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Case study on effects of the mandatory validation on bus commercial speed

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The paper aims to define the new operational requirements and procedures to allow the Gruppo Torinese Trasporti (Torino public transport company) to implement mandatory validation without negative impacts on both the company and the users. To this end, a four-step methodology has been put forward: a) choice of the reference route; b) sampling plan and data collection; c) data analysis design and model specification and d) definition and analysis of future scenarios.

Attained results show an increase of commercial speed from 1.5% to 14.5%, and an increase of the proportion of total dwell time on total trip time from 1 to 13 points. The most unfavourable situation for the company would be banning people from boarding the bus/tram through any door (the case today). Indeed, it would require an increase of trips in the morning peak hour in order to maintain the same time interval at bus stops. However, the impact on passengers' travel time is non negligible since total vehicle trip time shows a rise of up to 10 minutes during weekends shifts (from 62 minutes in the current situation to 72 minutes for the worst case scenario). Thus, the present system limits the outcomes negatively for the users in terms of waiting time. However, a change could lead to such positive consequences as fuller passenger cooperation to validate tickets/passes and a more ordered boarding, thus reducing fraud and improving the image of the company.

Keywords: *smart card, boarding time, public transport, commercial speed, validation.*

1. Introduction

The mandatory validation of transport tickets and passes when boarding public transport is useful to ensure a correct collection of fares, to limit free-ridership and to consolidate company revenues. Besides, it is a convenient practice for collecting huge amount of travel data, allowing a

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better operation, management, processing of information and control of the public service (Bagchi and White, 2005; Pelletier et al., 2011; Park and Kim, 2008; Briand et al., 2017). However, it may demand extra time for the users as well as some operational adjustments for the public transport (PT) operators.

Dwell time is defined by York (1983) as the time when the wheels are stationary at a bus stop while other researchers consider it as the time from the bus doors' opening to their complete closing (Dueker et al., 2004; Lin and Wilson, 1992; Tirachini and Hensher, 2011). This latter definition may include the time when the doors are already, or still, "open" even though passengers are not getting on or off. The practice, however, is to exclude from the dwell time that spent not serving passengers (TCQS Manual, 2013).

Dwell time depends on several factors according to the specific characteristics of the:

- vehicle (number and width of the doors, steps at the doors, deck height, number of decks, length and typology of the vehicle) (Dueker et al., 2004; Tirachini, 2013a; Levine and Torng, 1994; Fernandez et al., 2010);
- infrastructure (location and length of the platforms, stops location – near or far side –, dedicated lanes) (Sun et al., 2014; Tirachini, 2013a; Moreno Gonzalez et al., 2012; Diab and El-Geneidy, 2015);
- payment system (on board or not) and ticket type (paper, magnetic, smart card, etc.) (Tirachini, 2013a, Tirachini, 2013b; Fletcher and El-Geneidy, 2013).

However, despite the above factors, the key elements influencing dwell time are the transport demand and its characteristics (TCQS Manual, 2013): the number of passengers moving from one mode to another at the stop and their age (Tirachini, 2013a); particular conditions such as the presence of wheelchairs and strollers; time of day and weather conditions or the time required by passengers to approach the vehicle (TCQS Manual, 2013).

The dwell time may be very significant as regards to the total travel time. By analysing the data referring to several US cities from 1957 to 1980, Levinson (1983) estimated that dwell time in urban areas accounts for 9 to 26% of overall travel time, depending on incoming passengers. More recently, Tirachini (2013b), analysing public transport in Sydney, Australia, found lower values, from 3 to 13%, according to the transport demand. Such figures show how intervening on the factors affecting dwell time is crucial to increasing commercial speed and, consequently, to increasing the efficiency of operations of the Public Transport company. This would also guarantee positive impacts for the users (Tirachini, 2013a), since a more precise detection of passenger flow would help to organise the service, and better tailor transport offers to user needs. Furthermore, validation would help detect fraud.

Multiple regression models are the typical approach used to estimate the influence of the different factors on dwell time (Tirachini, 2013a); those models are based on data related to the number of passengers getting on (boarding) and off (alighting) at each stop, as suggested by the Transit Capacity and Quality of Service manual (TCQS Manual, 2013). Instead, Levinson (1983) defined a linear relation: the dwell time is 5 seconds plus 2.75 seconds per passenger getting on and off (s/pax), while Fernández et al. (2008) estimated a range of 2.05 to 6.04 s for each passenger.

The TCSQ Manual (2013) suggests using a multivariate linear regression differentiating incoming and outgoing flows and proved that boarding time for incoming passengers is greater than alighting time for outgoing passengers. Moreover, the change of vehicle/mode (in both directions) is faster during peak hours because of the different users' typology at different times of day. Similar to Levinson (1983), the TCSQ Manual (2013) proposes adding a constant time for each passenger boarding on or alighting from the bus.

Tirachini (2013a) suggests considering the difference between a simultaneous passengers' flow (use of different doors for boarding and alighting) or a sequential one (the same door used both for getting on and off).

Several studies analysed the influence of vehicle occupancy, particularly focusing on the effects of crowding and friction between passengers while boarding and alighting (Dueker et al., 2004, Lin and Wilson, 1992; Tirachini and Hensher, 2011; Fletcher and El-Geneidy, 2013). Zhang and Teng (2013) proved that considering the crowding on the bus allows for a better estimation of the dwell time than using only the number of people boarding and alighting.

Sun et al. (2014) showed that high occupancy slows down boarding (+0.340 s/pax) while slightly speeding up alighting (-0.083 s/pax). When the occupancy is about 60% of vehicle capacity, internal frictions produce delays in the boarding time since the incoming flow can get on only when the vehicle occupancy falls below a minimum level (Fletcher and El-Geneidy, 2013). Tirachini (2013a) focused mainly on the effects of frictions when boarding occurs in parallel queues. The relevance of this effect is surprisingly high, since boarding time requires extra time equal to 1.25 s/pax; these delays are more significant when the transport demand is higher.

To reduce bus travel time, Levinson (1983) considered decreasing the number of stops and the length of dwell times to be more effective, thanks to changes in fare collection policies and door configuration, than providing bus priority lanes or reducing traffic-related congestion.

Notwithstanding several existing studies, an additional effort is needed to understand which is the best configuration, taking into account the different contexts and typologies of passengers.

This paper aims to test the effect on boarding time – on public transport lines in Torino – of different hypotheses related to different doors' operation by evaluating three different scenarios. The motivation of the research arises because the Gruppo Torinese Trasporti (GTT), the PT company operating in Torino, was wondering whether changing or not the current way passengers board buses and trams. Indeed, a recent Italian law of the Regione Piemonte (L.R. n. 1, 27.01.2015, art. 21, comma 29, came into force in May 2017) has required mandatory validation by all PT passengers, including pass holders – the previous practice being that only single ticket holders had to validate.

The purpose of the above regional initiative would allow for the collection of massive travel data (Bagchi and White, 2005; Pelletier et al., 2011; Park and Kim, 2008; Briand et al., 2017) and, thus, support the transport authority (Agenzia della Mobilità Piemontese) to: evaluate if the current network well suit the current demand; monitor the quality of the service; better plan and program the transport services and, eventually, trigger a social control on-board thus making the system less susceptible to free-ridership.

Despite the fact that the new practice would generate multiple benefits, the GTT has had to face several operational issues:

- the increase of boarding time and consequently of travel time, entailing a lower commercial speed;
- the change in scheduling and, therefore, in the overall costs;
- the appropriate relocation of ticket machines and the introduction of new ones to speed up boarding time.

The scenario analysed by Tirachini (2013b) in Sydney – simultaneous flows, each through one door – is dissimilar to the Torino sequential flows through four doors. Indeed, the rule provides an alternating flow, alighting first and then boarding, but the practice of simultaneous flows through a double-stream door is common. The current study, unlike the Sydney study, does not differentiate the relevance of the characteristics of the vehicle, since all data are referred to the same bus typology (3-axle, 18 m long articulated urban buses).

The next section focuses on the methodology, describing the survey and the data analysis design. Following this, results are discussed and conclusions and suggestions to transport company are put forward.

2. Methodological approach

GTT decided to test the introduction of the mandatory validation before putting it into place, asking for the help of the authors to design the pilot program on the GTT lines. The test has followed a four-step methodology:

1. selection of a test line;
2. sampling plan and data collection;
3. data analysis design and model specification;
4. scenario definition and analysis.

The urban and suburban network operated by GTT includes approximately 100 lines (eight out 100 are operated with trams) with different functions – ordinary, school, special (e.g. industrial lines, night lines) – and, therefore, different passenger typologies. As the introduction of mandatory validation is supposed to increase boarding time, it has been decided to select for the test one of the busiest lines, namely line 18, being one of the ten surface lines carrying 50% of total passengers, the third most-used line of the entire surface network, and the first most-used bus line. Data collection for such line would ensure more reliable results and more significant suggestions for the PT Company, whose main worry was related to a potential increase of dwell time affecting the schedule of the service. Line 18 crosses dense residential and commercial areas, including the city centre, and runs along the North-South axis from Piazza Sofia (S Terminus) to Piazza Caio Mario (C Terminus) along 28.168 km, round-trip, on non-dedicated lanes, serving 88 stops (44 per direction, terminus excluded). Figure 1 displays the route and the stops' location of line 18.

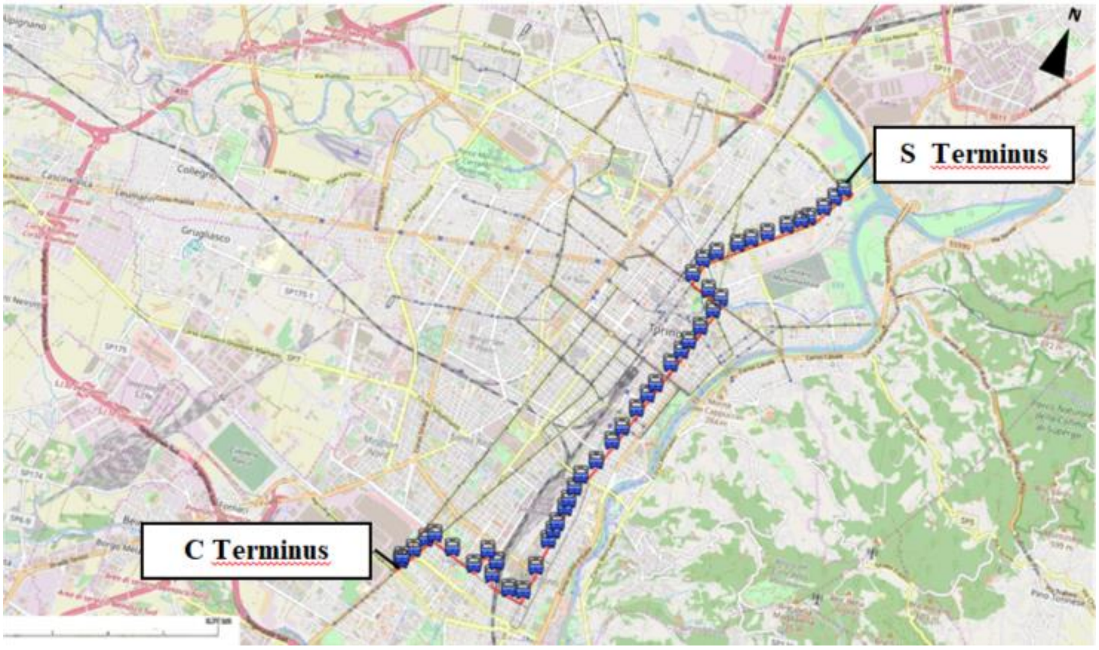

Figure 1. Line 18 route and stop's location.

The buses used along line 18 are IRISBUS CITELIS produced by Iveco, 18 meters long, articulated and low floor, supported by 3 axles. They are equipped with four two-way working doors (1.360

cm wide): boarding and alighting is authorised through all doors, with priority for passengers getting off. The vehicle capacity is equal to 159 passengers, including one disabled person.

2.1 Sampling plan and data collection

Sample trips to collect data on dwell time were selected according to the following criteria:

- weekday peak-hour trips: morning (7:00 – 9:00) and evening (16:00 – 20:00); peak-hour trips represent time of the day with the greatest ridership;
- weekday off-peak trips (9:00 – 16:00) in order to highlight, albeit partially, differences in scopes, habits, and user typologies that could influence boarding times;
- weekend trips: periods of greatest ridership (16:00 – 21:00 on Saturdays, 10:00 – 12:00 and 17:00 – 20:00 on Sundays) to have a picture of weekend trips;
- weather: all selected trips were run during non-rainy days, to limit bias resulting from differences in atmospheric conditions;
- holidays were excluded as they represent unusual periods for transport demand.

All trips were sampled from a period running from September to December 2016; Table 1 shows the details of sampled trips from line 18.

During the data collection period, only single-ticket holders were obliged to validate their ticket when starting their trip, because pass holders had to validate only at the beginning of period of validity of the subscription. As a consequence, the number of validations was very low because the majority of passengers were pass holders but also due to a strong inclination of riders to not pay the ticket. This is the reason why the validation data were not recorded and, consequently, the impact of the current fare collection system on dwell time was not investigated.

A wide range of methods was considered for the data collection on passenger boarding and alighting, from Automatic Passenger Counting devices to manual on-board monitoring. Eventually, data recording by closed-circuit television (CCTV, video surveillance cameras) was used because this method allows for the collection of all necessary data about the passenger and does not require additional hardware or staff costs. Moreover, the use of CCTV images is allowed by Italian Law, Article 100.1, D.L. 30 June 2003, n° 196, for educational and research purposes. CCTV is made by five cameras (model: AMELI Vigila M4/6 analogic cameras) whose position and approximate field of view – together with the position of validation machines – will be depicted later when presenting the scenarios (see section 2.3, Figure 2).

The vehicles used along the selected trips were identified, and when they returned to depot, the hard-drives were collected, the raw files were transferred to local machines and an operator analysed the videos and logged the following variables into a data sheet:

- trip direction, bus number and trip number, in order to associate the video with a single trip;
- opening time of the first door; usually all doors open at once, but in some cases some doors remained closed;
- closing time of the last door; usually doors do not close all at once but depend on the driver and passenger flow through each door;
- number of people boarding and alighting; flows through each door are bidirectional, people can get on or off. For each door the number of outgoing and incoming travellers was recorded;
- particular events. As some stops are located close to traffic lights, drivers often hold the doors open until the end of the red cycle. To exclude the traffic light influence, the time of the last passenger boarding was recorded and a 3-second interval added to simulate the

closing time of the doors as in free-flow traffic conditions. Moreover, any special event that could cause an abnormal timeframe between the opening and the closing of the doors was recorded (e.g. boarding of disabled people, families with strollers, or change of driver);

- stop duration at both termini (departure and arrival); the number of passengers on board and closing time of the doors were recorded at the departure terminus as well as opening time of doors and number of people alighting at the arrival terminus.

Table 1. Sampled trips from bus line 18.

DAY	TIME PERIOD	DIRECTION		DATE	DEPARTURE TIME	ARRIVAL TIME	TRIP CODE
		SOFIA-CAIO	CAIO-SOFIA				
Weekdays	7-9	X		16/09	07:02:22	08:02:54	SC1609_4612_4
			X	16/09	07:04:10	08:09:59	CS1609_4625_4
			X	21/09	07:23:45	08:29:39	CS2109_805
		X		20/09	07:25:39	08:32:12	SC2009_807
		X		21/09	07:25:14	08:33:36	SC2109_807
		X		13/09	07:50:31	09:00:38	SC1309
			X	16/09	08:04:56	09:21:58	CS1609_808
			X	13/09	08:10:52	09:14:49	CS1309
		X		16/09	08:14:19	09:17:43	SC1609_844
			X	03/10	07:28:32	08:49:12	C-S0310_824
	9-16	X		21/09	08:37:00	09:45:58	SC2109_805
			X	20/09	08:41:30	09:48:00	CS2009_807
			X	21/09	08:42:23	09:47:28	CS2109_807
			X	14/12	09:55:56	11:03:08	CS1412_822
		X		14/12	11:06:50	12:23:15	SC1412_822
			X	14/12	12:27:21	13:29:43	CS1412_4628_6
		X		14/12	13:32:39	14:31:18	CS1412_4628_7
			X	14/12	14:40:57	15:43:50	CS1412_4628_8
		X		12/12	14:14:35	15:14:26	SC1212_822
			X	12/12	15:24:55	16:26:43	C-S1212_822
	16-20		X	03/11	16:24:48	17:33:49	311
		X		03/11	17:39:59	18:58:21	S-C0311_824
		X		02/11	18:30:26	19:39:28	S-C0211
Weekends	16-18		X	29/10	16:00:49	16:58:57	C-S2910
		X		29/10	17:08:35	18:12:03	SC2910
	19-21		X	08/10	19:16:39	20:23:12	0810_822(2)
		X		08/10	20:25:28	20:25:28	0810_822
	17-20	X		04/09	17:30:32	18:32:10	S-C0409_4615_10
			X	04/09	18:42:33	19:43:02	C-S0409_4615_11
	9-12		X	11/12	10:07:27	11:08:20	C-S1112_822
		X		11/12	11:12:12	12:15:41	S-C1112_822

The above data were used to calculate the following variables for each stop:

- timeframe of opening/closing of doors: $T_{o/c}$ = timeframe between the opening of the first door and the complete closing of the last one, including the mechanical time to close the door;
- number of people boarding: N_B = total number of people getting on at the given stop;
- number of people alighting: N_A = total number of people getting off at the given stop;
- load factor: $\%_{occ}$ = ratio of the number of people on board to vehicle capacity (equal to 159 passengers);
- total trip time: T_{tt} = timeframe between the closing of the last door at the departure terminus and the opening of the first door at the arrival terminus;
- door usage percentage: D_{ib}, D_{ia} = ratio of total number of passengers at each stop boarding (b) and alighting (a) through the door (i), to total number of passengers at each stop boarding and alighting through all doors.

Even though the data collection through the on-board video-surveillance cameras allowed the manual acquisition of appropriate information, there are some external and internal methodological limitations:

- difficulties in obtaining desired specific CCTV registration disks due to a lack of full availability: damaged or malfunctioning hard-drives;
- poor visibility: the CCTV's camera position and framing were designed for security purposes, making them suboptimal for visualising and counting passengers.

Finally, occupancy, flow speed, parallel boarding, light refraction and low video quality made manual counting time-consuming, forcing the operator logging the information to watch the videos again (several times) to observe all the details useful to collect the needed data.

2.2 *Data analysis design and model specification*

The model specification, based on the relevant literature (Tirachini and Hensher, 2011; Zhang and Teng, 2013; Sun et al., 2014) is described in equation (1). Boarding and alighting have to be separately considered, since their associated times can be very different (TCQS Manual, 2013) as the mandatory smart-card validation concerns boarding passengers only. The time required by passengers to approach the vehicle when boarding will not be considered as all stops except the terminus provide a single loading area.

The relation between the dependent variable $T_{o/c}$ and the independent variables – number of people alighting, the number of people boarding and ridership percentage – has been studied thanks to a backward stepwise multiple regression analysis, where successive iterative estimates were computed after deletion of insignificant ($p>0.05$) regression coefficients, β_i. The model was defined as follows:

$$T_{o/c} = c + \beta_1 Nmax_a + \beta_2 Nmax_b + \beta_3 \%_{occ} + \beta_4 {Nmax_a}^2 + \beta_5 {Nmax_b}^2 + \beta_6 \%_{occ}^2$$
$$+\beta_7 Nmax_a Nmax_b + \beta_8 \times Nmax_b \%_{occ} + \beta_9 Nmax_a \%_{occ} + \varepsilon \qquad (1)$$

where:

- $T_{o/c}$ = timeframe of opening/closing of doors;
- c = intercept;
- $Nmax_a$ = number of people alighting through the most used door at the given stop;
- $Nmax_b$ = number of people boarding through the most used door at the given stop;
- $\%_{occ}$ = ridership percentage;

- β_i = regression coefficients associated with the independent variables, their quadratic measures and their respective pairwise interactions;
- ε = normally distributed error term.

The most used doors were identified by adding boarding and alighting passengers; thus, the maximum number of persons getting off and on through these doors is defined, respectively, as $Nmax_a$ and $Nmax_b$. Two different estimates of parameters were produced for weekdays and for weekends because the influence of the independent variables on $T_{o/c}$ is moderated by factors depending on the day of the week, notably trip scope, user habits and user typologies (TCQS Manual, 2013). To validate the model, the dataset has been split into a training sample (85% of the records) and a validation sample (15%) in order to test the good fit of the model.

2.3 *Definition and analysis of future scenarios*

For each of the selected bus trips, three scenarios were defined along with the current situation (S_0; two-way working doors and non-mandatory smart-card validation, values from previously manually recorded data); they are presented in detail in Table 2 and Figure 2. Indeed, the definition of scenarios has been conceived to identify the most efficient boarding procedure because GTT aims to understand if it is worthy to revise the current way to manage the boarding and alighting, also considering the introduction of mandatory smart-card validation.

Figure 2 depicts also the composition of dwell time, which is function of mechanical time to open and close the doors and it is constrained by the doors most used by passengers for alighting and boarding. In the Figure, door 3 mainly affects dwell time for S_0 and S_1, whereas door 1 is constraining dwell time for S_2 and S_3.

Table 2. Scenarios definition

	Mandatory smart-card validation	**Door 1**	**Door 2**	**Door 3**	**Door 4**
S_0	NO	Boarding and alighting	Boarding and alighting	Boarding and alighting	Boarding and alighting
S_1	YES	Boarding and alighting	Boarding and alighting	Boarding and alighting	Boarding and alighting
S_2	YES	Boarding only	Alighting only	Alighting only	Alighting only
S_3	YES	Boarding only	Alighting only	Alighting only	Boarding only

For the simulation of dwell time of scenarios S_2 and S_3, since the hypotheses consider one-way flows (see Table 2), the number of boarding and alighting passengers through each door were assigned as follows:

- Scenario S_2: all boarding passengers were associated with the front door (door 1) whereas those alighting from door 1 were equally redistributed through doors 2 to 4;
- Scenario S_3: passengers currently alighting through door 1 and boarding through door 2 were associated, respectively, with doors 2 and 1; those currently boarding through door 3 and alighting through door 4 were associated, respectively, with doors 4 and 3.

The data referred to the current situation (scenario S_0) allowed for the calculation of:

- total dwell time, by adding dwell time over all stops;

- total running time, by adding the timeframes when doors are closed;
- total trip time, by adding total dwell time and total running time.

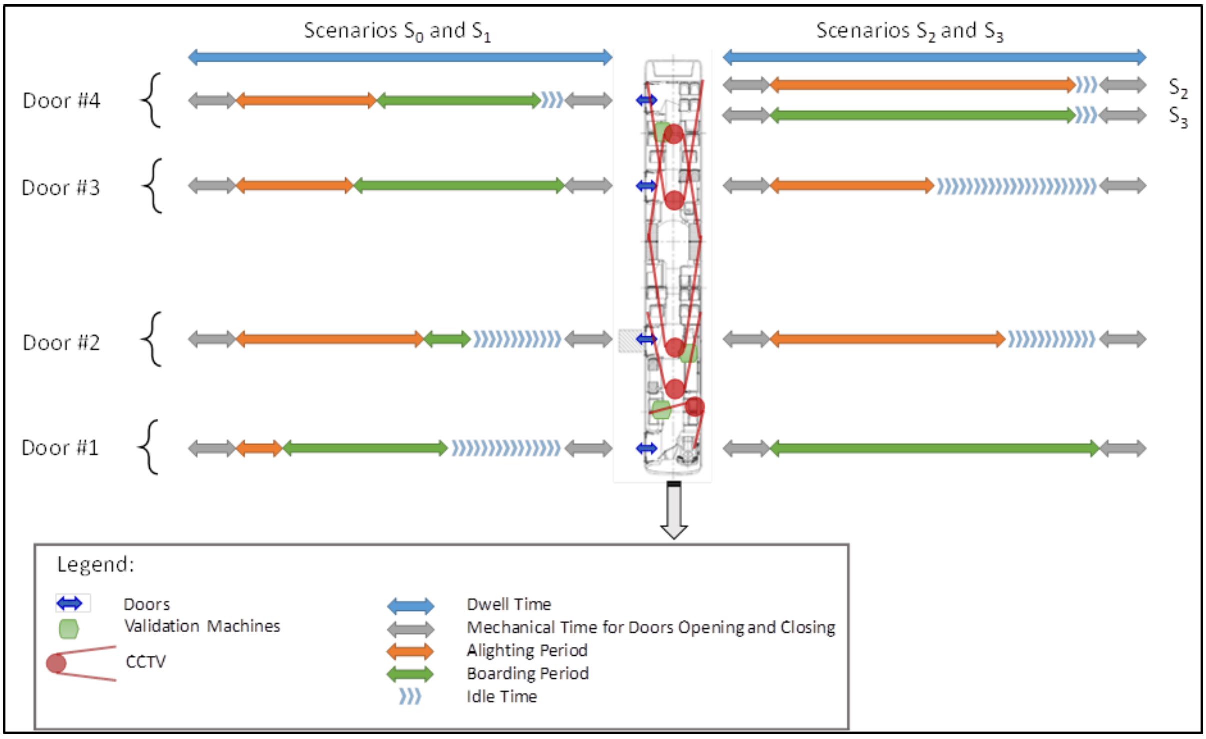

Figure 2. Position of doors, CCTVs and validation machines on board and composition of Dwell Time for each scenario.

The total dwell time will vary according to the scenarios, whereas the total running time is assumed to be constant throughout the different scenarios. Scenario S_0 is used to validate the regression model by matching computed total dwell time with the current situation. For scenarios S_1, S_2 and S_3 mandatory smart-card validation has been simulated by adding, to the β_2 estimate, a 1- to 3-second delay per person boarding; consequently, for each scenario, three sub-scenarios were compared (+1s, +2s, +3s); the reasons are:

- exact or estimated validation times taken from the literature were found to be irrelevant as they refer to specific and very diverse urban environments and transport systems, not suitable to Torino PT;
- validation time may present high variability as it depends on the type of travel documents (e.g. smart-card or single ticket) and on traveller speed (Tirachini and Hensher, 2011, Tirachini 2013a).

Afterwards, the necessary timeframes between the opening and the closing of each door were calculated and the simulated dwell time was assumed as time related to the door with the largest timeframe for each stop.

For each trip and scenario, the single dwell times and the total dwell times were simulated. By adding up the total dwell and running time, the commercial speed–for each trip and scenario–was calculated.

Trips were divided into subgroups corresponding to different headways, both during the week and the weekend, in order to identify the number of vehicles needed to maintain the current headways:

- weekdays:
  - from 7:00 to 9:00 6 minutes headway
  - from 9:00 to 16:00 7 minutes headway
  - from 16:00 to 20:00 8 minutes headway
- weekends:
  - Saturdays: 10 minutes headway Sundays:16 minutes headway.

Finally, according to GTT practice, dwell time is considered to be 5 minutes at the arrival terminus.

3. Results

Table 3 presents the main descriptive statistics (average value, minimum and maximum values, standard deviation) for dependent ($T_{o/c}$) and independent ($Nmax_a$, $Nmax_b$, $\%_{occ}$) variables included in the regression model, together with Total Trip Time, Total Dwell Time and Commercial Speed.

Table 3. Table 3: Descriptive statistics for main relevant variables.

	Average	Min	Max	S.D.
Total Trip Time [minute]	65.9	58.1	80.7	5.3
Total Dwell Time [minute]	8.3	5.4	14.9	1.9
Commercial Speed [km/h]	12.9	10.5	14.5	1.0
Dwell Time, $T_{o/c}$ [s]	12.4	0.0	61.0	6.4
$Nmax_a$	1.9	0.0	21.0	2.3
$Nmax_b$	1.9	0.0	17.0	2.2
$\%_{Occ}$	21.5	0.0	78.6	15.1

Regression analyses were carried out on data referring to both weekdays and weekends. Table 4 reports the model parameters as well as the corresponding standard errors (S.E.).

Table 4. Regression model parameters (weekdays and weekends).

	Weekdays		Weekends	
Adjusted R^2	0.497		0.378	
Y	β_i	S.E.	β_i	S.E.
c	7.060***	0.408	8.584***	0.550
$Nmax_a$	1.347***	0.157	1.030***	0.135
$Nmax_b$	1.627***	0.188	1.044***	0.290
$\%_{occ}$	-0.138***	0.032	–	–
$Nmax_a^2$	-0.031**	0.011	–	–
$Nmax_b^2$	-0.066**	0.021	0.081*	0.034
$\%_{occ}^2$	0.003***	0.001	–	–

$Nmax_a*Nmax_b$	-0.080*	0.036	–	–
$Nmax_b*\%_{occ}$	0.017**	0.006	–	–
$Nmax_a*\%_{occ}$	–	–	–	–

* significant at p <0.05; **significant at p <0.01; ***significant at p <0.001

The intercept estimate (c) is the timeframe during which the doors are open without passenger flow: such timeframe covers the mechanical time necessary for opening and closing the doors and the time taken by the operator between the last passenger boarding and the activation of the door lock device. The mechanical opening/closing time is nearly 6 seconds (3 for opening, 3 for closing) and the driver operation (door lock) can vary according to his/her alertness.

During the week, according to the model, alighting time per person is slightly lower (β_1= 1.347 s) than boarding time (β_2 = 1.627 s), which is consistent with the current literature. The negative coefficients of the squared values of the number of people boarding (β_5= -0.066) and alighting (β_4= -0.031) signify a decrease of marginal (boarding or alighting) time with the increase of passengers going through doors, or, mathematically, that the second derivative of time is negative. Thus, dwell time at crowded stops will be less affected by the presence of additional travellers than dwell time at less crowded stops. Although this is reasonable for most situations, it could be more questionable in case of overcrowding; but such situation has never occurred even in the worst periods (see Table 3: Max[$Nmax_b$] =17). Then, the load factor has a non-linear effect on dwell time (β_3= -0.138, β6=0.003) that drops digressively when loadings increase.

The interaction between the number of alighting and boarding passengers leads to a reduction of the dwell time (β_7= -0.080); this effect can be explained by assuming there are parallel flows of people getting on and off, allowed by the width of the doors. On the contrary, the interaction between the number of boarding passengers and the load factor increases the boarding time (β_8 =0.017); this is consistent with the notion of friction between boarding and on-board passengers.

During the weekends, fewer variables influence the boarding time and the coefficient of multiple determination is lower than for weekdays. This is certainly due to the small sample size (N=8) used for weekends parameters estimation. For this reason, the reliability of the values obtained for weekends is weaker than for weekdays; on Saturdays and Sundays the average time per passenger is lower than for weekdays and very similar for boarding (β_2= 1.04 s) and alighting (β_1=1.03 s). The fact that people are faster getting on or off during the weekend may seem counter-intuitive; furthermore, during weekends, we observe an increased marginal time per boarding passenger, significant (p-value <0.05) even though quite small (β_5=0.08). Indeed, considering the second-order effects of $Nmax_b$, when more than three passengers are boarding, boarding periods for weekends are higher than those during weekdays.

Finally, on weekends, loadings do not have a significant impact on dwell time. The first hypothesis was that vehicle loadings are lower during weekends than during weekdays, explaining why the regression model was insensitive to passenger flow variation. However, after comparing average loadings over single trips for both periods, no significant difference was observed, thus conflicting with the first hypothesis.

Figure 3 and 4 and Table 5 show the main results for the different scenarios, focusing on the change of commercial speed ($V_{comm,}$ Figure 3) and, consequently, on the number of vehicles required (Figure 4) to avoid an increase of the waiting time at the bus stop.

The simulation of scenario 0 (two-way working doors and non-mandatory smart-card validation) well represents the current situation very well, revealing the good fit of the model. The computed Total Dwell Time (TDT) slightly differs from the current scenario: the maximum difference (-2.69%) is recorded for the weekdays from 09:00 to 16:00. The predicted commercial speed fits the current one well, showing a maximum difference of +0.34%, recorded for the same time slot (weekdays, 9:00-16:00). Observed and simulated TDT range from 11% (morning period) to 15% (Sunday) of the total trip time, confirming the lower impact of TDT during peak time, as consistent with state-of-the-art literature (TCQS Manual, 2013).

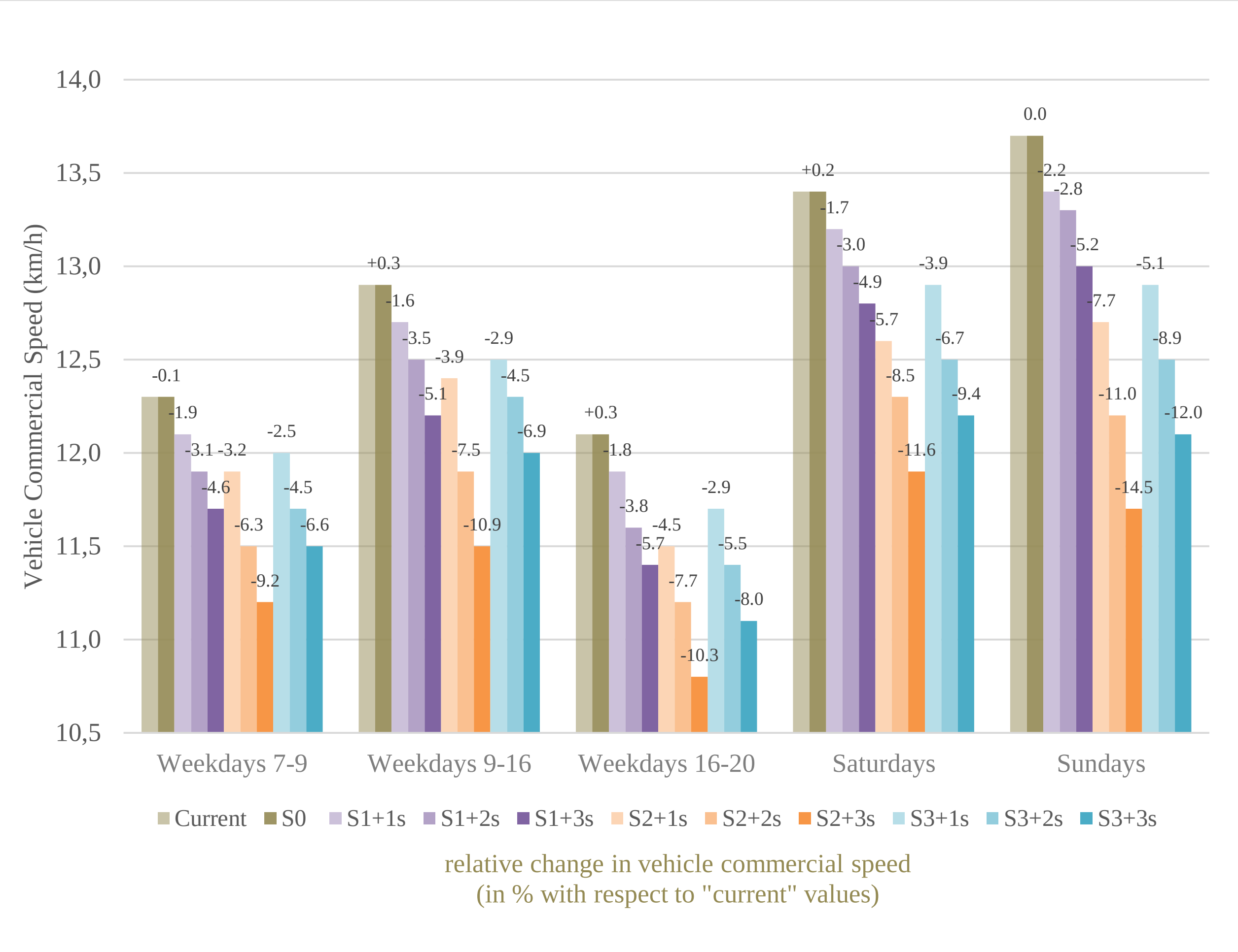

Figure 3. Vehicle commercial speed and its relative change for different sub-scenarios.

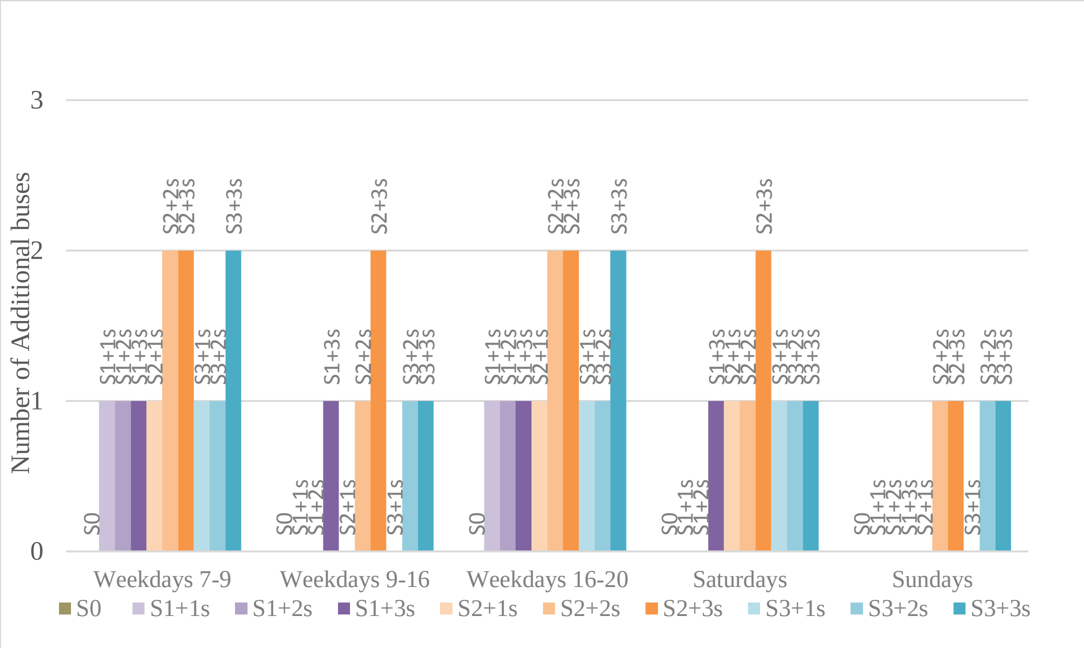

Figure 4. Number of additional vehicles in different sub-scenarios to maintain existing headings.

The good fit of the model justifies its use to estimate the effects of mandatory validation on the different scenarios. Scenario 1 (two-way working doors and mandatory smart-card validation) is slightly critical, notably in the two peak-periods (07:00 - 09:00 and 16:00 - 20:00), when all sub-scenarios would require a supplementary vehicle in order to avoid an increase of the waiting time. The worst sub-scenario (+3 s/pax to validate) causes a non-negligible decrease of the commercial speed (> -4.5%) for all the considered periods. Nevertheless, such a scenario would not affect the operational requirements to satisfy the demand on Sunday. In fact, although the +3s sub-scenario causes a considerable decrease of the commercial speed (-5.15%, the second highest value in S_3), the number of vehicles currently used in this time period allows such a drawback to be overcome, avoiding adding another one, as required for the other periods. For the S_1+3s scenario, the share of TDT on total trip time increases from 15% (morning period) to 17% (afternoon and evening period) and to 19% for the weekend. Scenario 2 (boarding from the front door only, mandatory smart-card validation and alighting through all other doors) is the most critical one, requiring at least one supplementary vehicle for all time periods and sub-scenarios, except for the "+1s" scenario in the off-peak period during the week and on Sunday.

In this latter case the decrease of commercial speed is important (-7.68%), but the number of vehicles currently used in S_0 would allow the current headway to be maintained. The most serious deficiencies would clearly occur in the "+3s" sub-scenario: a) two supplementary vehicles needed for all time-periods except Sunday, despite the great decrease of commercial speed (-14.5%); and b) the highest impact of the simulated TDT on the total trip time (27%) for the two peak-periods on the weekdays, when two supplementary vehicles would also be required in the "+2s" sub-scenario. The “+1s” sub-scenario of S_3 (boarding from the front and the rear doors, mandatory smart-card validation and alighting through middle doors) would not require any supplementary vehicle as regards the two similar cases of “S_{2+1s}”: the off-peak period on weekdays and on Sunday. The same cannot be said of the "+3s" sub-scenario, which would require two supplementary vehicles to avoid any increase in the waiting time at the bus stop during the morning and evening peak-periods on weekdays.

Table 5. Results of simulations of the different scenarios

		Current	S_0	S_1+1s	S_1+2s	S_1+3s	S_2+1s	S_2+2s	S_2+3s	S_3+1s	S_3+2s	S_3+3s
Weekdays 7-9	TDT [minute]	7.7	7.8	9.0	9.9	11.0	10.0	12.3	14.7	9.4	10.9	12.5
	Δ TDT/current mean		1.2%	16.9%	28.6%	43.1%	29.8%	60.1%	91.1%	22.6%	42.0%	63.3%
	Total trip time [minute]	68.7	68.8	70.0	70.9	72.0	71.0	73.4	75.7	70.5	72.0	73.6
	Vcomm [km/h]	12.3	12.3	12.1	11.9	11.7	11.9	11.5	11.2	12	11.7	11.5
	Δ Vcomm/current mean		-0.1%	-1.9%	-3.1%	-4.6%	-3.2%	-6.3%	-9.2%	-2.5%	-4.5%	-6.6%
	N. veh. (+additional buses)	25	25 (+0)	26 (+1)	26 (+1)	26 (+1)	26 (+1)	27 (+2)	27 (+2)	26 (+1)	26 (+1)	27 (+2)
Weekdays 9-16	TDT [minute]	8.1	7.9	9.2	10.5	11.7	10.8	13.4	16.1	10.1	11.2	13.0
	Δ TDT/current mean		-2.7%	13.0%	28.8%	43.7%	32.5%	65.3%	98.1%	24.1%	37.5%	59.7%
	Total trip time [minute]	3929.60	65.5	65.3	66.5	67.8	69.0	68.1	70.8	73.5	67.5	68.5
	Vcomm [km/h]	12.9	12.9	12.7	12.5	12.2	12.4	11.9	11.5	12.5	12.3	12
	Δ Vcomm/current mean		0.3%	-1.6%	-3.5%	-5.1%	-3.9%	-7.5%	-10.9%	-2.9%	-4.5%	-6.9%
	N. veh. (+additional buses)	21	21 (+0)	21 (0)	21 (+0)	22 (+1)	21 (+0)	22 (+1)	23 (+2)	21 (+0)	22 (+1)	22 (+1)
Weekdays 16-20	TDT [minute]	8.3	8.1	9.6	11.1	12.5	11.6	14.1	16.9	10.4	12.4	14.4
	Δ TDT/current mean		-2.4%	15.5%	33.4%	51.3%	39.8%	69.8%	103.4%	25.2%	49.1%	73.4%
	Total trip time [minute]	69.9	69.7	71.2	72.7	74.2	73.2	75.7	78.5	72.0	74.0	76.0
	Vcomm [km/h]	12.1	12.1	11.9	11.6	11.4	11.5	11.2	10.8	11.7	11.4	11.1
	Δ Vcomm/current mean		0.3%	-1.8%	-3.8%	-5.7%	-4.5%	-7.7%	-10.9%	-2.9%	-5.5%	-8.0%
	N. veh. (+additional buses)	19	19 (+0)	20 (+1)	20 (+1)	20 (+1)	20 (+1)	21 (+2)	21 (+2)	20 (+1)	20 (+1)	21 (+2)
Saturdays	TDT [minute]	9.1	9.0	10.2	11.0	12.3	12.9	14.9	17.3	11.6	13.6	15.6
	Δ TDT/current mean		-1.3%	12.3%	21.4%	35.3%	42.2%	64.0%	90.9%	28.2%	49.7%	71.7%
	Total trip time [minute]	63.0	62.9	64.1	65.0	66.2	66.8	68.8	71.3	65.6	67.5	69.5
	Vcomm [km/h]	13.4	13.4	13.2	13	12.8	12.6	12.3	11.9	12.9	12.5	12.2
	Δ Vcomm/current mean		0.2%	-1.7%	-3.0%	-4.9%	-5.7%	-8.5%	-11.6%	-3.9%	-6.7%	-9.4%
	N. veh. (+additional buses)	14	14 (+0)	14 (+0)	14 (+0)	15 (+1)	15 (+1)	15 (+1)	16 (+2)	15 (+1)	15 (+1)	15 (+1)
Sundays	TDT [minute]	9.0	9.0	10.4	10.8	12.4	14.1	16.6	19.5	12.7	15.0	17.4
	Δ TDT/current mean		0.0%	15.6%	19.7%	37.2%	56.9%	84.4%	116.0%	40.6%	66.6%	92.7%
	Total trip time [minute]	61.7	61.7	63.1	63.4	65.0	66.8	69.3	72.1	65.3	67.7	70.0
	Vcomm [km/h]	13.7	13.7	13.4	13.3	13	12.7	12.2	11.7	12.9	12.5	12.1
	Δ Vcomm/current mean		0.0%	-2.2%	-2.8%	-5.2%	-7.7%	-11.0%	-14.5%	-5.6%	-8.9%	-11.9%
	N. veh. (+additional buses)	9	9 (+0)	9 (+0)	9 (+0)	9 (+0)	9 (+0)	10 (+1)	10 (+1)	9 (+0)	10 (+1)	10 (+1)

In this case, the share of TDT on total trip time varies from 17% in the morning period to 25% on Sunday. For all other sub-scenarios, only one supplementary vehicle would be needed. The observed values of the average commercial speed differ according to the different time periods, due to the change of both running time (mainly affected by traffic conditions) and dwell time. The lowest commercial speed is observed in the evening peak-period, followed by the morning period, the weekday off-peak period and, finally, Saturday and Sunday. For the different scenarios, the commercial speed varies only in function of the dwell time which, in turn, depends on the different use of the doors and on the different delays considered for mandatory validation.

4. Discussion and conclusions

The regression model offers a good estimate of dwell times, notably for weekday trips, and the estimates of boarding and alighting times per passenger are consistent with the existing literature

- results for weekdays show a dwell time equal to 7 seconds idling time plus 1.627s per boarding passenger; Levinson (1983) proposed considering 5 seconds idling time plus 2.75s per boarding or alighting passenger;
- Sun et al. (2014) found that high occupancy slows down boarding; the estimate of interaction between the number of boarding passengers and load factor confirms this phenomenon;
- estimates of boarding time (1.627s) and alighting time per passenger (1.347s) are remarkably close to values suggested by the TCQS Manual (2013): 1.75s per boarding passenger and from 1.2 to 2.2 s per alighting passenger. These values are proposed for a situation with two available doors, comparable to the analysed situations.

Observed data highlight that in the current situation, with two-way working doors, the passengers prefer both to board and alight through doors 2 and 3 (which together account for 65% of the total flows, mainly for alighting), while doors 1 and 4 are less used and mainly for boarding. This may be due to the bus layout, which has less space in the front, due to the driver cabin and to the shelter location at stops. The length of the bus (18 m) may explain lower use of door 4, which is sometimes less accessible from the platform.

The results from the scenario simulations will allow GTT to carry out an economical evaluation and take the best decision in order to satisfy both operational and users' needs. From the Company's point of view, the most critical scenarios would be the ones entailing the abolition of two-way working doors (S_2 and S_3), particularly if the boarding would then be allowed only through one door (S_2). The company should indeed increase the number of circulating buses in order to guarantee the same level of service. However, such a change may lead to positive consequences, such as a tidier boarding process and a greater propensity to validate, since in S_2 the boarding would occur only through the door next to the driver. The Company could benefit from a lower fraud rate and its public image would benefit from that. Furthermore, the introduction of canalised flows would encourage the passengers to occupy areas currently underused, such as corridors and the inner parts of the buses. As a consequence, crowding would decrease in the door areas, creating less friction among the passengers during boarding and alighting.

The variation of the number of buses needed depends on validation time: the same number of buses is required both for Scenario 2 (boarding through the front door – door 1) with 2 s of validation time and for Scenario 3 (boarding through doors 1 and 4) with 3 s of validation time.

The suppression of two-way working doors could be quite unfavourable, particularly if implemented together with the introduction of mandatory validation. Passengers who are still not used to the new practice, may take a rather long time to validate. Considering the lack of precise data related to the effective validation time, the choice to keep the two-way working doors would need more thought, perhaps requiring an initial test period to evaluate the magnitude of the impact produced by the validation.

In fact, a test period would allow the real changes produced by mandatory validation to be assessed and also, notably, precise data about the average validation time to be collected. Afterwards, the introduction of channelled flows may be considered and possibly tested. Of course, the different proofs-of-payment which may be used for validation entail different validation times and, thus, different Total Dwell Times. Tirachini (2013a) proved that, compared to the absence of validation, the increase of the boarding time varies from 1% to 17% with the use of a smart card, from 26% to 77% with the use of a magnetic card, and from 241% to 619% with on-board payment. Compared to the magnetic card, the use of a smart card allows saving from 22% to 51% of boarding time (Tirachini, 2013a). Another way to mitigate the undesired effects of the new policy would be to introduce off-board validation, which, however, would compromise data collection from smart-card validations as the line number would not be recorded anymore.

The study has highlighted the great importance of having precise data concerning passenger counts. This information, used to analyse the dwell time, allows transport companies to partially understand their user habits and the effective use of the PT service; these are, of course, key elements for proper and efficient management of the transport system. To this extent, it would be crucial to take advantage of more efficient and automatic data collection methods, given the problems faced during the manual data collection.

Sensitivity analysis about the influence of validation time on dwell time performed in this paper could be adopted by practitioners as a methodology in those contexts, like Torino, where inaccuracy about some relevant variables is high.

For the time being, GTT has introduced mandatory validation and it is trying to encourage users to validate by means of an intensive advertising campaign. Estimates from the Company show that less than 20% of passengers validate. Such a figure reflects the difficulty users experience when the buses are crowded, discouraging virtuous behaviour. From the city’s perspective, the introduction of mandatory validation is expected to trigger more revenue from tickets sales and less free ridership thanks to social control over the validation. Indeed, the City being the owner of GTT, both a lower financial contribution and a lower dependency on transport authority subsidies would alleviate the current expenditures, which are continuously challenged due to the decrease of regional funds. Nevertheless, the decrease of commercial speed will require a greater number of vehicles in order to maintain a constant waiting time at stops, implying that the service must be optimised to tackle the current budget restrictions. However, the mix of mandatory validation with other policies such as traffic priority schemes for PT services, can induce an increase in the quality of service in the coming years.

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