An investigation of dwell time patterns in urban public transport systems: The case of the Nantes tramway

Z. Christoforou [1], E. Chandakas [2], I. Kaparias [3*]

[1] Université Paris Est, Paris, France
[2] Transamo, Transdev Group, Paris, France
[3] Transportation Research Group, University of Southampton, UK
[*] E-mail: i.kaparias@southampton.ac.uk

Abstract

The present study investigates the determinants of vehicle dwell time at public transport facilities. Using data collected from an on-board Automatic Passenger Counting system of the light rail network of the French city of Nantes during a long period, the study performs graphical and statistical analyses enabling the identification of cause and effect relationships of a number of attributes on the dwell time. The results confirm the significance of the boarding and alighting passenger volumes, as well as of the on-board passenger loading, on the dwell time. Additional effects on dwell time are also found from the vehicle type (low- or high-floor), from the time of the day (peak, off-peak, inter-peak), and from the location of the stop (city centre, proximity to Points of Interest). Also, it is found that operations are not symmetrical and dwell times tend to be higher in one direction of the same line.

Keywords: *dwell time; urban public transport; tramway; graphical analysis; multiple linear regression*

1. Introduction

The fact that travel time in road networks is not constant, but entails an element of variability, resulting in uncertainty when attempting to predict it, has been recognised in the literature for a long time. Already in a very early study by Wardrop (1952) it was noted that travel times follow a skewed distribution with a long ‘tail’ representing the few very slow vehicles, such that it is very likely for the mean travel time to be exceeded. In a later study by Thomson (1968), travel time variability was identified as an important characteristic of road networks and it was pointed out that the unpredictability of travel time is one of the most important sources of time losses.

The importance of travel time variability has been the objective of much research in the past and has therefore been extensively analysed from both the traveller’s and the operator’s perspectives. Many studies have concluded that although travel time is an important factor affecting the traveller’s route choice behaviour, travel time variability can be even more important. Hence, much research and practice has focussed on measuring and controlling travel time variability, concentrating almost exclusively on motorised vehicular traffic. As opposed to road networks, however, where traffic congestion can be fairly easily identified as the sole source of uncertainty, passengers in public transport networks of large cities may be exposed to delays arising from a number of sources. For instance, Turnquist and Bowman (1980) identified that variability in bus networks exists primarily in the in-vehicle time (as the impact of traffic congestion on the bus), but also in the out-of-vehicle time (i.e. time spent waiting or transferring), which may be prone to the effect of aspects such as service reliability and overcrowding.

An important component of travel time in public transport, currently getting very little attention in passenger journey planning or in operational studies, is dwell time of vehicles at stops. In fact, while dwell time at an individual stop is usually only a few seconds long and rarely exceeds 2 minutes under normal circumstances, when accumulated along an entire vehicle run or passenger trip, it can amount to a fairly significant proportion of the total journey time (estimated to roughly 25-30%). What is even more important is that dwell time can be a source of variability of the total travel time, over which the operator may have little or no control and influence. This variability may be further amplified downstream the line resulting to the so-called "bus bunching" problem. In addition, given that dwell time is in essence idle time rather than actual travel time, it is not seen favourably by travellers and can negatively affect their perception of customer service.

But while dwell time is recognised as an important influencing factor of the operation of large cities' public transport networks (for example, in London it is no longer possible to buy a bus ticket from the driver in the interest of dwell time), its causes and potential effects have received little attention in the literature. The aim of this study is, hence, to shed light into the under-explored topic of vehicle dwell time at public transport facilities, with a view of identifying cause and effect relationships, through which operators could devise solutions for minimising this important source of time loss. Focussing on the tramway network of the French city of Nantes and using data obtained from on-board measurements, the study investigates dwell time patterns performing a graphical analysis in the first instance, and then deriving statistical models enabling prediction as a function of a number of other factors.

The present paper is structured as follows: Section 2 presents the background of the study, focussing on previous research on the topic of dwell time analysis and modelling. Section 3 then goes on to present the study site, the data collection method employed, and the analysis methodology. Section 4 reports the results of the graphical and statistical analysis performed, and presents the model for explaining and predicting dwell time in tramway networks. Section 5, finally, concludes the paper and identifies areas of future research.

2. Background

The understanding of the determinants of dwell time and its modelling has attracted significant attention from the scientific community. Dwell time is understood as the period during which a vehicle is immobilised at a station. It is composed of three components: the door manoeuvre time (door opening and closing) and vehicle departure, the passenger flow time, and the time the doors remain open without passenger flow (TRB, 1999). Therefore, a link between passenger flows (defined as the number of boarding and alighting per service or vehicle) and service operations exists, where the former influences the latter and vice-versa.

TRB's Transit Capacity and Quality of Service Manual (1999) proposes a function of boarding and alighting flows for the calculation of a vehicle's average dwell time:

$$DT = x_a t_a + x_b t_b + t_c \quad (1)$$

where x_a and x_b denote the alighting and boarding passenger numbers through the busiest door, while the parameters t_a and t_b express the flow rate (or service time) per passenger for boarding and alighting respectively, and t_c corresponds to the time needed for the doors to open and close, and for the vehicle to depart.

While Equation (1) is widely used by practitioners due to its simplicity, it does not include the particularities of each public transport mode. This matter boasts an extensive literature, each one focusing on a single or on a number of determining factors of dwell time by transport mode (bus, light rail, metro and train). For instance, Szplett and Wirasinghe (1984), and Wirasinghe and Szplett (1984) investigated the impact of the distribution of passengers waiting at a station. They inferred dwell time models sensible to the stop location (suburbs and Central Business District (CBD)). In another study the impact of overcrowding and the difference among different vehicles was demonstrated by Fritz (1983). In line with the same idea Lin and Wilson (1992) proposed linear and non-linear dwell time models to take into account the number of boarding, alighting and on-board passengers, and that for one and two-car vehicles. Currie et al (2013) conducted a survey to establish a positive correlation between dwell time and on-board congestion.

A considerable amount of research has focused on assessing the impact of the interface between vehicle and platform and of the boarding process. Daamen et al (2008) established the impact of a vertical or horizontal gap on the passenger flow rates, while Fernandez et al (2010) focused on the relation between horizontal gap and door width and the impact of on-board payment. They concluded that a small gap reduces the passenger flows and they inferred dwell time models for use in metro stations and bus stops. Both these studies were based on laboratory experiments were it was possible to extract each one of these effects. In another study by Milkovits (2008), the impact of payment methods on the dwell time were investigated using data from Automatic Fare Counting (AFC), Automatic Passenger Counting (APC) and Automatic Vehicle Location (AVL) systems installed in an urban bus system. The results suggested that smartcards can accelerate the payment process on board and can hence reduce vehicle dwell time; however, the benefits were mostly evident in uncongested conditions, as the effect was not noticeable under crowding.

In the urban rail context, Weston (1989) developed a sophisticated formula for London Underground that takes into account an important number of variables. Harris and Anderson (2007) confirmed the validity of Weston's formula on other metro systems, although they agreed on the site-specific character of the boarding and alighting flow rates. Harris (2005), on the basis of an experiment conducted with train mock-ups, suggested that these flow rates are not constant, but that they significantly vary with the evolution of the dwelling process. Indeed the fastest alighting rates come from the first alighting passengers, while the fastest boarding rates come from those in the middle of the boarding group.

Furthermore, an alternative approach for the modelling of the dwell time comes from the use of micro-simulators. Zhang et al (2008) developed a micro-simulation model, where passengers correspond to cellular automata. By defining the behaviour of the passengers against obstacles and attractions at an individual level, the simulation lets a range of complex phenomena emerge on a macroscopic level on the platform, during the vehicle's dwelling. It is possible then to understand the interactions between passengers and assess the impact of different station, vehicle configurations and passenger flows on dwell time.

3. Methodology

3.1 Site description

The present study focuses on the tramway system of the French city of Nantes. Nantes is located on the Loire river in Western France, close to the Atlantic coast. It is the sixth largest city of France, with a metropolitan population of 900,000. Its tramway network is operated by Semitan, and with its opening in 1985 Nantes became the first city to introduce a modern generation tramway, built from scratch. Nowadays the network consists of three lines (numbered 1,2 and 3) running in 44 km of track and serving a total of 83 stations.

The Nantes tramway is shown in Figure 1. Line 1, shown in green, has a length of 18.4 km and serves 34 stations. It consists of two branches at each end (Beaujoire and Ranzay in the East, and François Mitterand and Jamet in the West) and a central trunk between the branches with 19 stations. Its frequency reaches 15 vehicles per hour during peak times, and it is the busiest line on the network (and with 120,000 passengers per day, it is also one of the busiest of the whole of France), serving several principal locations of the city, including the city's stadium and the main railway station. Line 2, shown in red, runs from Orvault in the North to Gare de Pont-Rousseau in the South, has a length of 11.7 km and serves 25 stations, including important educational (university) and health establishments. It has a frequency of 8 vehicles per hour during peak times, and its patronage approaches roughly 80,000 passengers per day. Lastly, Line 3, shown in blue, runs from Marcel Paul in the North to Neustrie in the South, has a length of 14.1 km and serves 34 stations. It has a similar operation with Line 2, with which it shares the track for seven stations (Hôtel Dieu to Gare de Pont Rousseau) in the city centre. It serves several major commercial sites and is used by 75,000 passengers per day. The three lines run radially off the city centre but meet at Commerce. They are combined with Park and Ride (P+R) facilities on the outskirts, and also have major transfer points with the other public transport modes: the Busway (exclusive right-of-way Bus Rapid Transit (BRT)), the Chronobus buses (buses with limited segregated lines), the local buses and the regional coaches.

The tramway system is served by three types of rolling stock, irrespectively of the line: the Alstom TFS, the Bombardier Incentro, and the CAF Urbos. The Alstom TFS is a 39 m long vehicle with a capacity of 236 passengers (including 74 seats) which began operation in 1985. Each Alstom vehicle is composed of two high floor carriages with three-step accesses (of which one mobile step) and a lower floor carriage in the middle; access is provided by six double length doors and two simple doors per vehicle side. The Bombardier Incentro is 36 m long with a capacity of 252 passengers (including 72 seats) and started operating in 2000. It has an integral low floor and six double (1.30 m) doors per side. Finally, the CAF Urbos is the newest vehicle in the network, having started operations in 2012. It is 37 m long with a capacity of 249 passengers (including 68 seats) and has an integral low floor and six double doors per vehicle side.

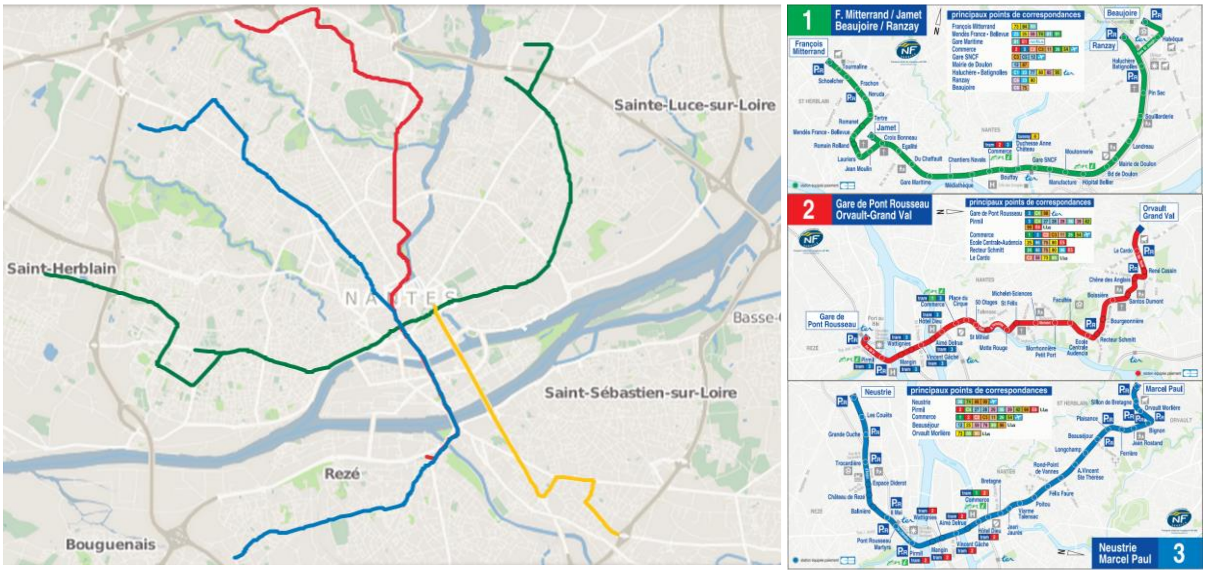

FIGURE 1: The Nantes light rail network (Source: www.tan.fr)

3.2 Data collection

The data used in this study have been collected from the Opthor system, used by the operator. Opthor is an Automatic Passenger Counting (APC) system measuring the number of passengers boarding and alighting at each station, on one hand, and the dwell time, as well as a number of other performance-related measures, on the other. Passengers are detected by an infrared system installed at each door of the vehicle. Dwell time is measured as the difference between the opening of the first door and the closing of the last door of the trainset. Since door operation is not forced by the driver, the value corresponds roughly to the duration of the passenger exchange. The operator has installed the system on a limited number of vehicles (of Alstom TFS and Bombardier Incentro class only) and runs frequent counts with it for various purposes.

The data employed here were collected during a count conducted between 5 September 2013 and 10 April 2014. As part of the count, the operator collected 134,500 valid entries from 124 weekdays and a total of 4900 runs. This sample corresponds to roughly 10% of the number of daily runs. Each entry of the data reports the number of boarding passengers, alighting passengers and dwell time for a stop and for a given run (where dwell time is considered as the time that the doors remain open). In addition, the system calculates the volume of on-board passengers at each station.

Further filtering of the data has been conducted so as to identify and limit the impact of extreme values. Specifically, only dwell time values between 1 and 120 seconds and passenger exchange volume values (sum of boarding and alighting) between 5 and 150 are considered. The reasoning behind this filtering is that the values excluded either lack significance (less than 5 seconds of dwelling) for the scope of the research conducted, or are beyond the normal operational values. Given the high frequency of the lines, dwell times of over 2 minutes may be attributed to a system malfunction or schedule regulation strategies, and can, consequently, be excluded. On the other hand, the infrared technology used for passenger counting is less precise at high volumes of people. Finally, terminal stations are also omitted (both origin and destination), as the doors remain open at those during "turnback" and interior supervision, as well as the Commerce transfer station in the city centre, where holding strategies are applied. As such, following the filtering, a total of 118,957 observations are included in the analysis.

3.3 Analysis methodology

The analysis proceeds in two parts. The first part involves the investigation of dwell time patterns using a graphical method. Considering each line and direction separately, a set of heat maps of on-board passenger loading and dwell time are produced, allowing for the variation of these parameters as a function of the location along the line and of the time of the day to be observed. This enables the preliminary identification of causal relationships between dwell time and other relevant parameters, preparing the ground of the second part of the analysis, which involves the use of inferential statistics to more formally identify these relationships.

In the second part, hence, dwell time is modelled using regression in order to derive explanatory statistical models. Multiple linear regression is employed, which is commonly used to model the relationship between a continuous dependent variable and several regressors that are thought to co-vary. Dwell time here is a continuous nonnegative variable, which can be reasonably assumed to vary with the field data.

Following Washington et al (2010), dwell time can be modelled as follows:

$$Y_i = \beta_0 + \beta_j X_{ij} + \varepsilon_i \tag{2}$$

where Y_i is the dwell time for stop i=1,2,… of line l for a specific vehicle run, β_0 is the constant term, β_j denotes the coefficients to be estimated for j=1,2,…, ρ independent variables considered, and ε_i is the disturbance term for stop i. The error term of this type of regression model is independently and identically normally distributed with zero mean and constant variance. Furthermore, the functional form of the multiple linear regression in Equation (2) assumes that the estimated parameters are the same for all observations. This assumption seems to hold, as no significant heterogeneity is observed.

4. Results and analysis

The results of the graphical and statistical analysis of dwell time of the tramway system analysed are presented next.

4.1 Graphical analysis of dwell time

Six heat map sets demonstrating the spatial and temporal variation of dwell time are produced and are shown in Figure 2, each one corresponding to each of the two directions of each line. The first column on the figure lists the stops of the line in their order of occurrence in any run

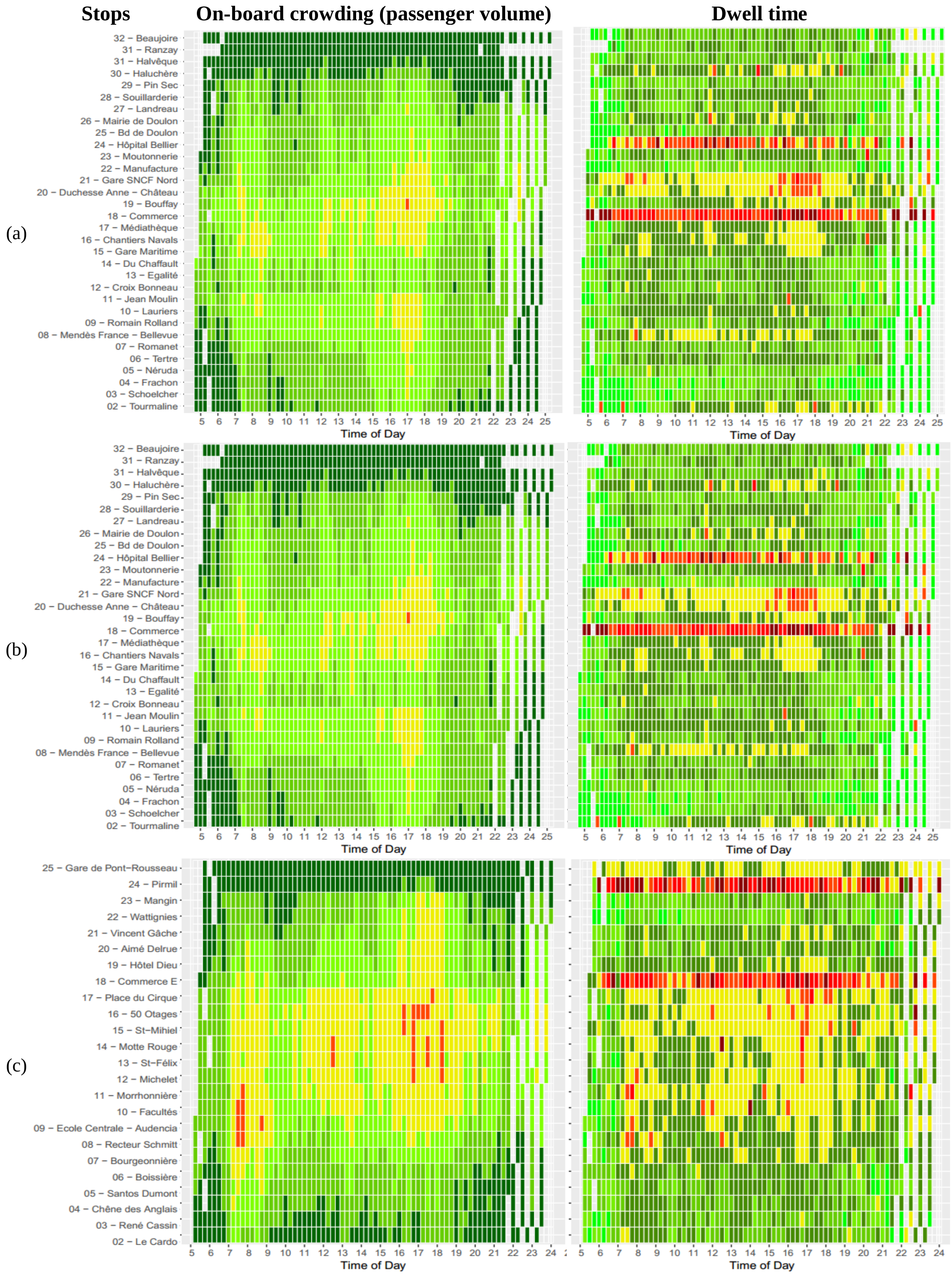

FIGURE 2: Dwell time heat maps for each line and direction: (a) Line 1 westbound; (b) Line 1 eastbound; (c) Line 2 southbound; (d) Line 2 northbound; (e) Line 3 southbound; (f) Line 3 northbound

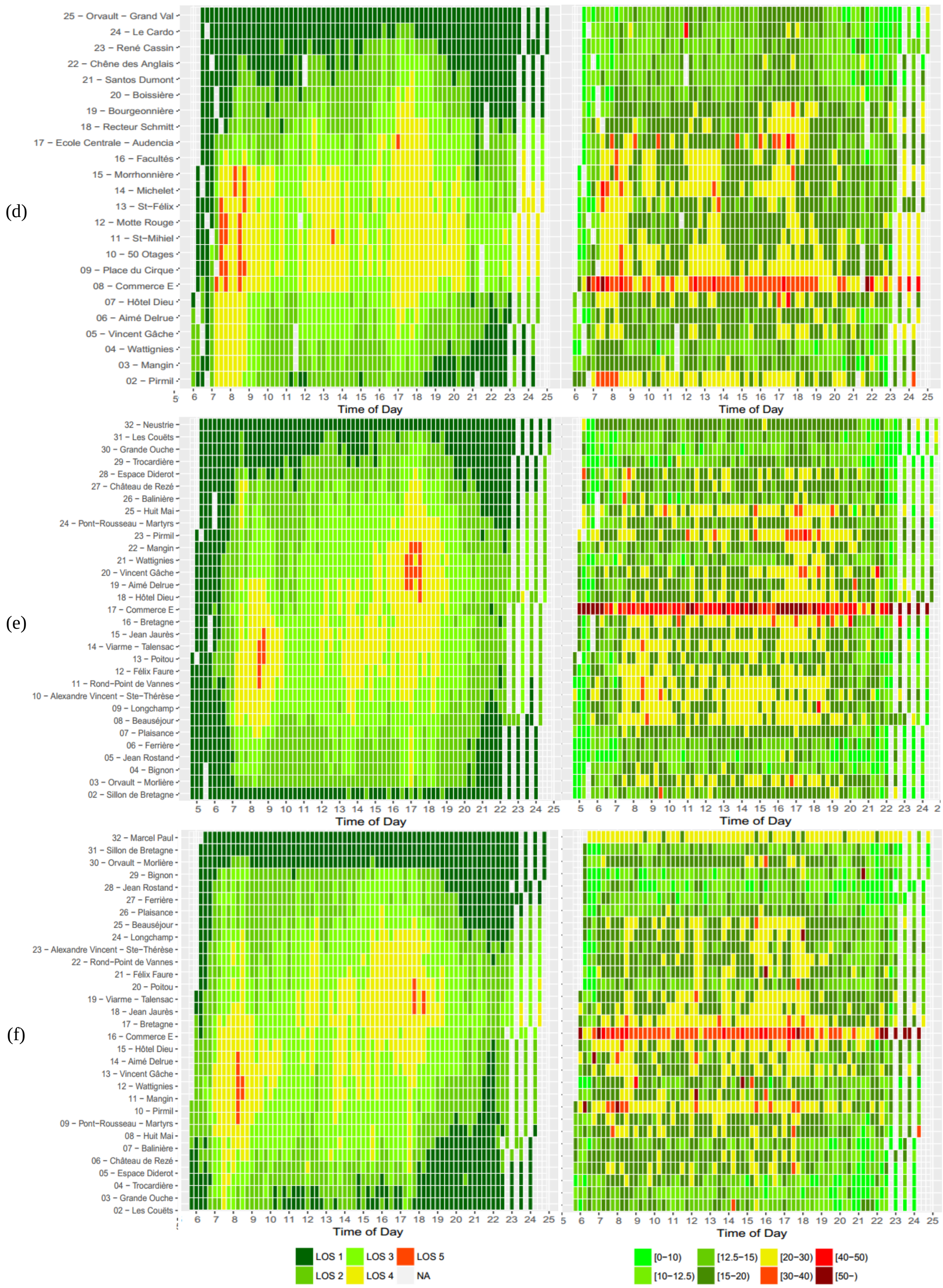

FIGURE 2 (continued)

from bottom to top, while the first column of heat maps shows the on-board passenger volume, expressed by means of crowding levels of service (LOS), as defined in TRB's Transit Capacity and Quality of Service Manual (1999). The second column then shows the average dwell time at each of the stations and time of the day, classified into eight categories according to its duration.

A number of observations can be made from the heat maps. First and foremost, the average dwell time at Commerce station is considerably longer than anywhere else on the network. This is expected, as Commerce is the main interchange station, and holding strategies are applied there on all lines. A similar pattern is also observed at Pirmil station, where Line 2 southbound merges with Line 3. This occurrence introduces a bias in the data, and therefore justifies the decision to exclude the data from these two stations in further analysis.

Further interesting features can be extracted from the heat maps. Namely, it can be observed that different dwell time patterns occur in the two directions of each line, which suggests that the line direction may have an influence on the dwell time. Also, the dwell time varies quite considerably throughout the day, with city-centre-bound runs closer to the beginning of the line experiencing higher dwell times in the morning peak and outskirts-bound runs closer to the end of the line facing higher dwell time in the evening peak. Stations located in the city centre, on the other hand, experience higher dwell times at all times and regardless of the line direction, and the same applies to stations located close to Points of Interest (POIs), such as P+R facilities, hospitals and educational establishments. This suggests that the location (rank) of the stop along the line and the time of the day may have effects on dwell time.

Furthermore, it can be observed that there is an association between high on-board crowding levels and longer dwell times, but also that longer dwell times occur at stations and times where there are big changes (drops or increases) in the on-board crowding. This suggests that both the number of passengers on board, and the total number of passengers boarding and alighting, may have an influence on the dwell time.

The potential causal relationships identified are next analysed more formally using inferential statistics.

4.2 Statistical modelling of dwell time

Three multiple linear regression models are used to model dwell time from the field observational data, i.e. one per tramway line. The descriptive statistics of the models and the variables included in the regression are shown in Table 1, from where it can be seen that the regression is based on large numbers of observations. Dwell time is modelled against the following variables, as identified in the previous sub-section: the direction of the line ("LINE", categorical), the location of the stop in the city centre ("CBD", binary), the time of the day ("HOUR", categorical), the number of on-board passengers upon arrival at the stop ("ONBO", continuous), the number of passengers boarding and alighting ("BNA", continuous), and the location of the stop near a POI, a transport hub or a P+R facility ("POI", binary). In addition, the influence of the vehicle type on the dwell time is examined ("VEH", categorical).

TABLE 1: Descriptive statistics of the dwell time regression models

Variable	Type	Definition	Descriptive statistics
Line 1 : F.Mitterand /Jamet-Ranzay/Beaujoire			Number of observations=65,535
DT	continuous	dwell time (sec)	Min= 6.0; Max=119.0; Mean=17.0 ; SD=8.6
LINE	categorical	=1 if eastbound ; =2 if westbound	F(1)=0.47 F(2)=0.53
CBD	binary	=1 if stop within CBD; =0 otherwise	F(1)=0.41
HOUR	categorical	=1 if 4h00-6h59; =2 if 9h00-15h59 or 19h00-19h30; =3 if 7h30-8:59 or 16h00-18h59	F(1)=0.10 F(2)=0.57 F(3)=0.33
ONBO	continuous	number of onboard passengers upon arrival	Min= 0.0; Max=236.0; Mean=50.5 ; SD=34.7
BNA	continuous	Number of passengers boarding and alighting per stop	Min= 1.0; Max=148.0; Mean=14.7 ; SD=14.4
VEH	categorical	=1 if vehicle type is Bombardier =2 if vehicle type is Alstom	F(1)=0.51 F(2)=0.49
POI	binary	=1 if stop is a POI, has P+R, or is a transfer hub; =0 otherwise	F(1)=0.19
Line 2 : Orvault Grand Val – Gare de Pont Rousseau			Number of observations=26,680
DT	continuous	dwell time (sec)	Min= 6.0; Max=120.0; Mean=18.7 ; SD=9.0
LINE	categorical	=1 if southbound ; =2 if northbound	F(1)=0.52 F(2)=0.48
CBD	binary	=1 if stop within CBD; =0 otherwise	F(1)=0.41
HOUR	categorical	=1 if 4h00-6h59; =2 if 9h00-15h59 or 19h00-19h30; =3 if 7h30-8:59 or 16h00-18h59	F(1)=0.04 F(2)=0.63 F(3)=0.33
ONBO	continuous	number of onboard passengers upon arrival	Min=0.0 ; Max=268.0 ; Mean=58.34 ; SD=43.83
BNA	continuous	Number of passengers boarding and alighting per stop	Min=1.0 ; Max=150.0 ; Mean=18.1 ; SD=16.1
VEH	categorical	=1 if vehicle type is Bombardier =2 if vehicle type is Alstom	F(1)=0.00 F(2)=1.00
POI	binary	=1 if stop is a POI, has P+R, or is a transfer hub; =0 otherwise	F(1)=0.23
Line 3: Marcel Paul – Neustrie			Number of observations=25,942
DT	continuous	dwell time (sec)	Min= 6.0; Max=116.0; Mean=17.7 ; SD=7.7
LINE	categorical	=1 if southbound ; =2 if northbound	F(1)=0.50 F(2)=0.50
CBD	binary	=1 if stop within CBD; =0 otherwise	F(1)=0.28
HOUR	categorical	=1 if 4h00-6h59; =2 if 9h00-15h59 or 19h00-19h30; =3 if 7h30-8:59 or 16h00-18h59	F(1)=0.08 F(2)=0.59 F(3)=0.33
ONBO	continuous	number of onboard passengers upon arrival	Min=0.0 ; Max=232.0 ; Mean=50.7 ; SD=36.6
BNA	continuous	Number of passengers boarding and alighting per stop	Min=1.0 ; Max=135.0 ; Mean=13.8 ; SD=12.8
VEH	categorical	=1 if vehicle type is Bombardier =2 if vehicle type is Alstom	F(1)=0.14 F(2)=0.86
POI	binary	=1 if stop is a POI, has P+R, or is a transfer hub; =0 otherwise	F(1)=0.30

Ordinary least squares (OLS) regression is used to specify the models through the LIMDEP statistical software package, and the estimation results are shown in Table 2. The statistics of the fitting of the models are shown in part (a) of Table 2. As can be seen, the models achieve R-squared values of between 0.26 and 0.32, which initially suggests that they may not be very good fits of the data. However, it should be considered here that the models are based on a very large number of observations, which increases the overall variability of the dataset and makes it, hence, more difficult to achieve an accurate prediction. Also, it should be noted that the dependent variable takes generally small values, thus making the goodness of fit less significant, in the sense that prediction errors of a few seconds may appear as large from a statistical perspective, but are rather minor from a practical perspective. It can be, hence, concluded that the models are acceptable fits.

The regression coefficients for each of the parameters included are then shown in part (b) of Table 2. Variables that are not statistically significant at the 0.05 level are omitted, and hence all estimated parameters included in the final models are statistically significant. Elasticities are estimated for all continuous variables to assess the sensitivity of dwell time with respect to changes in the regressors.

TABLE 2: Model estimation results for dwell time

(a)	Line 1	Line 2	Line 3
Number of observations	65,535	26,680	25,492
Log-likelihood at zero LL(0)	-234,285.1	-96,476.30	-88,047.69
Log-likelihood at convergence LL(β)	-224,455.2	-91,404.49	-83,060.71
Number of parameters	7	6	7
R-squared	0.26	0.32	0.32

(b)		Line 1			Line 2			Line 3		
Attribute	**Variable**	**Coef.**	**t-stat.**	**Elast.**	**Coef.**	**t-stat.**	**Elast.**	**Coef.**	**t-stat**	**Elast.**
	Constant	10.39	62.74		13.54	80.05		10.97	36.13	
Line	LINE	0.95	16.32		-1.57	-17.28		-0.93	-11.80	
Time period	HOUR	0.13	2.67					-0.20	-2.72	
On-board passengers	ONBO	0.20	19.00	-0.01	0.21	14.68	-0.01	0.03	21.47	-0.01
Board. & alight. pass.	BNA	0.27	102.84	-0.01	0.26	71.47	-0.01	0.28	73.93	-0.01
Vehicle type	VEH	-0.16	-2.83					1.65	14.31	
Point of Interest	POI	0.39	4.87		2.76	22.97				
City centre	CBD				2.28	23.95		0.39	4.22	

Looking at the coefficients for each of the parameters, it can be first seen that the variable “LINE” has a statistically significant impact on dwell time at the 0.05 level. This finding indicates that different directions of the same line have different characteristics. In particular, longer dwell times are observed on the eastbound direction of Line 1 (compared to the westbound), on the northbound direction of Line 2 (compared to the southbound), and on the northbound direction of Line 3 (compared to the southbound). This can be explained by the smoother distribution of afternoon peaks compared to morning peaks, or by the local characteristics of the stops on each direction given that frequencies are equal. It is an important finding, indicating that future research efforts should consider the two directions of the same line separately when investigating dwell time variations.

Then, it can be seen that the variable “HOUR” is statistically significant for Lines 1 and 3 only.

For Line 1, increased values of "HOUR" (that indicate moving towards peak hours) results to higher dwell times. This intuitive finding supports the generally accepted idea that more passengers cause longer stopping. However, this is not the case for Line 3, where the opposite is observed. This may be due to frequency increase during the peaks in order to accommodate increasing demand. This analysis is important, as it allows for direct recommendations to the operators to be made on whether planned increased frequencies during peak hours can sufficiently respond to the increased demand without loss in terms of level of service. Along the same line of reasoning, it can be deduced that the variable '"HOUR" is not significant for Line 2, as the frequency increase outbalances the extra passengers during the peak hours.

Furthermore, the volume of passengers on-board upon arrival ("ONBO") and the volume of boarding and alighting passengers ("BNA") are statistically significant in all models. This is an intuitive result, as higher levels of passenger numbers, both boarding/alighting and staying on-board the vehicle, are likely to cause longer dwell times. As in-vehicle congestion can make access to the doors difficult for alighting passengers and also impede the boarding of new passengers, this can result in longer stops. It should be noted here that for a given vehicle run, the coefficient of "BNA" and the constant term of the model can be used to approximate the parameters of Equation (1) for different on-board passenger levels.

In addition, the vehicle type ("VEH") has statistically significant effects on the dwell time for the Line 1 and Line 3 models. Specifically, it appears that there is a strong association of new low-floor vehicles (Bombardier) with shorter dwell times on Line 3, but also a weak association with longer dwell times on Line 1. An explanation could be the fact that Line 1 has a greater proportion of segregated track and dedicated rail-type stations (especially at each eastern section) than Line 3, providing already an important facility for the boarding and alighting of passengers, such that the impact of the vehicle type is less evident. Conversely, many more stops along Line 3 are designed conventionally, and at such locations the new low-floor vehicles do much more to facilitate the boarding and alighting process, and hence have a positive impact in reducing dwell time.

Moreover, the "POI" and "CBD" variables appear to have significant effects on the dwell time, such that dwell times at stops located in the city centre and at stops serving one or more POIs are generally longer than at other stops. Both variables have strong significant effects on dwell time along Line 2 stops, while weaker effects are observed in the other two lines, with "POI" only being significant in Line 1 and "CBD" only being significant in Line 3. This is a sensible result, as stops located in the city centre and close to POIs are usually associated with larger passenger volumes, which increases dwell time. It should be noted, however, that some of the effect of these variables is likely to be confounded with that of the "BNA" variable, and further analysis of the two- and three-way interaction effects, in addition to the main effects, is required to shed light on these. This, however, is beyond the scope of the present study.

Finally, the elasticity analysis of the continuous variables shows a very low sensitivity of dwell time to boarding and alighting volumes. This can be explained by the high value of the constant term that is observed in all models and corresponds to a fixed minimum dwell time that cannot be under-passed. As such, for low passenger volumes there is very little or no impact on dwell time. This is sensible, as the vehicles employed have six large doors that allow for many simultaneous boarders and alighters, and only little impact on dwell time is expected.

5. Conclusions

The aim of this study has been to investigate the topic of vehicle dwell time at public transport facilities and to identify cause and effect relationships. Using APC data from the tramway system of the city of Nantes collected over a period of one year, graphical and statistical analyses have been carried out in order to identify how dwell time may be influenced by a number of attributes. The results confirm that, as conjectured, boarding and alighting passenger volumes, as well as on-board passenger loading, have a significant impact on dwell time. Additional significant effects on dwell time are also found from the vehicle type (low- or high-floor), from the time of the day (peak, off-peak, inter-peak), and from the location of the stop (city centre, close to POIs). An interesting result in this context is also the lack of operational symmetry between the directions of a line, in what stops located at different directions of the same line exhibit different dwell time trends.

The findings of the present study can be, hence, used by operators to devise solutions for minimising this important source of time loss. But while the study has shed some light on the determinants of the dwell time of light rail systems, research in this direction continues. Further work will concentrate on the detailed investigation of the factors that lead to non-symmetrical operations, with a view of providing a useful insight for efficient configurations of light rail lines. In these terms, a comprehensive investigation of different station configurations will be carried out, so as to determine their impact on dwell time. Moreover, a similar analysis is foreseen for other tramway, as well as bus networks, with a view of comparing and confirming the significance of the non-site-specific determinants.

Acknowledgements

The authors would like to thank Semitan for supplying the data used in this study, and in particular the Direction of Performance of Semitan for their assistance in analysing the winter 2014 Opthor dataset.

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