

Train dwell time models – development in the past forty years

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Abstract

The accuracy of dwell time estimation is crucial for both tactical and operational practices of public transport. This paper aims to make a systematic review of the dwell time models that have evolved over the past 40 years. The scope of this study is limited to the dwell time models pertaining to the passenger rail. Studying the literature concerning train dwell time models, similarities and differences were analysed and discussed based on the modelling approaches and assumptions made in the development of the models. For instance, models were categorised based on modelling philosophy, time-period, key variables involved, data collection and validation methods. Through the comparison, common interests and future trends were then identified. It is found that there is no perfect model that fits all scenarios. The best outcome relies on the effort of choosing the most appropriate model, calibrating the parameters, making some ad-hoc adjustment and continual improvements.

1 Introduction

Travelling by train has becoming an increasing popular choice of public transport mode in Victoria. According to Public Transport Victoria Annual Report 2017-18 document (PTV, 2018), metropolitan train patronage in 2017-2018 financial year has reached to 240.9 million, which is an increase of 1.7% as compared to 236.8 million in 2016-2017 (PTV, 2017). With the increasing train patronage, a more efficient and safer rail network is a priority for railway operators. However, improvement on rail infrastructure generally requires huge financial investment. Besides, those projects often take relative long time to plan and execute. Managing and reducing train dwell time is proposed by several researchers (Perkins et al., 2015, Karekla and Tyler, 2012) as one of the potential solutions to improve the operations of railway in a timely manner and more cost-effective way.

Over the time, many models have been proposed to gain understanding of the dwell time performance. Understanding how dwell time can be varied is very important at both tactical level and operational level.

Despite many dwell time models for railways that have emerged in the literature over the last four decades, there are limited studies on the state-of-art of the dwell time models. Therefore, the aim of this study is to review the progress made on the train dwell time models over the past forty years. Detailed review and analysis of the

existing train dwell time models are presented in section 2, followed by an overall conclusion and recommendations in section 3.

2 Literature review

This section provides a thorough review of train dwell time modelling and its applications. To the best of author's knowledge, the earliest paper found discussing about train dwell time was published in 1983. Therefore, the review period was set from the 80's to date.

As a matter of fact, Fritz (1983)'s study focus was on the passenger boarding rates and boarding time, which is believed to be as key component of dwell time. This paper and other papers published in the later years modelling boarding/alighting rates or time would fall within the boundary of this review since those boarding or alighting models can be treated as a sub model of the train dwell time model.

Other dwell time models found in the earlier publications were mainly motivated by studying the bus network. Since bus dwell time or some specific type of light rail can be greatly influenced by on-road traffic and/or individual driver's behaviour, which may result in different parameters being considered in the modelling process, those literature is not included in this review. Therefore, papers published since the 1980s discussing either train dwell time model as a whole or sub models of the train dwell time were reviewed and discussed based on modelling approach and other aspects as specified in the following sections.

2.1 Dwell time definition and key components

Going through the relevant literature, it is noticed that the term "Dwell Time" is not clearly defined in the nineteenth century. Koffman et al. (1984) did a study on the light rail car trip of the MBTA Green Line. The record of "Total time train stopped" was marked as "dwell time". Lam et al. (1998) described dwelling time as "the duration between the train doors start to open and close completely". Apart from these two, all other researchers' publications found before year 2000 failed to provide a proper definition. Fernández et al. (2008) used the term Passenger Service Time (PST) instead. They defined PST as "the time that a public transport vehicle remains stopped transferring passengers", which describes the same concept as dwell time.

Looking through the literature published in the specified time period, it is found that dwell time is also known as Passenger Service Time, Train Loading Time, Train Standing Time, Train Staying Time, Station Stop Time, or Stop Time at Platform. It is worth pointing out that Transport Research Board Highway capacity Manual (TRB, 2000) defined dwell time in the glossary as "the time a transit unit (vehicle or train) spends at a station or a stop, measured from stopping to starting", which has become a well-accepted definition in this century. However, the above definition is not deemed official. Different researchers may have slightly different interpretations and focuses. Some treated dwell time as the passenger related dwell time, meaning the time that passenger utilise for boarding/alighting, while neglecting other function time such as the time for door opening/closing. Others took dwell time as more relating to station dwell time.

We might be able to tell the differences more easily by looking at how the dwell time were decomposed.

To start with, Wirasinghe and Szplett (1984) suggested to consider 2 main components. One is the constant function time, which is the time for door opening and closing. The other one is the maximum door utilization time, which is the time for passenger boarding and alighting among all doors. Lam et al. (1999) suggested 2 similar components T_m and T_u , where T_m is the fixed time for door to function, and T_u is the door utilisation time for the boarding/alighting process.

Parkinson and Fisher (1996) suggested 3 components: time of passenger flow, time of doors still open, and time of train waiting for departure. They started counting the dwell time when passenger flow started. However, the time for the train to come to a complete stop to the time passengers got ready for boarding was neglected in this study. Similar to Parkinson and Fisher, Wiggeraad (2001) divided dwell time into similar components: alighting and boarding time, unused time and dispatching time. Goverde (2005) also proposed three components, with the last 2 components identical to the previous studies. However, he introduced the minimum dwell time as the first component which includes 2 sub components, i.e. door opening time and boarding and alighting time.. Buchmüller et al. (2008) further divided dwell time into five components: DU as door unblocking, DO as doors opening, BA as passenger boarding/alighting, DC as door closing and TD as train dispatching.

Rather than breaking the dwell time into smaller components, Zhuge et al. (2009) stated that Dwell time was made up of 2 main components, i.e. the time of opening and closing doors and the time of passengers getting on and off. This is almost identical to what Wirasinghe & Szplett proposed in 1984.

Although theoretically dwell time covers the whole period of a train staying at the platform, if a train is required to stay for longer time in some special cases, those extra time is usually not considered as part of the dwell time. Martínez et al. (2007) conducted a study on the dwell time and train running time for Metro Madrid in Spain. They deliberately excluded some unusually long dwell times from the analysis. They suggested to treat those data as incidences other than dwell time, thus it needs to be modelled separately.

Based on the study of dwell time components, it is fair to say that most researchers would agree that dwell time covers the time that a train stay stationary at the platform. In addition, it would rule out the scenario of train staying for other reasons rather than loading and unloading passengers.

2.2 Key factors and variables affecting dwell time

There were many factors identified by different researcher that has impact on dwell time. Lin (1990) suggested the key factors as “the congestion level on the station platform, type of fare collection, number of passengers alighting and boarding, and passenger crowding level on board”. Compared with Lin’s work, Parkinson and Fisher (1996) failed to mention the crowd level on the platform and inside of the train, but adding some factors closely relates to the platform and train design.

Wiggeraad (2001) examined the dwell time from an overall planning point of view. Besides the passenger flow and infrastructure characteristics, they also listed the “length of the planned dwell times” and “planned connection” as key determinant elements. “Signal headway” was listed as another key factor affecting dwell time by Jong and Chang (2011). Jiang et al. (2015) put “Scheduled dwell time” on their top list of affecting dwell time.

Rollingstock itself is another significant factor not to be missed out. The impact of internal layout of the train carriage was revealed by Fernández et al. (2008). More attentions were paid to the design aspect by Fujiyama et al. (2008). They stated that the dwell time performance can be improved by finding the optimal combination of doorway width, vestibule setback and train platform gap.

According to Transit Capacity and Quality of Service Manual (KfH Group, 2013). Key factors affecting dwell time were identified as: Boarding/alighting passenger volume specifically during peak hours; platform configuration including the width, length, curvature, usable area for passenger queuing and circulation, and vertical circulation capacity; passenger boarding/alighting rate; vertical and horizontal gaps between train door and the platform edge; door reaction time; and other operational procedures affecting the boarding process.

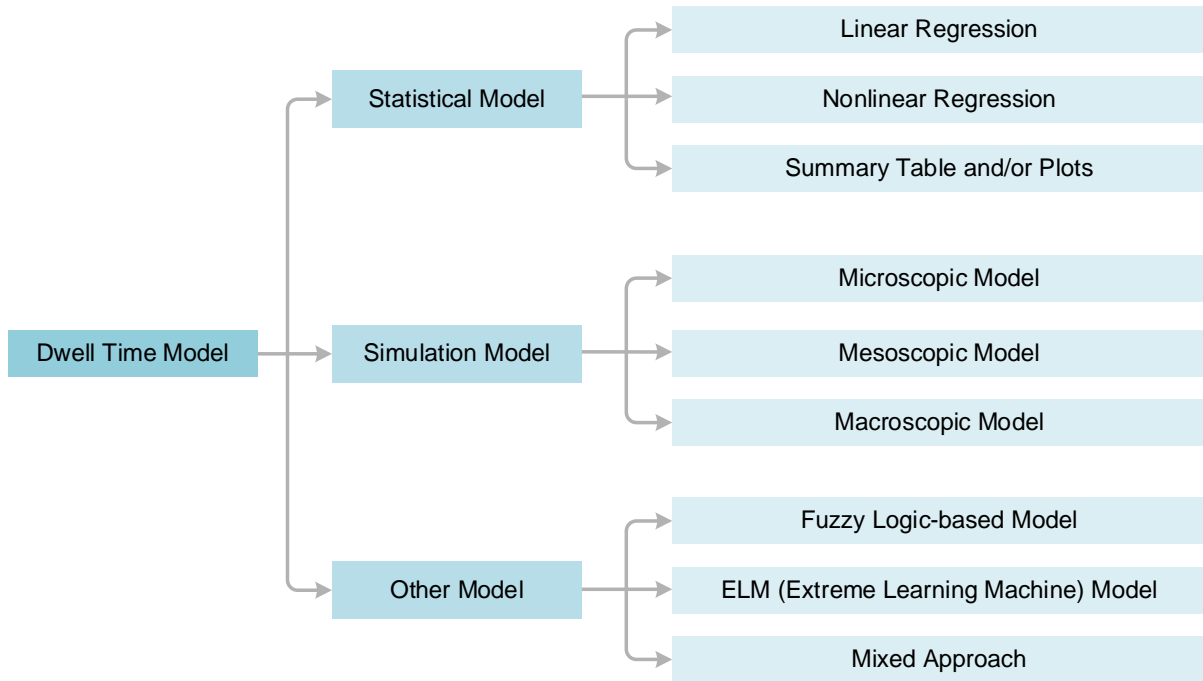
Variables were often grouped. According to Daamen et al. (2008), 3 groups were discussed as vehicle related; passenger flow related; traffic condition related. Harris et al. (2014) put total 17 variables into 3 groups: station-based variables, train-based variables and passenger-based variables. Seriani and Fernandez (2015) also identified three types of variables, but they suggested to group the variables by physical, spatial and operational characteristics. Recent work by Li et al. (2016, 2018) proposed 5 groups: Passenger, Rolling stock, Station, Operation and External.

Looking through the literature, it is reasonable to say that there are some differences when identifying the key factors for the dwell time, and there are certainly different ways to group the variables. However, a common factor was found almost on every research's list, which closely relates to the passenger boarding/alighting process. We believe "the number of boarding/alighting passenger" (short for number of B/A) can be treated as the most determinant variables among all. Crowd level, which is often measured by the number of standee or number of through passengers on board, is also not to be missed.

2.3 Modelling and validation approach

In terms of model classification, there are many ways to categorise the modelling approach. As shown in Figure 1, we use 3 levels of categorisation when studying the existing models.

Figure 1: Model classification



With regards to the statistical models, regression analysis was often involved. The mathematical expression can be a linear form or nonlinear form depending on the selection of dependent variables. Summary statistical table or plots can also be used as a simple but direct expression.

The very early linear models found focused on partial dwell time, referred as door utilization time model (Koffman et al., 1984). Other linear model proposed by various modellers are found with similar form, which can be addressed as:

$$DT = c_0 + c_1A + c_2B \quad (1)$$

Dwell time DT is a function of the number of alighting (A) and boarding (B) passengers. c_0 is a constant, usually determined by door opening and closing time, c_1 and c_2 are coefficients measuring the rate of alighting and boarding respectively. Lam et al. (1999) studied several stations for Hong Kong MTR and use the collected data to calibrate the above linear model.

Other linear regression models were found including not just variable A and B, but also other dependent variables. Koffman et al. (1984) modelled the passenger loading time with total boardings, total de-boardings and total passengers on-board. Harris et al. (2014) used a general linear-form function to test out many more dependent variables. Lin and Wilson (1992) established and tested both linear and nonlinear dwell models.

The well accepted non-linear dwell time model, also known as LUL (London Underground Ltd.) model, was proposed by Weston (1989) as:

$$SS = t_0 + 1.4 \left[1 + \frac{F}{35} \left(\frac{T-s}{D} \right) \right] \left[\left(\frac{FB}{D} \right)^{0.7} + \left(\frac{FA}{D} \right)^{0.7} + (0.027 \left(\frac{FB}{D} \right) \left(\frac{FA}{D} \right)) \right] \quad (2)$$

Dwell time, i.e. station stop time (SS) is a function of number of through passengers per train (T), number of alighting (A) and boarding (B) passengers per train, number of seats on train (S) and number of doors on train (D). As can be seen from the formula,

a peak door/average door factor (F) is also considered as a variable affecting train dwell time. A constant value t_0 was added to account for the 'function time' i.e. door opening and closing time, which is suggested as 15 seconds for the London Underground Rail.

Harris (2006) tested out Weston's LUL model based on the data collected at Clapham Junction station of South West Trains network in the UK. Harris and Anderson (2007)'s later work applied the same formula to test a greater number of metro stations around the world. Result suggested that LUL model seemed valid globally.

Compared with the LUL model, Puong (2000)'s non-linear model has less dependent variables involved. Three dependent variables were identified as alighting passengers per door, boarding passengers per door and through standees per door. Similar to Puong's model, same equation was used for the estimation of dwell time for Comeng train in Melbourne (as cited in Coxton, 2013).

Other than using regression analysis, some researchers studied dwell time and presented the findings in statistical summary table and plots (Li et al., 2014, Karekla and Tyler, 2012, Wiggenraad, 2001).

The second type of dwell time model is simulation model, which is further classified into microscopic, mesoscopic, and macroscopic model according to the level of details that a model describes its elements and their activities. Shiwakoti et al. (2013), in their review of emergency evacuation models, classified the simulation models into similar class, i.e. micro, meso, and macro. Similar to that concept, considering dwell time models, the microscopic models focus more on the movement of each individual passenger and the interactions among them. Macroscopic models explain the passenger movement as a complete flow, and how it interacts with other higher-level elements in the system. While mesoscopic model works as a hybrid model to connect the micro with the macro simulation.

Several dwell time models were built based on the Social Force Model. Passengers boarding/alighting process was modelled at a microscopic level (Perkins et al., 2015, Coxon et al., 2013, Sourd et al., 2011, Zhang et al., 2008). Similarly, Bae et al. (2012) established a Cellular Automata (CA)-based micro-simulation model for passengers' movement inside the train carriage and on the station platform. CA is a discrete modelling approach that automata (entities) update their states according to some fixed rules of occupying neighborhood cells.

Agent-based micro-simulation model becomes more common in recent years. Yamamura et al. (2013) established an agent-based model with the model environment covering both in the train and on the platform. Ahn et al. (2016) also took an agent-based simulation approach to model passengers' behavior. However, the focus was limited to the platform only.

It is to be noted that there are some models that do not simply fit into statistical or simulation category. Therefore, "Other" category was introduced. Various modelling approaches that being classified as other model will be discussed in the following sections.

An innovative approach to model the passenger flow and dwell time was taken by Alvarez (2014, 2015). Their model used an Origin-Destination (OD) matrix approach with fuzzy logic intelligence. Chu et al. (2015) took a new approach of using an extreme learning machine (ELM) method for the dwell time modelling.

In summary, regression models have proved to be useful tools to describe observed data and examine the relationship between dwell time (i.e. independent variable) and corresponding factors (dependent variables). While for the simulation models, certain rules and assumptions needs to be established beforehand. Model accuracy is heavily dependent on the parameters chosen and the base case. Mixed modelling method and some innovative approaches could potentially lead dwell time modelling into a new phase.

2.4 Number of publication and shift of interests

Martínez et al. (2007) claimed that there were limited resources about modelling dwell times on metro lines, and many models had not been confirmed by experiments. This statement was made more than 10 years ago. Many efforts have been made since then. Table 1 lists number of publications found from 1980s to date that studied train dwell time model or sub models.

Table 1: Number of publications by time period

Decade	Total number of Publications	Statistical Model vs Simulation model	Details of Publications
1980s	5	4 vs 1	Fritz (1983), Koffman et al. (1984), Wirasinghe & Szplett (1984), Campion et al. (1985), Weston (1989)
1990s	6	6 vs 0	Lin (1990), Breusegem et al. (1991), Lin & Wilson (1992), Parkinson & Fisher (1996), Lam et al. (1998), Lam et al. (1999)
2000s	14	12 vs 1*	Puong (2000), TRB (2000), Wiggenraad (2001), Goverde (2005), Fernandez et al. (2006), Harris (2006), Harris & Anderson (2007), Martinez et al. (2007), Buchmuller et al. (2008), Daamen et al. (2008), Fernandez et al. (2008), Fujiyama et al. (2008), Zhang et al. (2008), Zhuge et al. (2009)
2010s	22	8 vs 9*	Hansen et al. (2010), Jong & Chang (2011), Sourd et al. (2011), Bae et al. (2012), Berbey et al. (2012), Karekla & Tyler (2012), Coxon et al. (2013), Yamamura et al. (2013), Alvarez et al. (2014), Harris et al. (2014), Li et al. (2014), Alvarez et al. (2015), Chu et al. (2015), Jiang et al. (2015), Kecman & Goverde (2015), Perkins et al. (2015), Seriani & Fernandez (2015), Ahn et al. (2016), Li et al. (2016), San & Masirin (2016), D’Acierno et al. (2017), Li et al. (2018)

Note: *There are “Other” models left out in the case of the total number of publications does not add up with the statistical models and simulation models.

As can be seen from the number of publications, there’s a growing interest on train dwell time modelling over the last decade. There were only 5 publications in the 1980s, and it has now reached to 22 since 2010. Statistical modelling approach used to be very dominating, but the simulation model is becoming more popular in the past 10 years.

Dwell time model can be applied in various fields in the rail industry. In terms of the study focus, researchers started with making effort of understanding passenger

boarding/alighting behaviour (Fritz, 1983, Koffman et al., 1984, Wirasinghe and Szplett, 1984). Many discussions were centred around railway traffic control and timetable planning/rescheduling (Campion et al., 1985, Breusegem et al., 1991, Fernandez et al., 2006, Buchmüller et al., 2008, Jong and Chang, 2011, Berbey et al., 2012, D'Acierno et al., 2017, Li et al., 2018). Delay management and system performance improvement was also often discussed (Wiggenraad, 2001, Hansen et al., 2010, Bae et al., 2012, Jiang et al., 2015). Some researchers were motivated by the idea of managing dwell time could potentially help with the improvement of line capacity, level of service and customer satisfaction (Parkinson and Fisher, 1996, Lam et al., 1999, Karekla and Tyler, 2012, KFH Group, 2013, Ahn et al., 2016). More recently, dwell time model has been recognised as a useful tool in the field of rollingstock evaluation (Sourd et al., 2011) and train body/ interior design (Coxon et al., 2013, Yamamura et al., 2013).

It has come to our attention that, prior to 2008, there was little discussion about using simulation tool in dwell time analysis. Publications in the past 10 years confirmed a growing interest in building dwell time model with simulation software packages. Agent-based modelling has become more common in the past six years. A Passenger Service Time (PST) model was built by Seriani and Fernandez (2015) using a multi-agent simulation package LEGION Studio. In the same year, a dwell time model was developed by Perkins et al. (2015) based on the widely used simulation tool AnyLogic. Ahn et al. (2016) also chose to use the same software (AnyLogic) for dwell time modelling.

Historical publications demonstrated a trend of using agent-based simulation tool in dwell time study. There is still great potential to be discovered. Moreover, innovative approach or mixed-use modelling method may also improve the performance of dwell time model and hence enlarge the area of application.

3 Conclusion and recommendation

Over the years, train dwell time modelling has drawn many interests from the academic area as well as the industry. Yet there's no widely-accepted model established yet. San and Masirin (2016) also indicated a need to continuously study the key dwell time factors and improve the model.

Operation wise, proven by different researchers, dwell time management is crucial for managing the delay and thus improving customer satisfaction. There were many discussions regarding the timetable planning and rescheduling. It is to be expected that in the future one would be able to build the dwell time model into network optimisation.

Analysing the models from the past, both similarities and differences are identified. It is found that the boarding/alighting behaviour is commonly believed as one of the most influencing factors. It is also recognised that many researchers treated the factors same way as the variables. This assumption can be true under certain circumstance. However, we would suggest referring a factor as variable only when it is to be used as an input of the dwell time model. Confusions can be easily avoided if the modeller could keep the terminology consistent. A clear description of the key components being studied would also be beneficial. Based on the understanding gained from the review on the existing train dwell time models and the associated variables, we recommend 4 major categories for the influencing factors: train carriage and

rollingstock related factor, platform and station related factor, passenger and behavior related factor, management and operation related factor.

In terms of the modelling approaches, additional effort should be made to improve the accuracy as well as the generalisation of the models. Although regression models have been the mainstay for dwell time models, the true potential of dwell time simulation models have not yet been realised. Once the model is enhanced to the extent that can mimic the critical features of the real-world, greater social and economic benefit can be appreciated.

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