

Train Dwell Time Models for Rail Passenger Service

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Abstract. In recent years, more studies had been conducted about train dwell time as it is a key parameter of rail system performance and reliability. This paper draws an overview of train dwell time models for rail passenger service from various continents, namely Asia, North America, Europe and Australia. The factors affecting train dwell time are identified and analysed across some rail network operators. The dwell time models developed by various researches are also discussed and reviewed. Finally, the contributions from the outcomes of these models are briefly addressed. In conclusion, this paper suggests that there is a need to further study the factors with strong influence upon dwell time to improve the quality of the train services.

1 Introduction

Rail transport is growing continuously and is becoming the preferred mode for land public transport in both developing and developed nations due to its sustainability [1]. As the facilities for railway transport continue to expand and improve, this has become a pulling force for the public to use the railway transport as the preferred choice for public transport. However, the quality of service, particularly its reliability is also a determining factor in the public's choice of mode. Train punctuality is a very important aspect of the reliability of the service. The perceived utility of the system will definitely decrease if trains are late or cancelled very often [2]. According to Puong [3], dwell time is a key parameter of system performance, service reliability and quality in any mode of public transportation. Over the years, more researches had been conducted about train dwell time. The following highlights the importance of dwell time studies: i) Dwell time studies gives insight into the travel time and headway variations and can produce effective timetables; ii) With known parameters affecting dwell time, efforts can be made at critical stations to reduce dwell time.

2 Factors Affecting Dwell Time

Train dwell time is the time a train stands at the platform usually for the purpose of allowing passengers to board or alight [4]. It is devoted to the loading and unloading processes of the train, along with door opening and closing processes. Thus, boarding and alighting at stations are likely the most significant factors causing dwell time variations.

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Kraft, in his studies on street transit systems highlighted seven main categories of factors affecting dwell time: human, modal, operating policies, operating practices, mobility, climate and other system elements [5]. Each of these factors was further subdivided into selected areas for analysis and where possible, the effects of each of the factors on dwell time were quantified by the author. In a more recent report, Douglas categorised the factors affecting dwell time into five categories, which are passenger volume, passenger profile, train design, station design and operational factors [4].

Passenger volume, which refers to the number of passengers alighting and boarding a train, is considered as the main factor influencing its dwell time. The dwell time is determined by the number of passengers alighting and boarding and the speed at which they alight and board. Mixed flow of passengers tends to lengthen the time of dwell time as compared to uni-directional flow. Based on Weston's model, 35 s is needed for 40 passengers per door to alight or board (uni-directional) but the dwell time increases to 40 s for a mixed flow of 20 alighting and 20 boarding passengers [6]. Similarly, Douglas' model showed that a mix flow of 30 alighting and 30 boarding passengers requires 40 s compared to 60 alighting or boarding passengers which require between 25 to 35 s [4]. A high number of standing through-passengers is also likely to slow down the speed of boarding and alighting. Puong highlighted that for when there are 5 and above standing through-passengers (per door) on board, the marginal boarding time will increase significantly [3]. Douglas estimated that dwell time will increase by 9 s when there are 30 alighting and 30 boarding passengers with 20 standing through-passengers (per door) on board [4]. Passenger profile also has an effect on dwell time. Passengers with strollers or luggage and those who require special assistance (visually impaired and on wheelchairs) would extend the process of boarding and alighting [4] but it is uncertain as to how much the dwell time is affected. Regular passengers may alight slightly faster than those who are irregular and unfamiliar with the stations [4] but this is difficult to quantify as the distinction between regular and irregular travellers is not very obvious.

Train design also influences boarding and alighting times. The number of doors and their width will affect the alighting and boarding speed. Wider doors enable more passengers to board and alight, thus increase the rate of boarding and alighting process, though it may take slightly longer for the doors to open. Wider doors lead to 10% shorter times and narrower doors to 10% longer times than the mean value [7]. For trains with a minimum door width of about 80 to 90 cm, increasing the door width only results in a moderate increase in passenger flow rate [8]. This is because the passengers do not usually utilise the whole door width, especially if a queue is formed. A wider door only transfers the problem of congestion further into the train as narrow sections further into the train gradually becomes limiting factors for the passenger flow rate. The vertical distance between the platform of the station and the floor of the train heavily influences the dwell time. Heinz found out that there is no great difference between level entrance and 2-steps, particularly for passengers without any luggage but for passengers carrying luggage or with some form of impairment, the difference became apparent. For trains with 3 steps, the boarding and alighting times increased for all categories of passengers studied. He also found out that for horizontal distances, gaps of less than 5 cm, did not affect passengers while for gaps above 15 cm, passengers needed to adjust their step, and this cost a little more time [8].

Dwell times are also influenced by the design of stations. Narrow platforms become crowded easily, especially during peak hours [4]. The number, capacity and location of stairs, escalators and lifts influences the distribution of waiting passengers along the platform and hence the boarding time for trains. The timetable, which is an operational factor determine the length of dwell time, especially if the station is a timed stop. Trains arriving early will have longer dwell times so they don't depart before the scheduled time. At interchange stations, longer dwell times may be required to allow for trains to connection.

3 Previous Dwell Time Models

Various models had been developed by researchers to study the dwell times of trains of rail passenger services. One of the earliest train dwell time models was found to be a model developed by

Wirasinghe & Szplett (1984) for Calgary LRT [9]. Referring to Table 1, three separate equations were produced based on the percentage of boarders for a train. The coefficients for alighting passengers ranged from 0.4 s to 1.4 s per passenger, whilst the coefficients for boarding passengers ranged from 1.4 s to 2.4 s per passenger, where the lowest of each coefficient is found to be within the alighting and boarding category ($0.33 \leq \psi \leq 0.66$). Thus, the authors have proven that the number platform entrances and “friction” between boarding and alighting passengers have significant effect on dwell time and that dwell time should not be determined simply by using the average demand per door [9].

Table 1. Predictive equations for dwell time.

Group description (ψ = fraction of boarders)	Predictive equation $t = l + \lambda(a) + \mu(b)^*$
Exclusive or dominant alighting $\psi \leq 0.32$	$t = 2 + 1.0(a) + 2.4(b)$
Alighting and boarding $0.33 \leq \psi \leq 0.66$	$t = 2 + 0.4(a) + 1.4(b)$
Exclusive or dominant boarding $\psi \geq 0.67$	$t = 2 + 1.4(a) + 1.4(b)$

* l = lost time (s)

λ = average time per passenger to alight (s)

μ = average time per passenger to board (s)

a = average demand per door for alighting

b = average demand per door for boarding

In 1989, Weston established a model for London Underground Ltd [8], which was later used as a main reference by many other researchers. He had incorporated a great number of variables into the model. As shown in Equation (1), the variables were number or boarding and alighting passengers, number of doors, peak door and average door factor, number of seats and the number of through passengers. Weston used a constant of 15 s for the process of door opening and closing, and for power to be applied for acceleration. However, the value should vary by rolling stock type and door type. The dwell time estimated increases with the number of passengers boarding and alighting but at a declining rate. This model therefore incorporates an ‘alighting/boarding congestion effect’. The additional time needed in the event of a mixed flow (boarding and alighting at the same time) is also accounted for in the model.

$$SS = 15 + 1.4 \left[1 + \frac{F(T - S)}{35D} \right] \cdot \left[\left(\frac{FB}{D} \right)^{0.7} + \left(\frac{FA}{D} \right)^{0.7} + \left(0.027 \left(\frac{FB}{D} \right) \left(\frac{FA}{D} \right) \right) \right] \quad (1)$$

where SS = station stop time (s), A = number of alighting passengers per train, B = number of boarding passengers per train, D = number of doors, F = peak door/average door factor, S = number of seats, and T = number of through passengers.

In 2007, Harris & Anderson applied the same model to estimate dwell times of metros and suburban railways around the world. They concluded that despite parameters had to be varied slightly, “Weston’s formula for estimating dwell time appears to have validity around the world, and the overall structure of the approach appears sound” [10].

Lam et al. [11] conducted a study on train dwell time at the Hong Kong MTR system. They established regression models for dwelling delays due to congestion and developed a simulation model to assess the reliability of the estimated train dwell time. This model is a combination of three separate models developed based on data collected at three different stations. When comparing these three models, it was found that the constants and the coefficients for the number of alighting and boarding passengers were in the same order and of approximate value. Therefore, a generalised model that includes a fixed time for doors opening and closing, and the number of boarding and alighting passengers per train was produced (refer to Equation (2)). Lam et al. [11] also highlighted that dwell time does not increase infinitely with the increase of passengers as the train headway governs the maximum allowable dwell time of trains, which is around 3 minutes in Hong Kong.

$$DT = 10.5 + 0.021A + 0.016B \quad (2)$$

where DT = train dwell time (s), A = number of alighting passengers per train, and B = number of boarding passengers per train.

Puong [3] developed a model to analyse dwell times for the Massachusetts Bay Transport Authority (MBTA) in Boston based on an observation of 54 dwell times of trains with three or four single doors per carriage. All dwell times observed were below 90 s. He estimated that there was a constant of about 12 s for the process of door opening and closing and train starting. For each boarding and alighting passenger at a door, it was estimated that 2.27 s and 1.82 s was required respectively. The presence of standing through-passengers has no effect on the dwell time (specifically boarding time) if there were only 5 or below. But if there were more than 5, its effect is at cubed rate, as can be seen from Equation (3).

$$DT = 12.22 + 2.27B_d + 1.82A_d + 0.00062TS_d^3B_d \quad (3)$$

where DT = train dwell time (s), A_d = number of alighting passengers per door, B_d = number of boarding passengers per door, and TS_d = number of standing through-passengers per door.

Douglas was tasked by Transport for New South Wales (TfNSW) to review alternative ways of calculating train dwell time [4]. As a conclusion, Douglas established a model to predict train dwell time for RailCorp in Sydney. In his model (refer to Equation 4), the variables included were number of boarding and alighting passengers per door and the number of standing through passengers per door. He also estimated the function time to be 10 s. A power function of 0.7 gave a better fit than a linear function for both alighting and boarding. There was consideration for mixed flow of passengers and crowding caused by standing through passengers in the model. The best fit variable for standing through passengers was a linear function that multiplied standing passengers by the combined total of boarding and alighting passengers.

$$DT = 10 + 1.9A_d^{0.7} + 1.4B_d^{0.7} + 0.007(A_d + B_d)(Std_d) + 0.005(A_d \cdot B_d) \quad (4)$$

where DT = train dwell time (s), A_d = number of alighting passengers per door, B_d = number of boarding passengers per door, and Std_d = estimated number of standing through-passengers per door.

4 Comparing Dwell Time Models

These five studies show how dwell time data can be used to develop a model to calculate dwell times according to passenger volumes. The model by Wirasinghe & Szplett was one of the earliest dwell time models established and proved that “friction” due to a mixed flow has a significant effect on dwell time and that dwell time should not be determined simply by using the average demand per door. This conclusion proved to be an important basis for models developed thereafter. When Weston

came out with his model 5 years after Wirasinghe & Szplett, he managed to include the parameters found in Wirasinghe's model and further improved it by including a parameter for crowding effect.

Generally, all five studies agree that the increase of passenger volumes increase the dwell time of trains at stations, though at different rates due to factors such as door widths, platform gaps and movement of passengers. The model by Weston was non-linear and predicted that dwell times increased but at a decreasing rate as total of boarding and alighting increased. By contrast, the passenger dwell times in models by Lam, *et al.* and Puong increased proportionally. It is considered that the Weston formulation is more realistic especially for boarding time. Similarly, Douglas' model is also considered more realistic as he had adopted Weston's model.

The models by Weston, Puong and Douglas allowed for dwell times to increase with on-board train crowding. In Weston's model, a factor for excess demand compared to seats was applied that increased boarding and alighting times. Douglas's model also indicates that on-board train crowding increased the times for boarding and alighting. In comparison, the effect of on-board train crowding is only significant when there are more than 5 passengers per door in Puong's model. A summary of parameters included in the four models discussed is shown in Table 2.

Table 2. Parameters included train dwell time models.

Model	Parameters			
	Passenger volume	Mixed flow effect	Crowding effect	Others
Wirasinghe & Szplett Model (1984)	Yes	Yes	No	Yes
Weston Model (1989)	Yes	Yes	Yes	Yes
Lam et al. Model (1998)	Yes	No	No	No
Puong Model (2000)	Yes	No	Yes	No
Douglas Model (2012)	Yes	Yes	Yes	No

Referring to Table 2, it is clear that the models developed by Weston and Douglas are the best as they have included the three most influential parameters, namely passenger volume, mixed flow effect and crowding effect, though the model by Douglas is a simplified version of Weston's model. The Weston model can be considered as most relevant as it has been applied by Harris & Anderson on dwell time data for metros and suburban railways around the world.

5 Contributions of Dwell Time Models

The dwell time model established by Weston had later been tested by Harris & Anderson on over 30 railways around the world. Thus, the dwell time model could be applied to railways around the world but with adjustments to the parameters involved. Lam's model provides a reasonable estimate for the average train dwell time at MTR stations, and the reliability analysis can be used to give a reliable range for the estimated train dwell time for assessment.

The model by Puong uncovered the effect of on-board crowding on boarding times for the stations. This model enabled critical stations to be identified for maintaining high-frequency service during peak periods. The dwell time model by Douglas could be extended into a forecasting model for a

particular line by inserting initial timetable data and patronage forecasts. It can also predict boarding, alighting and on-board passenger loads for each station along the route for an individual service.

6 Conclusions

Dwell time is a key parameter of system performance, service quality and reliability in the rail passenger service. With known factors affecting dwell time, the dwell time at critical stations could be minimised, thus reducing the headway variations and enhancing service quality and reliability. All five models studied in this paper agree that dwell time is very much influenced by the passenger volume, though at different rates due to factors such as door widths, platform gaps and movement of passengers. A mixed flow of passengers and on-board crowding are also expected to increase dwell time.

From this paper, the numbers of alighting, boarding and standing through-passengers were found to be most influential and are dominant parameters for developing dwell time models. It is recommended that further research be conducted to study on train on-board crowding and how the different types of passengers affect the boarding and alighting time, which affects the dwell time of a train.

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