". However, the current spreadsheet multiplies $t_{b,2}$ and $t_{a,2}$ by 1.2 even if there are no boardings, leading to a modification of the condition. In addition, the formula has been updated to consider the 20% increment in both directions of flow, in accordance with the Manual's recommendation.

After applying Equation 2 to each door channel, the maximum value ($t_{pf,max}$) is selected. Adding t_{oc} and t_{bl}, we obtain the estimated dwell time (t_d) for each record, and proceed with its comparison to the actual values.

3.2. Melbourne tram

Melbourne is the capital of the Australian state of Victoria with a population of over 5 million. The tramway network in Melbourne comprises of 250 kilometers of double track, 25 routes, and around 1,700 tram stops. Yarra Trams, the transit operator, provided automatically collected records of the Route 11 tram stops for November 2018. The vehicles operating on this route are Class E trams, which are characterized by having a low floor, and a capacity of 210 passengers (64 seated and 146 standing). These trams are 33.45 meters in length and have five doors with two channels each (on each side), allowing passengers to board and alight from any door. Route 11 runs between West Preston and Victoria Harbour Docklands, serving various suburbs including Melbourne within the Free Tram Zone.

The automatically recorded data includes passenger load, and the number of boardings and alightings at each door and channel, which is obtained through the APC system. In addition, the arrival and departure times, and the delay compared to the scheduled time are also recorded. Database includes a dwell time value calculated as the difference between departure and arrival time, although this is not aligned with the Manual. Data cleaning was performed to eliminate incomplete or invalid records, the first and last stops of the route, and stops with no boardings and alightings. Only stops with available data from all 10 door channels and delayed trams were considered. A total of 17,227 records were deemed suitable for comparison with the dwell time provided in the Manual after the data cleaning procedures.

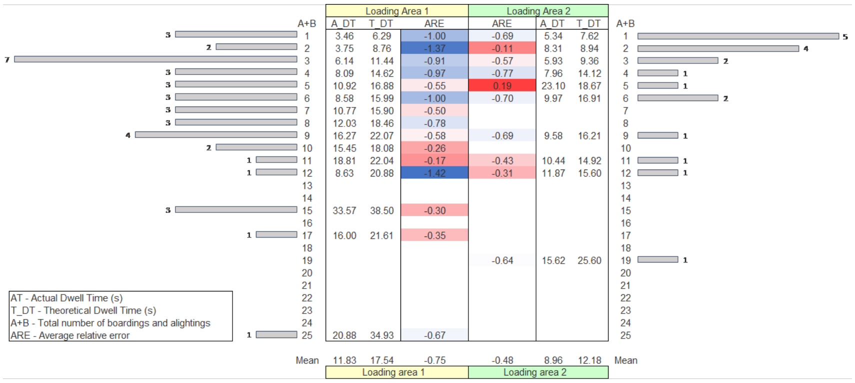
To calculate this theoretical time, it is necessary to input the required data in Table 1. Class E vehicles are level boarding, and due to their length, it is indicated that there is only 1 loading area. Although we do not have access to tram camera recordings, an average time for door opening and closing has been calculated through fieldwork in the city. Standees are considered when half of the available seats on the tram are occupied. Regarding the fare payment method, "none" has been indicated because it is the one that most closely resembles reality. If we indicate smart card, $P_{b,1}$ is always zero and it is assumed that the card is also used when alighting, neither being our case.

Regarding the automatic calculations in the template based on the inputs (Equations 1,2), the number of flows had to be increased from 6 to 10. In addition, for this case defined in the Manual as all-boardings, the distribution of P_a and P_b is limited to 6 door channels (Exhibit 6-58), and values had to be extrapolated. With 10 available door channels, 17% of passengers use the busiest door, and the rest are equally distributed. A different busiest door was assumed for boarding and alighting. The passenger service times t_a and t_b were modified following A Coruña's criterion of a 20% increase. Once the automatic calculations have been reviewed, it is possible to obtain $t_{pf,max}$ and, consequently, t_d.

4. Results and discussion

4.1. A Coruña urban bus

The results obtained for bus theoretical dwell times are notably higher than actual ones. The mean value of dwell time estimation provided by the Manual (15.81 s) increases the dwell time by 45.01% compared to the real value (10.90 s). The increase in mean values is lower in loading area 2 (35.93%, 12.18 s vs 8.96 s) than in area 1 (48.28%, 17.54 s vs 11.83 s). Figure 1 shows the average actual and theoretical dwell times and the average relative error of actual compared to theoretical dwell time for each area and total users boarding and alighting. It can be observed that the mean of relative errors for each value of users in loading area 1 is higher than in area 2 (-0.75 vs -0.48).



		Loading Area 1			Loading Area 2				
	A+B	A_DT	T_DT	ARE	ARE	A_DT	T_DT	A+B	
3	1	3.46	6.29	-1.00	-0.69	5.34	7.62	1	5
2	2	3.75	8.76	-1.37	-0.11	8.31	8.94	2	4
7	3	6.14	11.44	-0.91	-0.57	5.93	9.36	3	2
3	4	8.09	14.62	-0.97	-0.77	7.96	14.12	4	1
3	5	10.92	16.88	-0.55	0.19	23.10	18.67	5	1
3	6	8.58	15.99	-1.00	-0.70	9.97	16.91	6	2
3	7	10.77	15.90	-0.50				7	
3	8	12.03	18.46	-0.78				8	
4	9	16.27	22.07	-0.58	-0.69	9.58	16.21	9	1
2	10	15.45	18.08	-0.26				10	
1	11	18.81	22.04	-0.17	-0.43	10.44	14.92	11	1
1	12	8.63	20.88	-1.42	-0.31	11.87	15.60	12	1
	13							13	
	14							14	
3	15	33.57	38.50	-0.30				15	
	16							16	
1	17	16.00	21.61	-0.35				17	
	18							18	
	19				-0.64	15.62	25.60	19	1
	20							20	
	21							21	
	22							22	
	23							23	
	24							24	
1	25	20.88	34.93	-0.67				25	
	Mean	11.83	17.54	-0.75	-0.48	8.96	12.18	Mean	
		Loading area 1			Loading area 2				

Fig.1 – Average values per loading area

The difference between actual and estimated dwell times could be partially due to the influence of boarding lost time (t_{bl}). The actual average t_{bl} for the loading area 1 is 0.82 s, while it is 2.50 s for area 2. The overall average t_{bl} for all records is 1.35 s, which falls within the range between 0 and 4 s stipulated by the Manual for two loading areas. A value of 2 s is suggested to be used in the spreadsheet (32.55% more than the actual value) assuming that both stops will have similar usage or that passengers will wait in an intermediate area. However, for the case of A Coruña, 67.78% of buses use loading area 1 at the analyzed stop, and the stop shelter is located adjacent to this area.

Furthermore, Equation 1 always includes t_{bl}, even if the longest flow corresponds to rear alightings. In that case, t_{bl} overlaps with the theoretical dwell time, leading to an overestimation, as pointed out by Kathuria et al. (2016). Another reason that may justify this difference could be the assumption that all buses carry standees, which can lead to overestimations of theoretical dwell time. In addition, default values for the exact change payment method are quite high, at 4.5 s/p, and 15% of passengers use it. A sensitivity analysis for the hypothesis is recommended as future work.

4.2. Melbourne tram

The dwell times obtained from the database and the spreadsheet are shown in Figure 2, according to the total number of boardings and alightings at each stop. This figure shows how the actual dwell times are higher and more dispersed than those estimated following the Manual. The theoretical values are practically a lower limit of the actual ones. Although each door has two flows, boarding passengers often wait for those inside to alight, and these passengers do not always use both available channels, resulting in a longer real dwell time compared to the estimated dwell time. Another reason could be the weather: the spreadsheet assumes that the boarding lost time is zero, but if there is a small shelter and it is raining, the dwell time could increase, as boarders will not leave the shelter until the vehicle has stopped. Moreover, at some stops along route 11, passengers must wait on the sidewalk and cross the traffic lane to board the tram that runs in the center lane, which also increases the t_{bl}, and consequently, the actual dwell time.

The Manual warns (page 6-67) that AVL systems “may include time spent not serving passenger movements (e.g., waiting until a traffic signal turns green)”, while the Manual discards the time between the last passenger and the closing of doors. For this case study, that additional time that would be generated, if any, has not been discarded.

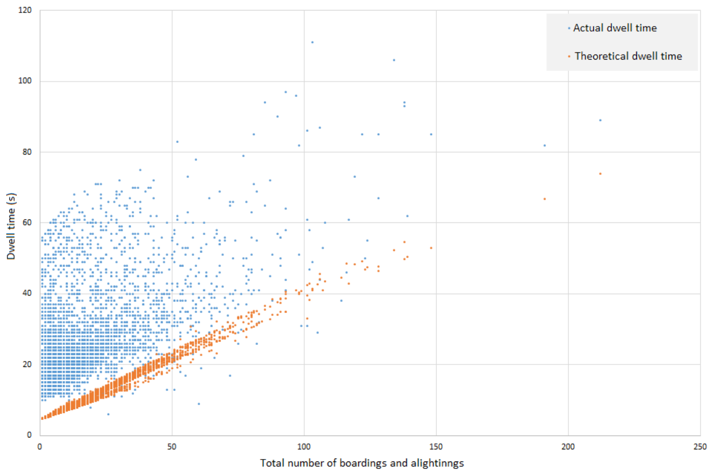


Fig. 2 - Actual and theoretical dwell time depending on the passenger flow

Figure 3 shows the average relative error with respect to the real dwell time and the average actual and estimated dwell time, differentiating by the stop of the line, the suburb where it is located, and the total number of passengers boarding and alighting at each stop (first 50 values). The average relative error of the 8,600 records is 62.74%. The error is higher for low passenger flows. For these same values, the errors are higher in the center zone (Melbourne). This may be due to the fact that they are central stops, with more lines and more people waiting, which could confuse the driver or hinder agile passenger flows at the stop.

The pedestrian movements in the center and the traffic lights could also influence the tram's time at the stop. The average theoretical dwell time of 13.27 s and actual dwell time of 32 s suggest a 142% increase in Melbourne suburb (within the Free Tram Zone), while the average theoretical dwell time of 5.54 s and actual dwell time of 16 s suggest a 189% increase at Northcote, in the outskirts. The Manual's estimate of 10 s for minor stops and 60 s for major downtown stops does not seem to reflect the actual conditions in Melbourne's tram network. It is essential to consider these discrepancies when using the Manual's estimations for other transit systems.

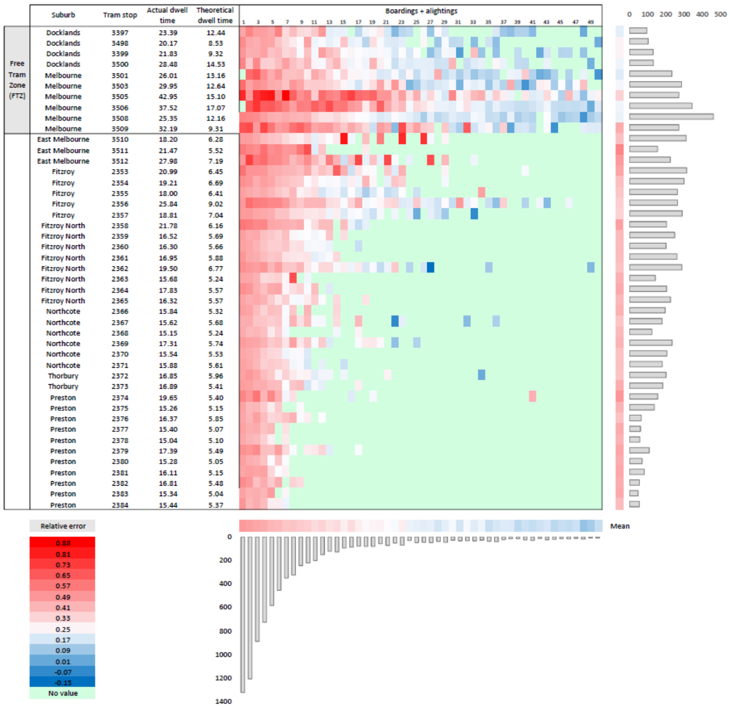


Fig. 3 – Average values depending on the tram stop and the passenger flow

5. Conclusions

Theoretical and actual dwell times for urban buses in A Coruña (Spain) and trams in Melbourne (Australia) were compared to evaluate whether the TCQSM provides acceptable estimations of transit vehicle dwell time and propose possible improvements. A methodology based on the TCQSM was used to calculate the estimated dwell times, following the steps indicated in the spreadsheet.

The results show that in A Coruña the estimated dwell time for buses is higher than the actual time, unlike what happens with trams in Melbourne. The real dwell time for A Coruña buses is reliable and not underestimated. However, the theoretical estimation could be overestimated since it always considers a t_{bl} of 2 s (48.14% more than the actual average), regardless of the main flow door. Moreover, around 35% of the analyzed buses in A Coruña have rear door main flow. In addition, due to the characteristics of the stop, it is assumed that there are always standees, which adds always 0.5 s to t_a and t_b. A sensitivity analysis regarding the presence of standees is recommended and more bus stops should be studied in future works.

By contrast, the theoretical dwell time in Melbourne trams seems to be underestimated. We have no information about the actual t_{bl}, but the theoretical calculation assumes it is zero. On the one hand, in many cases, the two door channels are not used simultaneously, and on the other hand, at some stops, the shelter is on the sidewalk, and it is necessary to cross a traffic lane to reach the tram stop. Additionally, the records of the real dwell time are automated, and the system does not discard the possible time between the end of the main flow and the door closing, which the Manual eliminates. Therefore, the current time could be overestimated, even though only vehicles that arrive and depart late are considered. For future work, it is recommended to consider the presence of traffic lights and their cycle after the stop, as well as rainfall values if data is available.

The Manual now includes the term t_{bl}, unlike the second edition, but it does not require its use only for the main boarding flow. Moreover, in Chapter 6 of the Manual, some concepts are defined differently. For instance, dwell time is defined as “the sum of passenger service time, boarding lost time, and door opening and closing time”. However, on page 6-126, it is clarified that “the passenger service time for each transit vehicle arrival is computed by taking the difference between the time that the door opens and the time that the main flow stops”, which means t_{bl} would be counted twice in the dwell time. Regarding the Manual, when there is a "double-channel boarding, all fares paid or inspected upon boarding (…) it can be assumed that 25% of alightings occur through the non-farebox front door channel and that the remainder occur via the rear door(s)". However, this distribution of alightings through the front door seems too high. In fact, when buses have 6 door channels, the Manual considers no alightings through the first channel, 25% through the second channel, and the remaining 75% distributed among the 4 remaining channels, resulting in a lower value than the flow through the front door and not reflecting the reality.

Several possible improvements have been identified regarding the spreadsheet provided by the Manual. Firstly, changing the number of doors and channels causes the sum of passenger distribution to not match the total. Furthermore, the Manual indicates a t_{bl} between 0 and 4 s for 2 loading areas. The default values of t_{bl} in the spreadsheet, 2 s, should be reconsidered based on the study's results. Additionally, in both Coruña and Melbourne, the increase of 20% of t_b and t_a "when more than 25% of the passenger flow through a single door channel is in the opposite direction of the main flow of passengers" is applied. Nevertheless, in the spreadsheet this increase is only considered in one direction of the flow, and it is applied even if there are no boardings, which does not reflect congestion conditions. A change in the formula could easily solve this issue. In the case of trams, the spreadsheet only allows for the distribution of passengers through 6 door channels, and the remaining flows must be extrapolated. Upon checking the data with the reference table, Exhibit 6-58, an incorrect value was located for the case of two available door channels and alightings. Chapter 6 of the Manual suggests a 75%, while the spreadsheet provides a 55%.

It is advisable to approach the estimation of dwell time using the Manual and its spreadsheet with caution, given the presence of certain inconsistencies and inaccuracies, and in some cases, its lack of adjustment to specific conditions of the real case.

Acknowledgements

The authors thank Compañía de Tranvías de La Coruña, Concello da Coruña, and Yarra Trams for providing the required data. This study was financed by grants RTI2018–097924–B–I00, PID2021-128255OB-I00 and PRE2019-089651, funded by MCIN/AEI/10.13039/501100011033 and by ERDF/EU and ESF/EU.

References

Christoforou, Z., Chandakas, E., Kaparias, I., 2020. Investigating the Impact of Dwell Time on the Reliability of Urban Light Rail Operations. Urban Rail Transit 6, 116–131.

Currie, G., Delbosc, A., Harrison, S., Sarvi, M., 2013. Impact of crowding on streetcar dwell time. Transportation research record 2353.1, 100-106.

Currie, G., Reynolds, J., 2016. Evaluating pay-on-entry versus proof-of-payment ticketing in light rail transit. Transportation Research Record 2540.1, 39-45.

Fernández, R., Zegers, P., Weber, G., Tyler, N., 2010. Influence of platform height, door width, and fare collection on bus dwell time: laboratory evidence for Santiago de Chile. Transportation research record 2143.1, 59-66.

Fletcher, G., El-Geneidy, A., 2013. Effects of fare payment types and crowding on dwell time: fine-grained analysis. Transportation research record 2351.1, 124-132.

González, E. M., Romana, M. G., Álvaro, O. M., 2012. Bus dwell-time model of main urban route stops: case study in Madrid, Spain. Transportation research record 2274.1, 126-134.

Jaiswal, S. K., 2010. Busway platform bus capacity analysis. PhD thesis, Queensland University of Technology, Brisbane.

Kathuria, A., Parida, M., Sekhar, C. R., Pathak, M., 2016. Examining bus lost time dynamics for a bus rapid transit station. Journal of Public Transportation 19.2, 168-182.

Kittelson and Associates, 2013. TCRP Report 100: Transit Capacity and Quality of Service Manual, 3er ed. Transportation Research Board of the National Academies, Washington, D.C.

Milkovits, M. N., 2008. Modeling the Factors Affecting Bus Stop Dwell Time: Use of Automatic Passenger Counting, Automatic Fare Counting, and Automatic Vehicle Location Data. Transportation Research Record, 2072.1, 125–130.

Novales, M., Orro, A., Pérez-López, J. B., Feal, J., Bugarín, M. R., 2021. Increasing boarding lost time at regular bus stops during rainy conditions: A case study. Journal of Public Transportation 23.1, 63-80.

Tirachini, A., 2013. Bus dwell time: the effect of different fare collection systems, bus floor level and age of passengers. Transportmetrica A: Transport Science 9.1, 28-49.